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EFFECT OF REPETITION ON TIME TO DON AND ADJUST A FALL PROTECTION HARNESS

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by

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Abstract

A major concern in the field of occupational safety and health is the fatalities resulting from falling from heights. In the construction industry, a common approach for protecting workers is the use of a fall protection harness connected to a secure anchor. To be effective, harnesses must be fitted and adjusted to the individual. This requires training on adjusting the straps of a harness, and the training must include practice to ensure the worker has the skills to make a secure fit. It would be useful for those who conduct training on harness fitting to know if trainees would benefit from more than one practice donning a harness and adjusting the straps.

The broad hypothesis for this study is that the repetition times for donning a harness to attain a satisfactory fit will be, after proper training and familiarity with the harness, longer on the initial repetition, and reduced each subsequent repetition. The reduction pattern is expected to follow the common learning curve model.

The specific aim of this project was to experimentally characterize how the time to don and adjust a harness changes with number of repetitions. A secondary intent was to obtain qualitative feedback about usability of harness fitting straps. The time to properly adjust the straps was used as an indicator of how skill level changes with additional repetitions. A repetition was defined for this project as donning and adjusting the harness with coaching by the trainer. General donning strap guidelines and visual observations by the trainer were used to help each trainee fit their harness according to the manufacturers' guidelines.

Twenty-five college students participated in a study by performing each of five steps in a harness-donning repetition. Each participant repeated the process four times while being timed. After each repetition the participant received tips from the experimenter. This approach was used to mimic the harness-fit training used in the construction company where the investigator interned.

Results showed reduced donning times with each repetition. The largest mean decrease was from the first to second repetition. Times continued to decline each repetition, with time reductions getting smaller with each repetition. The pattern of declining time followed a learning curve based on a power model. According to the fitted model the time will decrease 20.6% with each doubling of repetitions; thus, the second repetition will take 20.6% less time than the first, and the fourth repetition will take 20.6% less time than the second.

Keywords: fall protection, harness, learning curve, safety

Dedication

I want to thank my parents and grandparents for the endless support and motivation throughout the years. To my Mother and Kayla, thank you for pushing me and believing in me when times were tough. I could not have completed this without you two.

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1. Introduction

While working in an elevated location, workers are exposed to the gravitational hazard of falling. These exposures occur in all industries. However, the construction industries have historically experienced more than their share of fatal falls. Some recent statistics document the magnitude of the fall problem in the construction industries.

1.1. Falls in Construction Industries

The most comprehensive source of information about occupational fall injuries and fatalities is the U.S. Department of Labor's Bureau of Labor Statistics (BLS). That agency receives reports from private businesses in the United States based on standardized reporting requirements. Reports include occupational injuries, illnesses, fatalities, and hours worked by employees in particular establishments. BLS maintains multiple record systems; two contain valuable information about occupational injuries, illnesses, and fatalities: (1) the Census of Fatal Occupational Injuries, and (2) the Census of Occupational Injuries and Illnesses. Selected information from these national record systems is provided below to document the importance of falls in the U.S. construction industries.

1.1.1. Industry Comparisons

The Census of Fatal Occupational Injuries provides data suitable for comparing the number of fatal falls in various industries based on classifications defined by the North American Industry Classification System (NAICS). The NAICS has two broad categories: Good Producing and Service Providing. Construction is at the next level under Goods Producing. Data found on the Census of Fatal Occupational Injuries web site for the year ending September 2017 lists number of fatalities by various industry categories (Bureau of Labor Statistics, 2019a). Table I has been constructed from these data to compare four major industry sectors in the Goods

Producing group in terms of number of fatalities in the 2017 year. Out of the 5,147 total fatalities that year, the four industries in Table I accounted for 2,013 fatalities, or 39 percent. The Service Providing major group accounted for 3,134 fatalities, or 61 percent.

Table I. Number of Fatal Occupational Injuries in Four Goods Producing Industrial Sectors, 2017

Worker Employment Status	Construction	Agriculture, Forestry, Fishing, Hunting	Manufacturing	Mining	Row Total
Private	783	264	283	109	1439
Government	42	3	0	1	46
Self-Employed	188	317	20	3	528
Total	1013	584	303	113	2013

The Table I data show the construction industries had more fatalities than any of the other three industries listed. Additionally, the construction industry had more fatalities than the other three industries combined.

Counts of fatalities as noted in Table I do not provide risk information. Rates are needed to appreciate risks. The Census of Fatal Occupational Injuries provides rates for industries. The rates account for both number of fatalities (N) and number of employee hours (EH). The ratio of N to EH multiplied by 200,000 yields the equivalent rate per 100,000 full-time equivalent employees (see Equation 1).

Equation 1. The Rate Computation Formula

$$Rate = \left(\frac{N}{EH}\right) \times 200{,}000 \qquad \text{(Eq. 1)}$$

Table II provides fatality rates from the year 2017 for the construction industry and four other industries (Bureau of Labor Statistics, 2019b). The right-most column provides a risk ratio comparing one industry rate to the rate for the manufacturing industries. Data in the risk ratio column indicates that employment in the construction industries involves five times greater risk of a fatality than employment in the manufacturing industries. Of course, there are large differences in risk for different jobs within each industry.

Table II. Occupational Fatality Rate for 2017

Industry Group per NAICS	Fatality Rate for 2017	Risk Ratio to Manufacturing
Agriculture, Forestry, Fishing, Hunting	23.0	12.1
Transportation and Warehousing	15.1	7.0
Mining, Quarring, and Oil Extraction	12.9	6.8
Construction	9.5	5.0
Manufacturing	1.9	1.0

1.1.2. Events Preceding Fatalities Compared

The Census of Fatal Occupational Injuries provides data on the event most directly involved in occupational fatalities (Bureau of Labor Statistics, 2019c). A standardized list of common events is used for each fatality. Table III provides data relevant to fatal occupational injuries in all industries combined.

Table III. Occupational Fatalities by Event Preceding the Injury in 2017

Event Preceding Fatal Fall	Number	Percentage
Fall to lower level	713	81.77
Fall on same level	151	17.31
Jumps to lower level	4	0.46
Slip or trip without fall	4	0.46
Fall or jump curtailed by personal fall arrest system	0	0
Total	872	100

Based on data in Table III, falls to a lower level account for 81.77 percent, or approximately four out of five fatal falls. That suggests that fall protection was not adequate in those cases. Of interest is the last category. It indicates there were no fatal falls when a fall was successfully curtailed by a personal fall arrest system, such as a net or harness system. The reported data does not say how many falls were successfully curtailed by a personal fall arrest system.

Additional information on the fall from elevation fatalities is found in the Census of Fatal Occupational Injuries. For the construction industry, counts of work-related fatal falls are available. Annual data are presented for the years 2011 through 2016 (Bureau of Labor Statistics, 2018). The total number of fatal falls to lower level in construction was 350 and 370 for the years 2015 and 2016, respectively. The website also provides data on height of fatal falls by source of injury for the combined years 2011 through 2016. These data are presented in Table IV. The meaning of "source" in Table IV refers to the thing associated with the fall.

Table IV. Fatal Work-Related Falls to Lower Level by Source and Height of Fall, 2011–16

Height (ft)	Stairs, Steps	Roofs	Scaffold, Staging	Trees	Machinery	Vehicle	Ladder
> 30	4	127	93	81	81	62	29
26 – 30	2	100	26	30	19	19	27
21 – 25	3	130	43	12	14	16	59
16 – 20	6	146	48	16	33	27	109
11 –15	14	151	50	6	23	49	145
6 – 10	20	41	50	7	20	63	174
< 6	40	--	18	1	21	127	87
Unreported	67	67	59	32	29	53	206

Data in Table IV provide some information relevant to the current project on fall protection harnesses. Comments about the potential for using personal fall protection for these various activities are offered here. For fatalities on stairs and steps there were 89 with height reported. Of those, 60 were falls from under 10 feet. The usual fall protection for stairways is a guardrail, but during building construction, stairs with open sides may exist as temporary means of travel between flights, or while being built. In those situations, personal fall protection may be an appropriate option. For roofs, fatal falls occur throughout the range of heights. Fall protection for working on roofs may be achieved by multiple means, one being use of a personal fall arrest system. Scaffolding and staging involves work at many heights. The records do not tell us if the fall was from equipment failing or the person failing to maintain a secure body position. If the latter, personal fall protection would have been an appropriate means for protection. Falls from trees may involve tree trimmers or contractors hired to clear branches for power lines. Personal fall protection can be used, but it requires extending equipment to create a tie off about the tree trimmer. The small mom and pop businesses may not regard that expense as being necessary. Falls from vehicles and machinery can provide effective protection using personal fall protection, but it requires establishing a tie off site above the worker. Falls from ladders occur from all the heights found in Table IV. The use of harnesses for longer, fixed ladders is a common practice for tower access. That requires a ladder equipped with a sliding fall arrestor device and a harness with a frontal D-ring. In conclusion, the use of personal fall protection provides a feasible means of fall protection for worker exposures involving most of the sources listed in Table IV.

The injury and fatality data in Tables I–IV are recent, but not unusual in the historical sense. The Occupational Safety and Health Administration (OSHA) has numerous long-standing regulations about fall protection in the construction industry as well as recent actions directed at the problem. These are reviewed in the next section.

1.2. OSHA's Role in Fall Prevention

OSHA, a part of the U.S Department of Labor (DOL), publishes their top ten most cited standards across all industries for each fiscal year. Three construction industry fall protection standards are on the 2018 top ten list for the fiscal year ending with September 2018 (U.S. DOL OSHA.gov, 2018a). The number one most cited OSHA violation was CFR 1926.501—failing to have a fall protection program. Violating the fall protection training requirements in CFR 1926.503 was fourth, and violating requirements involving fall protection systems criteria and practices came in ninth.

A number of OSHA standards apply to fall protection in general industry and in construction industries. Listed below are the standards applicable to the construction industry and found in 29 Code of Federal Regulations (CFR) 1926 Subparts E, M, and R (U.S. DOL OSHA.gov, 2018b).

Subpart E—Personal Protection and Life Saving Equipment:

1926.104, Safety belts, lifelines, and lanyards

1926.105, Safety nets

1926.106, Working over or near water

Subpart M—Fall Protection

1926.501, Duty to have fall protection

1926.502, Fall protection systems criteria and practices

1926.503, Training requirements

Subpart R—Steel Erection

1926.759, Falling object protection

1926.760, Fall protection

1926.761, Training

Fall prevention addresses various means to prevent a person from falling, e.g., guardrails. *Fall protection* addresses prevention, plus personal fall protection and nets to catch a person who has fallen. The training requirements in 29 CFR 1926.21 Subpart M state that “the employer shall provide a training program for each employee who might be exposed to fall hazards. The program shall enable each employee to recognize the hazards of falling and train each employee in the procedures to be followed to minimize these hazards." Thus, a construction employer that uses personal-protection systems to comply must provide training on the proper use of the equipment, typically wearing a harness connected by a lanyard to a secure anchorage point.

Considering the data on fatal falls in Tables I through IV, and the numerous OSHA regulations, it is not surprising that non-compliance with fall protection requirements are frequently cited by OSHAs Compliance Safety and Health Officers (CSHOs).

OSHA regional offices have adopted a special Regional Emphasis Program on fall protection in construction (U.S. DOL OSHA.gov, 2018c). An example of how a Regional Emphasis Program is put into operation comes from the Denver Region III office. On October 1, 2018, they announced a plan to use a combination of enforcement and compliance assistance to encourage employers on a construction site to identify and address fall hazards in their work environment. CSHO will evaluate work sites to determine if their site is in compliance with all relevant OSHA requirements. They will identify fall hazards in the work site and help correct the hazards with intent to reduce the exposure of workers to fall hazards. According to the press release, OSHA Region III is trying to reduce fall hazards by increasing information shared between construction sites and area offices. Area offices will have a CSHO come to the construction work site, observe, inspect, document, and assist in the correction of fall hazards.

1.3. Research into Occupational Fall Protection

Research on harness fitting and usage has been conducted by the Division of Safety Research, National Institute for Occupational Safety and Health (NIOSH). According to the leader of that research team, a safety harness that is fitted and worn incorrectly can result in severe injuries when a fall is arrested (Hsiao, 2017). These injuries can be severe in the event of a fall. For example, a scenario occurs when the chest strap of the harness is too loose; this increases the probability that a fallen individual could slip out of the harness and continue to fall to the ground, instead of being caught by a correctly worn harness. A chest strap that is too high can restrict air flow during a fall by coming in contact with the neck when the harness slips up. Another scenario is when the leg straps are too tight around the thigh. This can result in a severe groin injury when the fall is arrested, as well as reduced circulation when hanging while awaiting rescue. These injuries can be avoided by properly donning a harness.

In a study conducted by NIOSH researchers, 98 construction workers (72 male and 26 female) were suspended in a full-body construction harness and had their bodies scanned using a 3-D full-body laser scanner to evaluate the fit and sizing efficacy of a harness system. Based on the study, the authors provided the following parameters for a good fit for a construction style harness (Hsiao, Bradtmiller, & Whitestone, 2003).

1) The thigh strap should be snug, but not cut off circulation. This is a comfort issue when standing but becomes a safety issue in post-fall suspension. The rule of thumb is that no more than two fingers should be inserted between the thigh strap and the thigh.
2) The chest strap should fall just below the sternum. Inadequate chest ring location can interfere with a person’s work, especially for female workers.

3) The harness should hold the body no more than 30 degrees off vertical in suspension. This is a safety as well as a comfort issue. With loose shoulder straps, the degree of the suspended person is increased.
4) The back D-ring should fall between the shoulder blades. This helps distribute the force of the fall arrest over the body's frame.

The construction industry employs a wide variety of people needing the fall protection harnesses and related equipment. In 2018, there were approximately 11,181,000 general construction workers in the United States with 9.9 percent females and 30.7 percent Hispanic (Bureau of Labor Statistics, 2019d). As stated by Hsiao, et al. (2003), the diverse workforces in the construction industry, as well as new roles for women in the workforce, make it likely that more construction occupations will show a greater variation in their range of body dimensions. "Incompatible harnesses, if worn by workers, are not likely to provide the level of protection and comfort the person requires to work productively" (Hsiao, et al. 2003). Thus, having the correctly sized harness for each employee who will use a harness is crucial for both safety and their productivity.

After the course of a fall, the employee is suspended in the air waiting to be rescued. The weight of the body is then resting on the straps of the harness causing compression by the shoulder and leg straps. With the straps being compressed into the body, this could cause a condition of the venous pooling of the arteries known as suspension trauma (Hsiao, 2017). A study reported by Hsiao, Turner, Whisler, and Zwiener in 2012 provided extensive information on suspension tolerance time as affected by body size and shape, and the harness fit. They explain that a prolonged suspension can cause the pooling of blood in the legs and reduce the flow of blood to the heart. "The restriction of the femoral arteries and veins caused by the harness straps can worsen venous pooling" (Hsiao, et al. 2012). With an incorrectly fitted harness, the suspension trauma has a quicker onset and greater severity leading to possibly catastrophic results. This could cause the employee a great deal of pain which would increase their pulse rate, blood pressure, and sweating—responses that will make the situation critical. With the harness sizing and training on proper donning of the harness, the likelihood of damage to vital organs due to reduced blood flow can be minimized.

Following a rescue, there are issues about how to care for the victim. One important issue is whether to have the victim lay down, be in a semi-sitting posture, or sit in a chair. An investigation into the evidence supporting recommendations for responders concluded there is no credible scientific support for any of the three options (Adisesh, Lee, & Porter, 2011). These authors recommended that rescuers follow the normal first aid practice of having the victim lay down.

1.4. Training Issues for Harness Fitting

An individual experienced in fall protection training shared his experiences on training for fall prevention, protection and rescue (McCurley, 2017). He observed that employers have discretion for setting their own aspirations for employee knowledge and skills training, and this includes fall protection. He stated that fall protection training should be customized to the specific situation. On the subject of what makes effective fall protection training, he offered the following points.

1. Effective training "requires attention to improving worker's knowledge and skills specific to fall protection, as well as their preparation through the availability of proper equipment along with hands-on training."

2. Effective fall protection training should be organized so it mimics as closely as possible the actual work environment and practices.
3. Employees should be given an opportunity to practice and apply learned knowledge and skills.

The OSHA training requirements state the learning objectives for trainees, without going into the “how” the training should be conducted. Three challenging aspects of learning to use fall protection harnesses are (1) how to select a harness that fits well, (2) how to don, and adjust a fall protection harness to achieve an effective fit, and (3) how much skill development occurs with practice donning and adjusting he straps—the focus of this project.

Research opportunities may stem from the needs of two very different groups. One is the safety coordinators and civil engineers responsible for planning and conducting training on the use of fall protection harnesses. The other is the harness manufacturers.

1.4.1. Needs of the Trainers

The safety coordinators and civil engineers responsible for training could benefit from information about skill development during training. Specifically, how does a novice harness user benefit from practice donning and adjusting straps while being coached? A substantial body of literature on “learning curves” exists. The term comes from graphing how performance changes with increasing repetitions or cycles. The graphs have repetitions on the x-axis, and some measure of performance on the y-axis. If the performance measure is skill level, the curves typically show an increasing level in skill until a plateau is reached. If the performance measure is time, the curves typically show a non-linear declining time with increasing repetitions. Time was selected for the present study because it is feasible to measure with available facilities and equipment. The theory behind this is that time is a practical indicator of improving skill at donning and adjusting a fall protection harness. However, improving time would be useless if it were to become a race. In order to avoid this, the investigator arranged a training protocol to mimic a training session similar to that used in a construction company where he interned.

The time to complete one donning and adjusting by an individual is expected to follow a decreasing time with each repetition of practice. Industrial engineers use a power curve for modelling the trend of declining time with repetition (Hancock & Bayha, 1982). Two applications for modeling time as a function of repetition are humans learning a new skill and manufacturers producing products (Hancock & Bayha, 1982). The terms for these two applications differ. For humans learning, the term “learning curve” is common. For manufacturing, the term “manufacturing progress curve” is common. In both applications, Equation 2 is used to predict time to complete a cycle (T_i) as a function of time for the first cycle (T_1), cumulative number of cycles (N), and a constant (A).

Equation 2. Power Model for Predicting Completion Time

$$T_i = T_1 N^{-A} \qquad \text{(Eq 2)}$$

The constant, A, is obtained by first taking the log of both sides of Equation 2 to obtain Equation 3.

Equation 3. Model for Predicting Log of Completion Time

$$log\, T_i = log\, T_1 - A(logN) \qquad \text{(Eq 3)}$$

By using linear regression to fit Equation 3, the value of the slope term (A) is the constant used in Equation 2. If the learning curve model fits experimental data, the slope term (A) should be greater than zero. This can be tested using a null and an alternative hypothesis appropriate for linear regression as described in the Methods section of this manuscript. If the learning curve model fits, safety coordinators and civil engineers will have some objective data to help decide how many repetitions to include when training a novice to don and adjust a fall protection harness.

1.4.2. Needs of Harness Companies

A second need was for harness designers and manufacturers. Specifically, how well are straps designed for ease of use by novice harness wearers? This issue was incorporated into this project as a secondary outcome. The intent of the secondary outcome was to obtain qualitative information about usability of harness fitting straps to share with the harness manufacturer.

1.5. Specific Aim of This Project

The broad hypothesis for this study is that the time to don a harness and adjust the straps to attain a satisfactory fit will be, after proper instruction and familiarity with the harness, longer on the initial repetition, and reduced each subsequent repetition. The specific aim of the project was to experimentally characterize how the time to don and adjust a harness changes with number of repetitions. A secondary aim was to obtain qualitative feedback about usability of harness fitting straps.

2. Methods

The methods used for this project started with designing a study, followed by a plan for recruiting participants, preparing equipment and facilities, planning specific procedures, and planning for statistical analyses. These activities are described in that order.

2.1. The Experimental Design

The study used a two-factor complete block design. The blocking factor was the individual subjects. Treatments were the four repetitions performed by each subject. Because the four repetitions were performed by every participant, the experimental plan uses *repetition* as the treatment factor. This design provides data for an analysis of variance (ANOVA) to examine the hypothesis that the mean times of each repetition are equal. The alternative hypothesis is that all four mean repetition times are not equal. Table V shows the plan for arranging measured times from the experiment into the cells of a table with subjects in rows and repetitions in columns.

Table V. Arrangement of Data for an ANOVA Data Table

Subject i	**Repetition 1**	**Repetition 2**	**Repetition 3**	**Repetition 4**
Subject 1	T1,1	T1,2	T1,3	T1,4
Subject 2	T2,1	T2,2	T2,3	T2,4
…	…	…	…	…
…	…	…	…	…
Subject 25	T25, 1	T25, 2	T25,3	T25,4

A single repetition of a donning consisted of five steps. Each of the five steps in a harness donning repetition had a similar table, plus one for the total times. That meant the experiment design would permit testing each step using the null and alternative hypotheses noted above.

2.2. Participants

Students were recruited from both the Occupational Safety and Health classes and Civil Engineering courses at Montana Technological University. Courses were those with large enrollments for the most diversity and availability of students. The students were shown a Power Point presentation and verbal explanation about the purpose and the intent of the study. The students were then given a sign-up form on which they could voluntarily sign up if they chose to do so. As a token of appreciation, participating students were promised a choice of $10 or extra credit in the individual class from which they were recruited. The protocol was accepted and approved by the University of Montana’s Institutional Review Board for the Protection of Human Subjects in Research (IRB Protocol Number 108-18). Demographics of the 25 participants are summarized in Table VI.

Table VI. Demographics of Study Participants

Gender	Height (inches)	S.D. (inches)	Maximum Height (inches)	Minimum Height (inches)	Body Weight (pounds)	S.D. (pounds)	Maximum Weight (pounds)	Minimum weight (pounds)
Males	70.7	2.7	74	66	166.3	32.5	205	105
Females	67.6	3.5	74	62	152.6	15.2	181	125

2.2.1. Participant Requirements

Requirements for participation were being over the age of 18, having no prior fall protection training, and meeting the standard requirements of a labor worker in the general construction industry. Requirements of a laborer include no physical disabilities or deformities, such as being wheel chair bound, or having the loss of an arm or leg that would cause improper fit of harness. A target population for this project was people who:

- Are likely to have a career where they will be using fall protection equipment;
- Have not become biased by learning or using fall protection equipment previously; and
- Are accessible to the researchers (i.e., students on campus).

The study originally intended for an even distribution of fifteen male and fifteen female students but with the limited supply of female volunteers, the female portion only collected 10.

To avoid biased subject selection, the first fifteen volunteers in the male gender group were selected.

2.2.2. Convenience Sampling

Figure 1 is a graphic depicting the sampling plan using a top down approach. On the right are terms for the sampling plan based on Professor Rick Rossi's book *Applied Biostatistics for the Health Sciences* (Wiley Press, 2010).

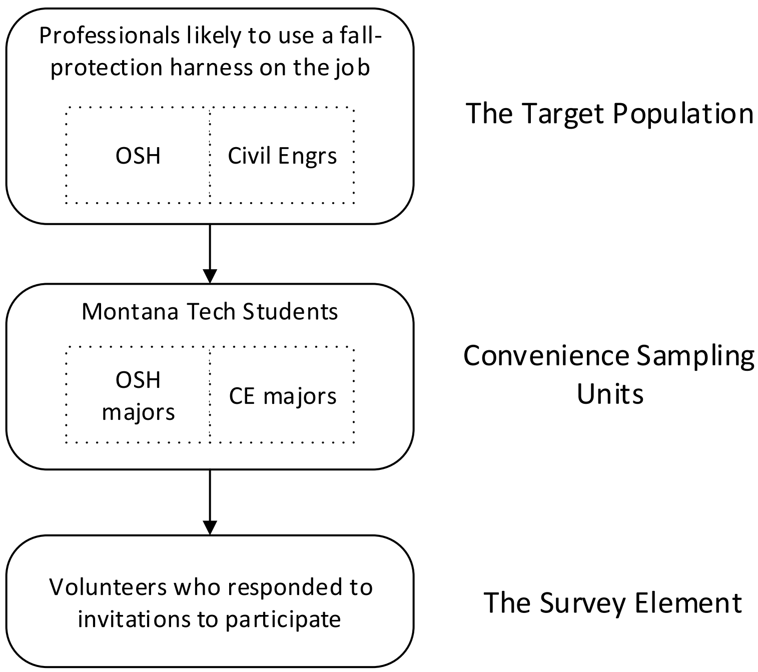

Figure 1. Summary of participant sampling plan

2.3. Preliminary Procedures

The volunteer students selected to take part in the study were contacted via email or text messages to arrange a time, location, and type of clothing they should wear for the experiment.

2.3.1. Subject Apparel

Each participant was provided with a unisex tank top t-shirt that was provided by the instructor on the day of the study. They wore their own pair of jeans or pants. The tank tops worn by everyone limited the variety in clothing from student to student, avoided potential clothing interference in donning, and allowed clear view of upper body straps.

2.3.2. Subject Arrival Procedures

Once each student arrived at their predetermined individual time slot, they were given a t-shirt. Their next step was to change into the t-shirt. They were then instructed on the tasks to be performed and possible hazards the study would entail. The students watched a training video illustrating the proper way to don the harness. The particular video shown was collected from DBI Salas' main website demonstrating the manufacturer's correct way to don the harness being used. Instructions included how to properly lift and shake out the harness so the leg straps were untangled and hanging freely, how to properly put the harness on with the D-ring located between the shoulder blades, and how to adjust shoulder, leg and chest straps for proper tightness.

After the video was shown, explanations about the risks and benefits of this study were stated again and the participant was asked to express any concerns they might have had.

- Risks presented during this study were possible personal embarrassment and frustration. The student could have possibly become embarrassed when being asked about their weight or having their weight recorded on a scale. Personal frustration might arise when the student has difficulties during a step or steps in the donning process.
- Benefits of the study were having civil engineering students and occupational safety and health students gain the knowledge of proper sizing requirements and correct donning

techniques which will be helpful in further schooling or future job practices. The students had an opportunity of learning how human usability research is conducted and were provided experience for when they conduct research of their own.

From there, the student decided if they would continue to partake in the study. If the student declined to participate, they were free to leave with thanks for their time in learning about this training. For students who chose to continue in the research, a consent form for participation in the study was presented for signature. Then, the above-mentioned training video was shown again a second time. After the video was shown for the second time, the participant had his or her height and weight recorded to determine the size harness appropriate for their upper body.

2.3.3. Harness Type and Sizes

The size harness for each participant was initially determined from the individual's height and weight using the DBI Sala ExoFit XP Full Body Harness Sizing Chart. The harness sizes that were available for the study were Extra Small (XS), Small (SM), Medium (MED), Large (LG), and Extra Large (XL).

There are several reputable harness manufacturers. The DBI Sala ExoFit XP Full Body Harness was selected for the study for the following reasons.

- DBI Sala is one of the top fall protection equipment manufacturers with quality products.
- Availability sizes from XS to XL in a model marketed for use in construction.
- The DBI Sala ExoFit XP Full Body Harness with quick connect buckles provides precise fit for a variety of individuals compared to other harnesses with the tongue buckle adjustment.

2.4. Donning Harness Repetitions

This section describes the procedures performed by the participants and the investigator, followed by a description of the harness fitting objectives.

2.4.1. Harness Donning Procedures

The participant's harness was set up and prepared for the first repetition. The harness straps were set at the original manufacturer's lengths for every repetition. The straps were measured for the amount of slack that the harnesses originally came with. This was to mimic as if the harness was brand new and taken out of the manufacture packages at the original lengths for every repetition.

The harness was fully expanded and arranged flat on a table. Each leg strap, chest strap, and the back belt were unfastened. Figure 2 shows an example. The lengths of the straps were measured prior to each experiment. These conditions were to be the starting preset condition for every repetition. The measured strap lengths are presented in Table VII.

When each repetition began, a campus video camera recorded each student and their attempt. The camera was used so later observations of each repetition could be made. The student performed the first repetition by trying to complete the donning of the harness the exact way as was shown in the initial training video and the manufacturer's instructions. The proper steps of the donning process per DBI Sala instruction manual are presented in Table VIII. Figures 3 through 10 are photos of some participants performing the steps.

Figure 2. DBI Sala ExoFit full body harness exhibited before repetition

Table VII. Manufacturers Pre-Set Strap Lengths

Harness Size	Chest Strap (In)*	Leg Straps (In)*	Shoulder Straps (In)*
Extra Small	4	6	7
Small	3	5	6
Medium	3	5	6
Large	3	3	6
Extra Large	4	3	9

* The lengths are measured from the end of the strap to the buckle of the designated area for adjustment

Once the student stated their donning was complete, the investigator examined the fit. The correctness of the fit of each tightened strap and the quality of the donning process was observed. Feedback based on the observations of the repetition was given to improve on future donning. Then the student removed their harness. The harness was then set back to the manufacturer's original conditions and laid on the table for the next repetition. The student could take as long of a break as needed before the next repetition. Each participant completed four repetitions.

Table VIII. Five-step Instructions for Adjusting the Harness

Steps	Instructions
1	Locate back D-ring held in position by the D-ring pad; lift up the harness and hold by this D-ring. Ensure the straps are not twisted.
2	Grasp the shoulder straps and slip the harness onto one arm. The D-ring will be located on you back side. Ensure that the straps are not tangled and hang freely. Slip your free arm into the harness and position the shoulder straps on top of your shoulder. Ensure that the straps are not tangled and hang freely. The chest strap, with quick connect buckle, will be positioned on the front side when worn properly.
3	Reach between your legs and grasp the gray leg strap on your left side. Bring the strap up between your legs and connect it by inserting the tab of the buckle into receptor of quick connect buckle on the left side in Figure 10. You will hear a click when the tab engages properly. Connect the right leg strap using the same procedure. Pull the free end of the strap away from the buckle to make a snug fit on each leg strap. To loosen the leg strap, grasp the yellow plastic portion of the buckle and pull through the buckle. A plastic end keeper on the end of the strap will stop it from pulling completely out of the buckle. To release the buckle, press the silver-covered tabs on the buckle toward each other with one hand, while pulling on the tab portion of the buckle with the other hand.
4	Attach the chest strap by inserting the tab of the buckle into the receptor of the quick connect buckle. You will hear a click when the tab engages properly. The chest strap should be 6 in. (15 cm) down from the top of your shoulders. Pass excess strap through the loop keepers. The strap may be tightened to a snug fit by pulling the free strap end to the left (away from the buckle). To loosen the chest strap, grasp the yellow plastic portion of the buckle and pull away from the body to allow the strap to pull through the buckle. A plastic end keeper on the end of the strap will stop it from pulling completely out of the buckle. To release the buckle, press on the silver-colored tabs on the buckle toward each other with one hand, while pulling on the tab portion of the buckle with the other hand.
5	Adjust the shoulder straps to a snug fit by pulling excess strap through the parachute buckles on each side of the harness. Left and right sides of shoulder straps should be centered on your lower chest, 6 in (15 cm) down from shoulder. Center the back D-ring between your shoulder blades. Adjust leg straps to a snug fit. At least 3 in (8 cm) of webbing must extend past the buckle on the leg straps. Adjust the wait belt.

After completing the four repetitions, participants were verbally thanked and given either ten dollars as a token of appreciation or put on a list for extra credit.

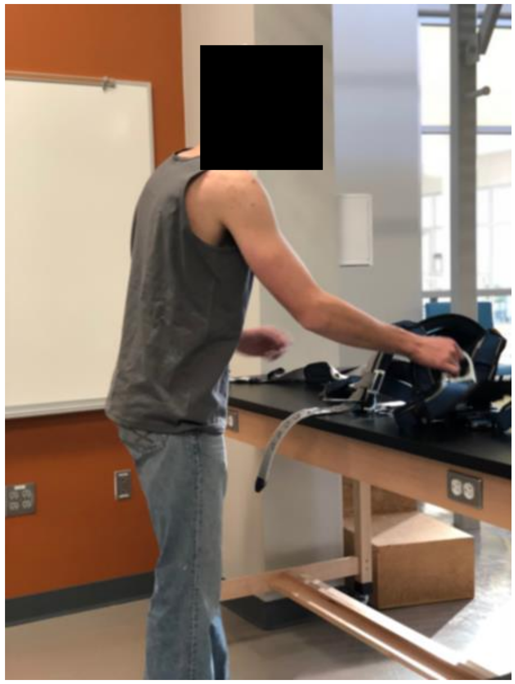

Figure 3. Participant grabbing the D-ring of harness to begin shake out portion

Figure 4. Participant ending shake out portion

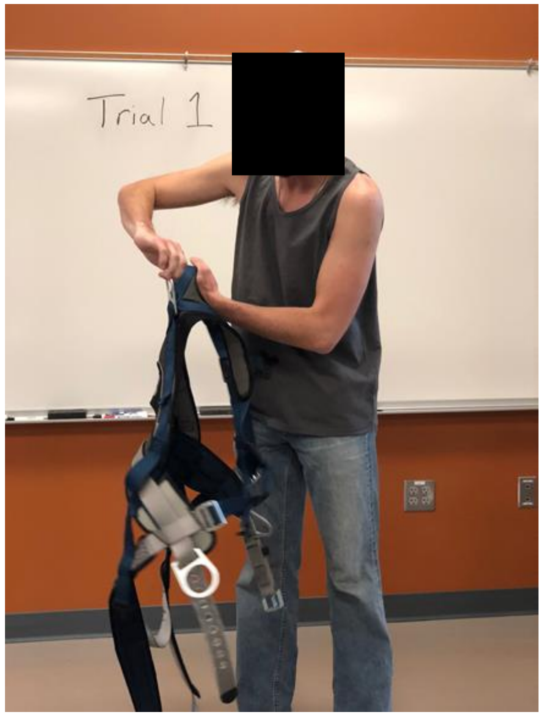

Figure 5. Participant grabbing the D-ring of harness to begin shake out portion

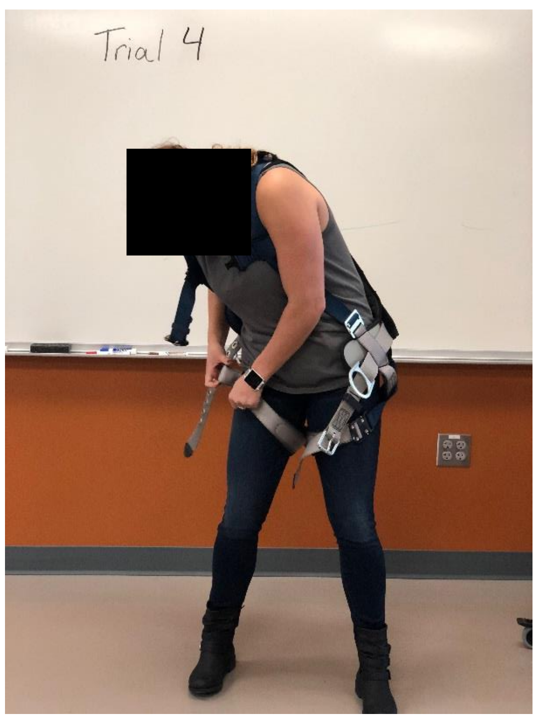

Figure 6. Participant adjusting leg straps of harness

Figure 7. Participant adjusting the chest straps of harness

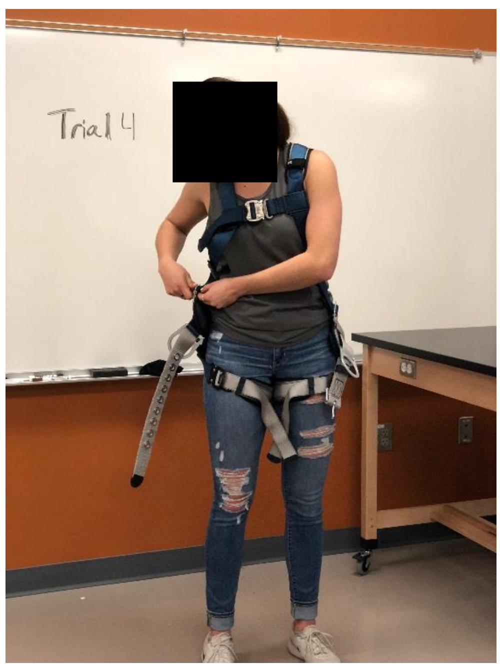

Figure 8. Participant adjusting the shoulder straps of the harness

Figure 9. Participant adjusting the waist belt and finishing the donning process

Figure 10. Harness fully donned: front and back views

2.4.2. Harness Fitting Objectives

After each donning and adjusting, the investigator provided feedback in the manner of a coach teaching an athlete a technique. The feedback was based on the following parameters.

- Tightness of legs straps (too loose, too tight, or adequate)
- Chest strap (too high, too low, or mid chest)
- Fit of shoulder straps (too loose on shoulders, too tight on shoulders, and tension)
- Location of D-ring (too high, too low, or in between shoulder blades)

2.5. Preparing Time Data for Analyses

In order to move from video tape recording to data suitable for statistical analyses, the following five steps were needed.

1. Videotape the participants
2. Use Observer XT 11 to review the video records and determine times for each step
3. Transfer time data to spreadsheet for limited analysis
4. Copy spreadsheet data to Minitab for statistical analyses

In Step 2, each recorded video of repetitions 1 through 4 was uploaded for each participant to the Observer XT 11 software. The software was used to precisely time how long each step took, and the overall time each repetition took. Additional observations were made by looking for mistakes or troubles that were encountered, and these instances were documented if they were missed in the original observation. In Step 3, the times were transferred to a spreadsheet to determine average times for each step and repetition.

The data sets were then moved over to an analysis software, Minitab version 18, to statistically compare the data.

2.5.1. Programming Observer XT 11 Software

The Observer XT 11 software is a computer program for the collection, analysis and presentation of observable data. Visual recordings of experiments are captured by the use of video cameras or cellular phones, then uploaded to this software where the video is imported into premade analysis templates that break down the recorded video into specific sections for data analysis.

The Observer XT 11 software was purchased by the Occupational Safety and Health program at Montana Technological University and the program was run on a computer in the Industrial Hygiene Laboratory.

The template used for this experiment was formatted to specifically break down the individual steps of the harness donning process. Each of the five steps was given a predetermined key on the keyboard, along with a key to track the overall time of each donning process. When each step of the process began and ended, the corresponding key was pressed. When each step was completed, the overall time key was pressed, and time was stopped. The predetermined keys for each step are listed in Table IX.

Table IX. Guide for Predetermined Keys Used in Tracking Start and Stop Times

Step	Start Time Indicator Key	End Time Indicator Key
Shake Out	A	Z
Over the Shoulders	S	X
Legs Straps	D	C
Chest Straps	F	V
Shoulder and Belt	G	B
Overall	H	N

2.5.2. Obtaining Time Data from Video

At the completion of every repetition, the steps of the donning process were broken down to the exact time when each step began and ended as well as overall time. These times were logged on the analysis tab in the Observer XT 11 software. Figure 11 is a screen shot illustrating the user interface used for obtaining times for each step.

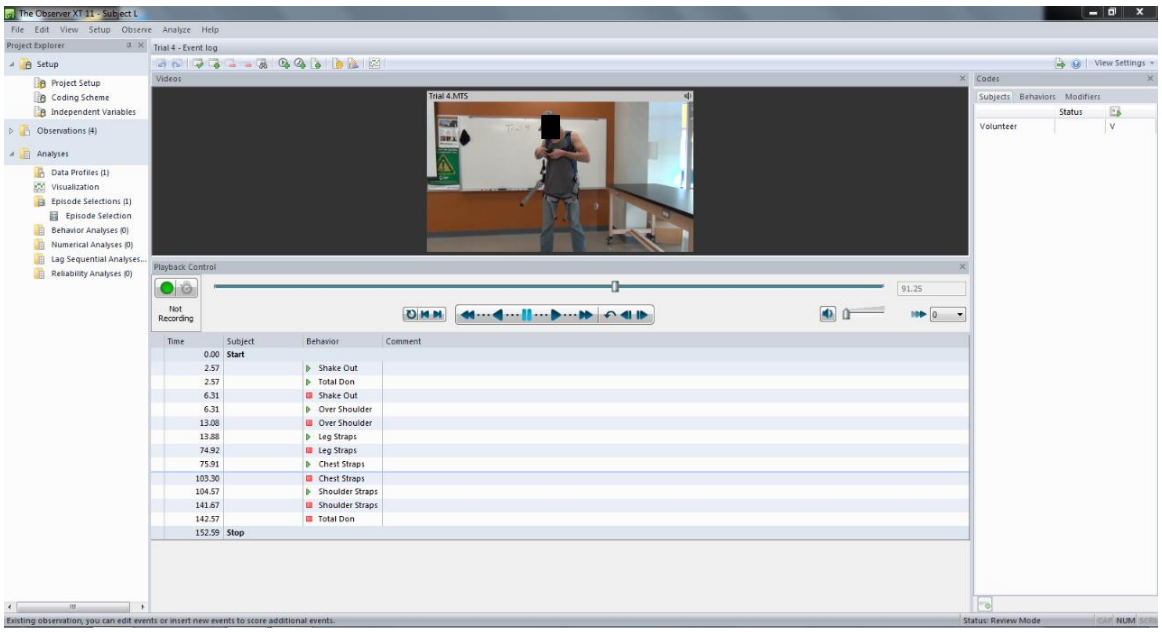

Figure 11. Screen shot of analysis using Observer XT 11

2.5.3. Organizing Time Data

The times of each harness donning were then copied and transferred into a Microsoft Excel spreadsheet. An image of how the spreadsheet was arranged is in Figure 12. It shows data for two subjects. It includes each subject's times for each step as well as total time of process. The spreadsheet also kept the recordings of height and weight for each subject, as well as the size of the harness each individual used. The type of reward chosen by each participant was documented in this spreadsheet, along with any noted communication or harness issues that were experienced during the repetitions.

Male						
Subject A	Duration				Height/ Weight	
	Trial 1	Trial 2	Trial 3	Trial 4	**5'8"**	**130**
Shake Out	4.7	3.57	3.44	3.94	Ft	lbs
Shoulders	5.54	4.8	6.27	4.74	Harness Size	
Legs	382.37	43.74	97.72	72.14	**Small**	
Chest	33.73	21.02	28.06	15.72	Extra Credit or $10	
Shoulder & Belt	98.9	68.73	72.87	50.32	**$10**	
Total	529.65	144.11	210.67	152.25		

Female						
Subject P	Duration				Height/ Weight	
	Trial 1	Trial 2	Trial 3	Trial 4	**5'2"**	**125**
Shake Out	4.6	6.84	6.24	6.44	Ft	lbs
Shoulders	6.47	5.74	5.61	3.9	Harness Size	
Legs	204.93	193.76	165.58	115.25	**Extra Small**	
Chest	35.65	20.75	10.81	13.01	Extra Credit or $10	
Shoulder & Belt	53.15	9.48	5.27	15.15	**Extra Credit**	
Total	313.67	241.24	195.39	157.45	***No Belt**	

Figure 12. Example of data for two subjects arranged in a spreadsheet

2.6. Hypotheses and Statistical Analyses

Statistical analyses were planned to initially determine if time to complete each step differs among repetition 1, 2, 3, and 4. If the ANOVA determines the repetition-specific times differ (as expected), post-hoc analyses will proceed. The test for equal means used the ANOVA model in Equation 4, where the subscripts indicate subject (i) and repetition (j). The variable Repetition was considered to consist of four treatments, with no particular order.

Equation 4. ANOVA Model Comparing Equality of Donning Times

$$T_{ij} = \mu_{\bullet\bullet} + \text{Subject}_{i\bullet} + \text{Repetition}_{\bullet j} + \varepsilon_{ij} \qquad \text{(Eq 4)}$$

The timed data sets were tested for normality in their original and log transformed versions. The two types of data were then tested for analysis of variance with a Levene's test, which is an inferential statistic that assesses the equality of variances for a variable calculated for two or more groups. In this case, there were four data sets consisting of all times in each of the four repetitions. As expected, the test concluded that the four means did not have equal times, thereby justifying further analyses.

Next, an ANOVA was run on the data sets through a Tukey's Pairwise comparison. It was used to analyze the differences and variation among and between data sets.

The second analysis was to determine if increasing repetitions would lead to reducing donning times. Unlike the first analysis, the variable Repetition was considered to be an ordered variable numbered 1, 2, 3, and 4. This analysis used regression. The applicable null hypothesis was there will be no effect of repetition on the time to complete the particular set of donning times (using $p < 0.05$). The alternative hypothesis was a significant relationship existed.

Finally, regression was used to examine how repetition affected donning time. The intent was to determine the extent to which the learning curve function in Equation 2 would fit the data. The log-transformed data sets were fitted by regression (Eq. 3) to determine the slope variable. The slope values were then inserted into the power function (Eq. 2). Graphs were developed to aid with visual comparison of the mean raw data to that predicted by the learning curve model. The fit was further examined using Minitab's graphs for comparing possible patterns of residuals.

2.7. Observations of Harness Usability

Throughout the total donning process, the five total parts were recorded on video as well as visually observed. During the repetition attempts, notes were taken throughout the individual's don. Each part of the donning process was documented on where the participant experienced difficulty, either being a certain step or the overall process of the don. Notes were also taken on the fit of each strap during the step, as well as an overall judgment on the complete don itself. Notes consisted of visual observation instances such as the student had trouble with leg strap buckle and gave up to move on the next step, student skipped a step but came back to the correct step, and student had to loosen strap instead of tighten strap. The notes helped explain why a certain step might have been out of the ordinary.

3. Results

3.1. General Findings

The experiment consisted of 25 volunteers. They were students majoring in either Occupational Safety and Health or Civil Engineering from the Montana Technological University as an undergraduate. The experiment took place in the Safety Lab in the Natural Resource Research Center (Figure 13) and took seven weeks to conduct all repetitions for all participants. Analyses of the timed data sets were then conducted for an additional four weeks. The general findings from this experiment were that the total time to don and adjust the DBI Sala ExoFit harness decreased in time with an increased number of repetitions. The correctness of the fit of the harness, as judged by the investigator, was also improved with an increase of repetitions.

Figure 13. Set up in the Safety Lab where the experiments took place

3.2. Donning Harness Repetition Times

The analyses started with data on the all-participants average time to complete each step and the overall total time of the donning (Figure 14). The average times it took males, females, and combined to complete each section are provided in Tables X–XII, respectively.

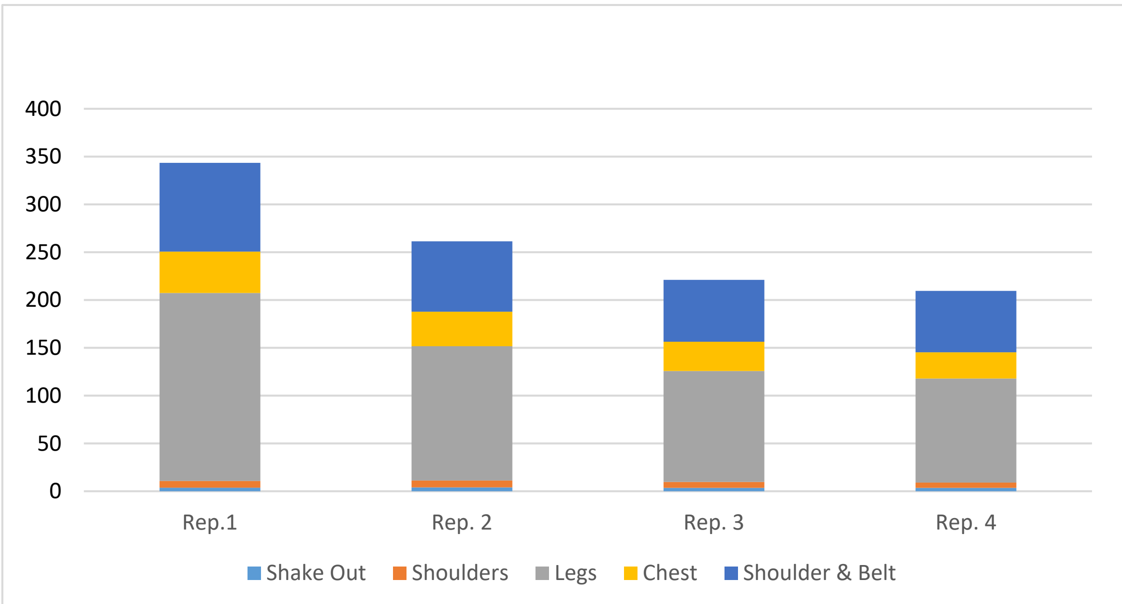

Figure 14. Average harness donning repetition times with step break down.

Table X. Harness Donning Times for Males in Seconds

Steps	Repetition 1	Repetition 2	Repetition 3	Repetition 4
Shake Out	3.7	4.0	3.7	3.7
Shoulders	7.8	7.8	6.7	6.0
Legs	211.7	141.6	116.3	117.8
Chest	41.2	30.2	27.2	28.6
Shoulder & Belt	82.6	71.6	61.3	59.3
Total	341.3	262.9	221.1	216.8

Table XI. Harness Donning Times for Females in Seconds

Steps	Repetition 1	Repetition 2	Repetition 3	Repetition 4
Shake Out	3.9	3.9	3.4	3.4
Shoulders	5.8	6.2	5.2	4.7
Legs	173.6	138.8	115.7	95.4
Chest	46.9	45.0	35.9	25.6
Shoulder & Belt	107.8	76.8	69.7	71.2
Total	344.6	278.5	236.3	205.9

Table XII. Harness Donning Times for all Participants in Seconds

Steps	Repetition 1	Repetition 2	Repetition 3	Repetition 4
Shake Out	3.8	4.0	3.6	3.6
Shoulders	7.0	7.1	6.1	5.5
Legs	196.5	140.4	116.1	108.9
Chest	43.5	36.1	30.7	27.4
Shoulder & Belt	92.7	73.7	64.7	64.1
Total	342.6	269.1	227.2	212.4

As indicated by the data in Tables X, XI, and XII, the amount of time in each step and overall time decreased with an increase in repetition. The step taking the longest amount of time to complete in each donning was adjusting the leg straps. In over 50% of the repetitions, the leg straps took more than half the time of each individual don. The next step, accounting for the second most amount of time, was the adjustment of the shoulder straps and belt.

3.3. Effects of Repetitions on Donning Time

Was there a statistically significant difference in learning among repetitions? To address this question, the total times of each individual harness donning were transferred over into Minitab software. With the sample size of data, there was no need to check for normality. The data set was then computed to check for equal variance in regular timed and log transformed data to determine what specific ANOVA test should be used. Based on the Levene's *p*-value of 0.893, it was determined that a one-way ANOVA would be used to accurately analyze the data sample and determine if there was a statistical difference in learning between repetitions.

A one-way ANOVA was run on the log transformed data sets of all 25 participants who completed repetitions of the total donning times and the leg straps portion of the donning. There was a total of 100 recorded times for both the total don and the leg straps portion. The reason for specifically running the ANOVA on the leg strap portion was to see if the reduction of learning time of the total harness was statistically reduced in the leg strap portion. The *p*-value of the one-way ANOVA for the total harness donning was calculated to be $p = 0.005$, which revealed that there was a statistically significant change in time from one repetition to another. This rejected the null hypothesis of the ANOVA that all means are equal. The leg straps section followed a similar trend as the total harness donning from the one-way ANOVA with the *p*-value calculated to be $p = 0.002$, which also indicated there was a statistically significant change in the leg strap times from one repetition to another. It was also determined that the null hypothesis that all means are equal was rejected again for this section.

To compare total donning times of the four repetitions, a graphical approach and a statistical analysis were used. The graphical approach made use of the boxplots in Figure 15 and 16. The statistical analysis used the Tukey's Pairwise Comparison test to compare the differences among the means of the four repetitions to see where the times differ statistically from the others. The Tukey's test outputs are displayed in Figures 17 and 18.

For the total donning times shown in Figure 17, these results concluded the difference between repetition 1 and repetition 3 were significantly different with the confidence interval of these two repetitions containing zero and $p = 0.019$. Repetition 1 and repetition 4, as well, did not contain zero within the confidence interval and had $p = 0.006$.

For the leg strap adjusting times shown in Figure 18, the same comparison test was run for the leg strap portion and the results were very similar. The difference from repetition 1 and repetition 3 were significantly different (p = 0.007) and repetition 1 and repetition 4 were significantly different (p = 0.005). Repetition 1 was not significantly different from repetition 3, and repetition 1 was not significantly different from repetition 4.

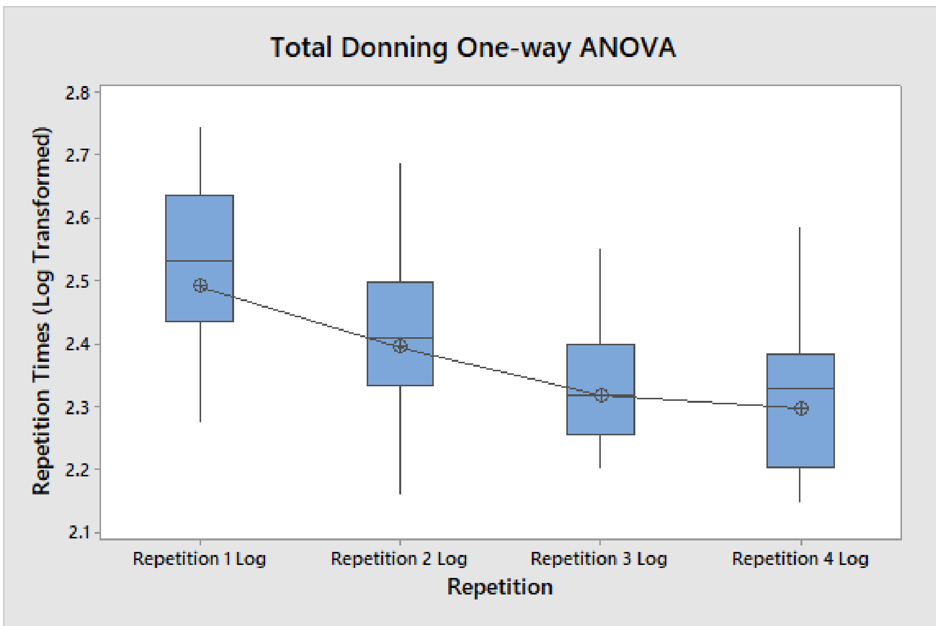

Figure 15. Boxplot of one-way ANOVA for log transformed total donning repetitions

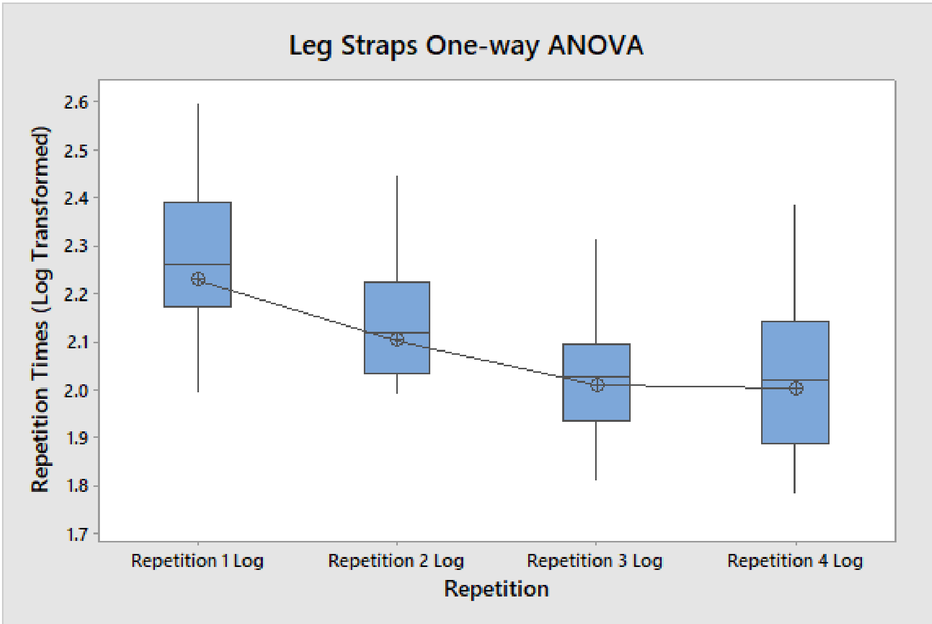

Figure 16. Boxplot of one-way ANOVA for log transformed times for leg straps portion

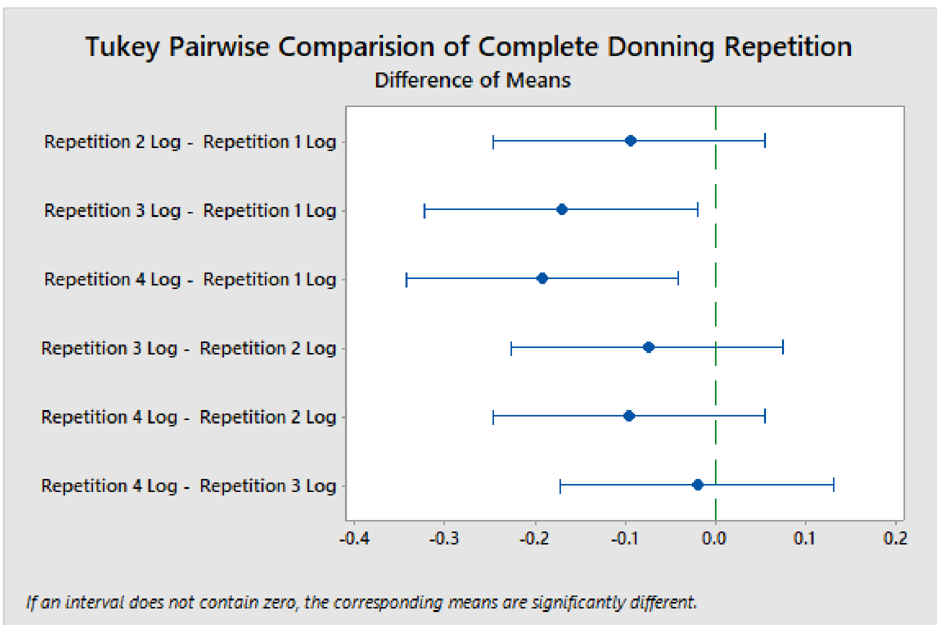

Figure 17. Tukey difference of means comparison between log transformed repetitions for total don

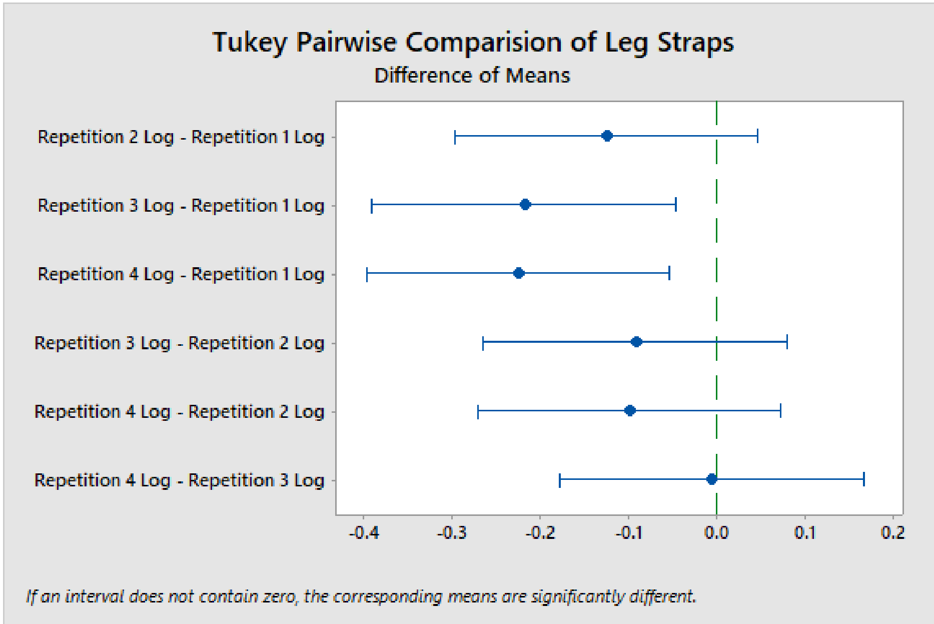

Figure 18. Tukey difference of means comparison between log transformed repetitions for legs portion of donning process

3.4. Test for Linear Regression

The data were formatted into a regression analysis between the values of the log of repetition (1 through 4) versus the log of the completion time. A fitted line plot was tested to determine the slope of the projected time reduction in the total time of the harness donning. Figure 19 is a scatter plot of all data with the linear regression line. As shown in the Figure 19, the first repetition took the participants the longest amount of time to complete the donning process. With each increase of repetition, the total time of the donning process gradually reduced from one repetition to another. The repetition times were log transformed to find the slope of the decreasing times that would be used in a learning curve model. The slope of the log transformed graph was negative indicating that there was a decrease in time with additional repetitions. The negative slope (-0.3328) was significantly different from zero meaning that there is a significant relationship between the dependent and independent variables (time vs repetition).

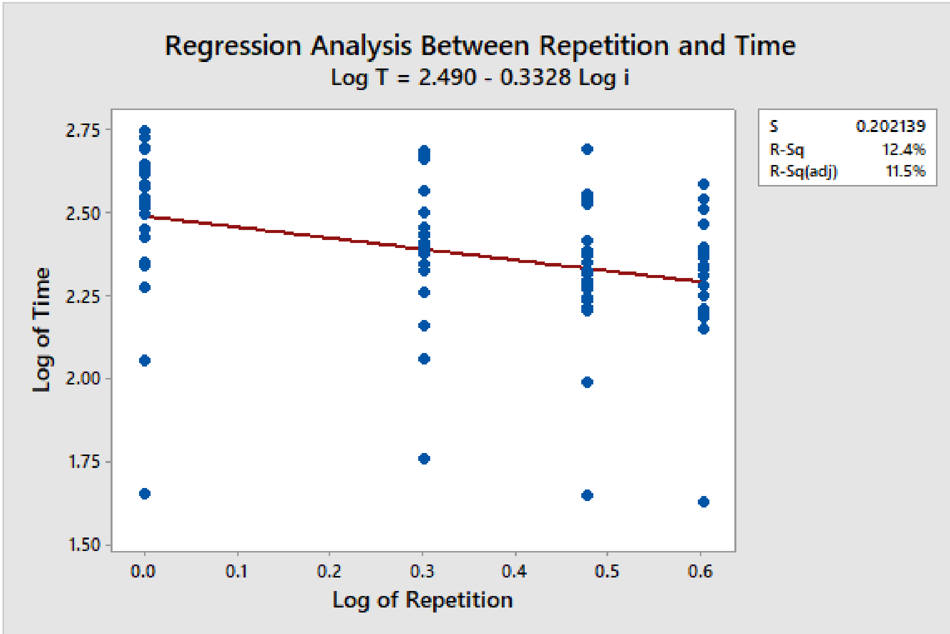

Figure 19. Regression analysis between the log-transformed value of repetition and time

3.5. Tests for Learning Curve Fit

Creating a learning curve in the form of Equation 2 used the all-subject data found in Table XII. It started with the linear regression fit for the log transformed data (Eq. 3). That fitted line provided a value for slope. The slope value was then used in Equation 2 to determine the time predicted by the learning curve. The findings analyzed in this manner were the mean total times and the mean times of the three donning steps that contributed most to the total time: leg strap adjustment, shoulder and belt adjustment, and chest strap adjustment. Comparisons between predicted mean times and measured mean times are presented graphically. Figure 20 shows the total time. Figures 21–23 show these comparisons for leg strap adjustment, shoulder and belt adjustment, and chest strap adjustment, respectively. All four graphs indicate close fit between predicted and actual means times.

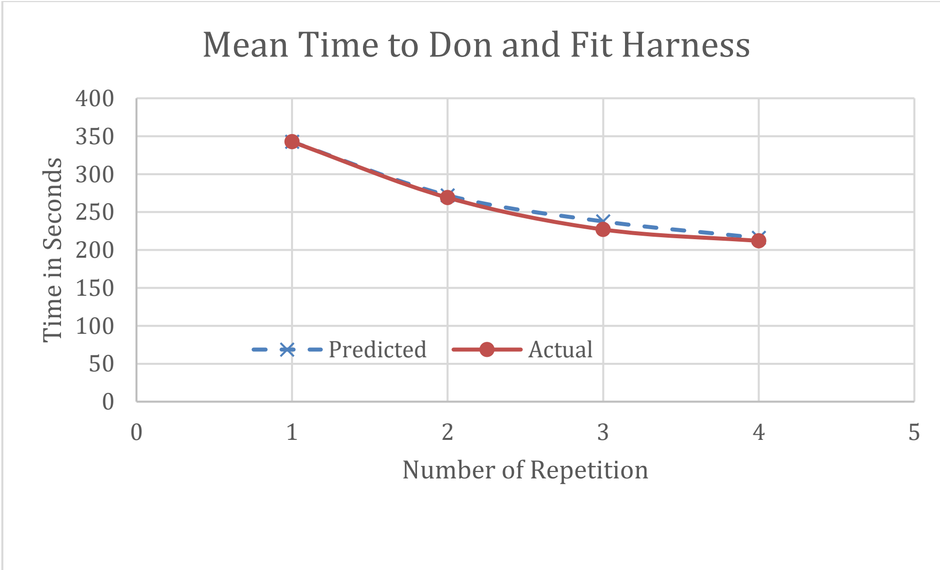

Figure 20. Mean total time of the 25 subjects as measured and as predicted

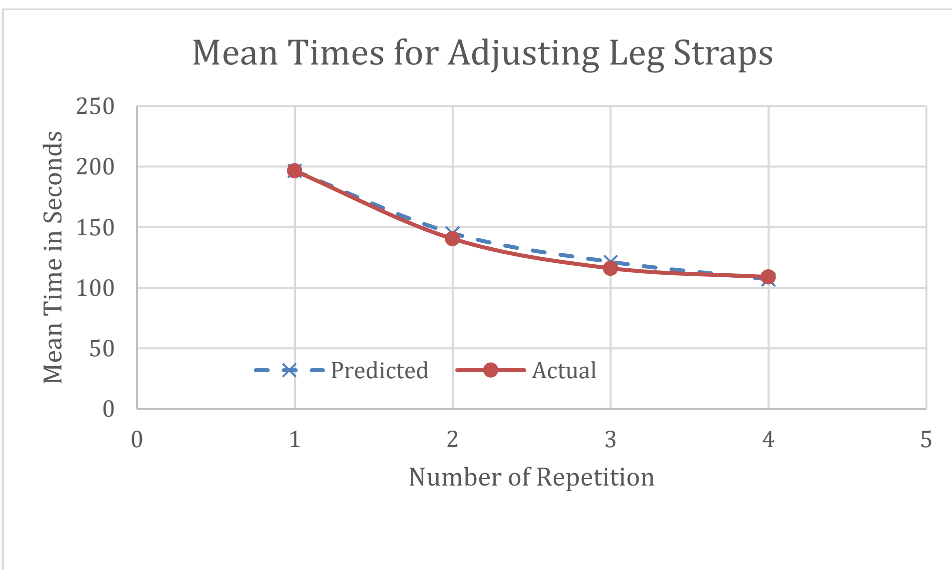

Figure 21 Mean time for leg strap adjustments as measured and as predicted

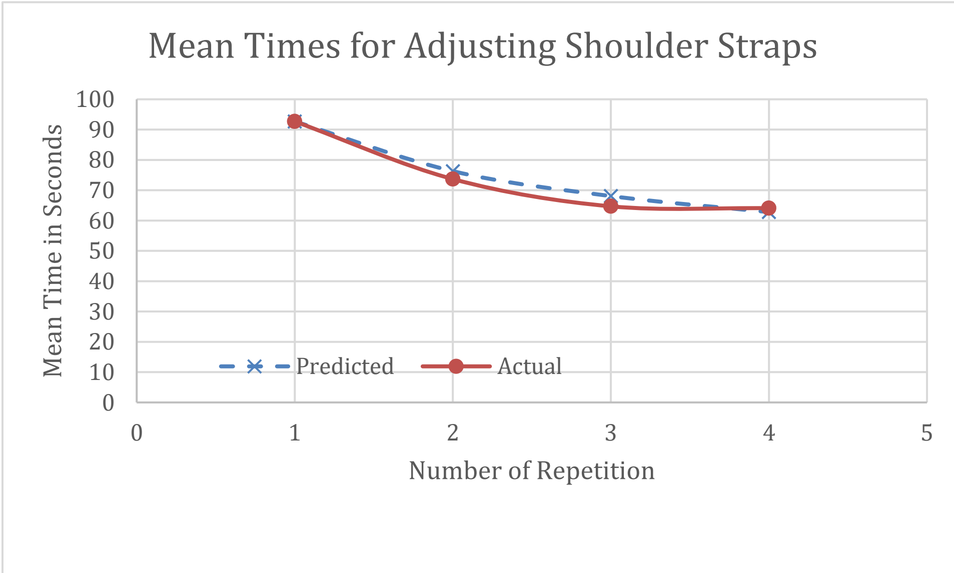

Figure 22. Mean time for shoulder and belt adjustments as measured and as predicted

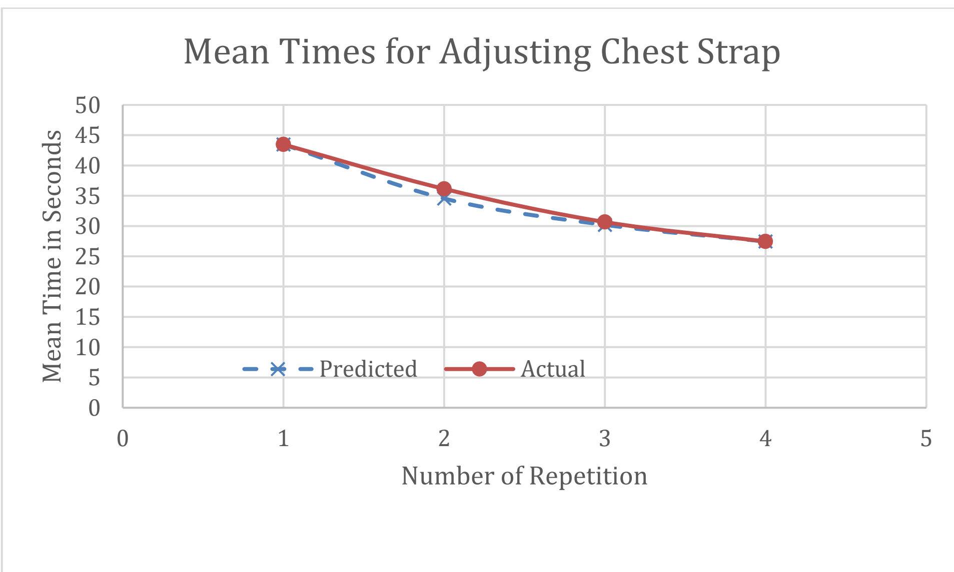

Figure 23. Mean total time for chest strap adjustment as measured and as predicted

3.6. Investigator's Observations

The investigator coached 25 participants through the repetitions and subsequently watched the video of their repetitions. Based on his experiences, the following observations are worth documenting. When students first encountered the harness, it was clear that the individual had no idea how to wear the harness. The first repetition was an actual learning experience and really set the mark on how much the student could improve. On the student's first repetition, the harness fit was not fully conforming to the instructions. Common shortcomings were the leg straps would be loose or the D-ring was not between the shoulder blades. In subsequent repetitions, improvement of the total fit was visually evident. Typical improvements included straps being tightened to the correct lengths and placed on the correct positions on the body. From watching the videos, it was clear that the first attempt was the most frustrating for all of the participants. For the second donning, the students showed considerable improvement. For the third and fourth repetition, their skill for donning and adjusting the straps continued showing improvement.

3.7. Predicting Times with Additional Repetitions

The time data from this experiment were fitted by the learning curves shown in Figures 20, 21, 22, and 23. Industrial engineers often refer to learning curves by a time reduction factor. For example, a "20% learning curve" will predict a 20% reduction in time with each doubling of repetitions. The reduction from this experiment was 20.6% with each doubling of repetitions. Table XIII illustrates how the time is predicted to decline with each doubling in repetitions. Starting with the average time for the initial donning of 343.6 s, the second is predicted to take 272.8 s. The "Percent Decline" column was computed from the predicted times for repetitions 1 and 2 using the function 100 * (rep. 2 – rep. 1) / rep.1. Similarly, going from repetition 2 to 4, the model predicts a 20.6% reduction in time computed from 100 * (rep. 4 – rep. 2) / rep. 2, and going from repetition 4 to 8, the model predicts a 20.6% reduction in time, computed from 100 * (rep. 8 – rep. 4) / rep.4.

Table XIII. Learning Curve Prediction of Reducing Times with Doubling of Repetitions

Practice	Percent Decline	Decline in Time (s)	Predicted Time (s)
Initial donning time			343.6
From repetition 1 to 2	20.6	70.8	272.8
From repetition 2 to 4	20.6	56.2	215.6
From repetition 4 to 8	20.6	44.6	171.0

The third column in Table XIII reports the decline in seconds. For example, going from repetition 2 to 4, the predicted decline would be 0.206 * 272.8 s = 56.2 s. Although the experiment ended with four repetitions, the learning curve allows predicting further out. If someone is interested in predicting time for an eighth repetitions, the learning curve would predict 171.0 s.

4. Discussion

The specific aim of this project was to experimentally characterize how the time to don and adjust a harness changes with number of repetitions.

4.1. Summary of Results

The mean times to complete a harness donning declined with each repetition. The decline followed a learning curve based on a power model. The times between males and females were very consistent with each other and the size of harness did not seem to be a key factor in the ability to don the harness correctly.

For all four repetitions, the largest amount of time involved adjusting the leg straps.

4.2. Strengths of Study

One of the most important strengths of this study was to observe and record an individual's learning progression with a new task. None of the volunteers had been exposed to any fall protection harnesses donning prior to the study which added value to their improvements from repetition to repetition.

4.3. Study Limitations

While the repetitions were being conducted, casual conversation took place between the volunteer and the instructor. This could have possibly had a factor on the times by distracting the volunteer while the repetition was being performed and not allowing the student to have complete and total focus on the task at hand.

Another factor that could have skewed the data is in between repetitions the student was not asked to leave the room while the harness was being prepared for the next repetition. The students could have possibly picked up a few tips or had learned how to adjust the straps of the harness by observing the repetition preparation.

A major limitation was the use of college students when the ultimate target for the study was workers in the construction industry who were receiving hands-on training on harness fitting. Differences between the study participants and construction industry workers include, among several factors, age and range of body sizes. Therefore, generalizing from the study findings to construction industry workers should be done cautiously.

The extra small sized harness is not manufactured with the adjustable waist belt like the rest of the harnesses used in this study. This size harness was only used by three participants in the study, but without the additional adjustment, the donning could have resulted in a reduced time.

Possible language barriers between the instructor and several volunteers were encountered when describing the procedure and teachings throughout the study. Important details about the study required communication between the two individuals, and the potential to not pass along information properly could have resulted in a misunderstanding. This is believed to have affected the initial repetition more than subsequent repetitions.

There was no precise and objective way to conclude if the harness was worn to the best of its abilities. Manual and visual inspections on each part of the harness straps were conducted to check the correct fit, but there was no standard to go off besides the manufacturer's recommendations and interpretations. This could have led to imperfections in the harness fit and possible inconsistencies in the judgement of the fit.

The DBI Sala ExoFit Sizing chart was not the most accurate way to measure what size harness each individual should have been wearing for the repetition. The chart took into consideration the height and the weight of the participant but did not include the specific body type/build. On certain individuals, the recommended harness size did not fit appropriately. On a few occasions, the leg straps of the harness were all the way tightened and were still loose on the individual. This caused for an improper and not complete fit of the harness, even though the chart stated this was the correct size. This limitation decreased the significance of the repetition times due to the fact the participant tightened the harness straps to a set mark every time without measuring the actual fit of each particular step of the donning process.

4.4. Possible Future Work

Possible future work for this topic would be to determine specific anatomical markers that could be used to objectively measure how well a harness fits an individual. This could be used for future experiments on factors that might help improve fitting.

Another area for future students at Montana Technological University is to establish the capability to perform harness fit tests using the NIOSH criteria (Hsiao, et al. 2012). In the NIOSH research, subjects wore special, tight fitting clothing with anatomical markers, and their movements were tracked using video cameras capable of mapping locations of each marker. This line of research could attempt to implement the NIOSH criteria with subjects wearing clothing more representative of the clothing worn by construction workers and using video cameras for analysis with the Observer XT software.

5. Conclusion

This project began with the broad hypothesis that the time to don a harness and adjust the straps to attain a satisfactory fit will be, after proper instruction and familiarity with the harness, longer on the initial repetition, and reduced each subsequent repetition. Based on both visual and statistical analysis, the observed time did reduce with each repetition. The specific aim of this project was to experimentally characterize how the time to don and adjust a harness changes with number of repetitions. Equation 5 says that total donning (T_i) may be predicted by the initial time (T_1) divided by the repetition (N) to the power 0.3328. Graphs demonstrate that the equation describe the data quite well, thereby achieving the specific aim.

Equation 5. The Learning Curve Resulting from this Experiment

$$T_i = T_1 N^{-0.3328} \qquad \text{(Eq 5)}$$

The study was conducted by having volunteers, who had no prior experience with a full body harness, develop skills by donning and adjusting a particular fall protection harness multiple times with feedback from an instructor. There were five main sections of the donning process observed during the study which were shaking out the harness, putting the harness over the shoulders, securing and tightening of both leg straps, connecting and tightening the chest strap, and tightening shoulder straps and buckling the waist belt. The Observer XT software was very useful for getting times for the various steps and total time.

Results of this study showed there was a significant decrease in total time it took to don the harness with an increase number of repetitions. From the data and the learning curves, it appears that four repetitions provide considerable decrease in time. According to the learning curve, additional repetitions would lead to less substantial reductions in time. Specifically, to achieve only 20 percent more reduction in time would take four additional repetitions (eight in total). This does not appear to be warranted.

With fall protection being the most sited OSHA violation year after year and falls being the leading cause of injury/death, fall protection training is a major need to eliminate these hazards and keep our employees from harm. Proper training on how fall protection is supposed to be used and awareness of the equipment can help reduce these injuries by preventing the occurrence of a fall from happening or limiting the injury as much as possible by having proper use of personal-fall protection equipment.

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SIGNATURE PAGE

This is to certify that the thesis prepared by Zachary Bunney entitled "Effect of Repetition on Time to Don and Adjust a Fall-Protection Harness" has been examined and approved for acceptance by the Department of Safety, Health, and Industrial Hygiene, Montana Technological University, on this 22th day of April, 2019.

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