

Abstract

Reid, Stephanie Ann. Learning Curve Analysis of a Patient Lift Assist Device.
(Under the direction of Dr. Gary A. Mirka)

The prevalence of musculoskeletal disorders (MSDs) among health care workers is extremely high. In response to high injury rates associated with the patient transfer tasks, one of the most physically demanding tasks in the health care industry, ergonomic interventions have been developed. These ergonomic interventions were created to lessen the risk of MSDs development by reducing the load required of the worker, however workers often complain of the added task time that using the interventions introduce. It has been shown that an increased number of replications of a task will yield an increased proficiency in the task, and that this increased productivity follows a response called a learning curve. The use of learning curve theory has not been applied to the introduction of ergonomic interventions in the workplace. The objectives of the current study were to explore the possible application of learning curve theory in the process of introducing ergonomic interventions, and to evaluate the impact of training technique (passive training vs. active training) on variables describing the learning process.

Eighteen subjects completed multiple replications of a patient transfer task after being trained in either an active or passive training method. The patient transfer task was completed with an ergonomic intervention, a mechanical patient lift assist device (“Opera” model manufactured by Arjo). The active training method took a hands-on approach to the training, while the passive method was similar to the see-one-do-one method currently prevalent in the health care industry. The task time-to-complete values

were recorded for each repetition, and the dependent variable values were calculated for each subject. The dependent variable Learning Rate, a standard measure of the decrease in task performance as a function of task repetition, was 85.2% for the hands-on training and was 81.1% for the see-one-do-one training (this difference was not found to be statistically significant). However, the dependent variable Trial 0, the time-to-complete values for the first time the subject completed the patient handling task, was found to be significant ($p < 0.05$). The average time-to-complete value for the hands-on method was 370 seconds while the average for the see-one-do-one method was 475 seconds. The dependent variable “Delta 3” was also found to be significant. This measure quantifies the decrease in time-to-complete values for the across the first four trials. The Delta 3 values for the hands-on method was 82 seconds while the see-one-do-one method was 170 seconds, indicating a rapid “merging” of performance in the two training methods.

The study successfully applied learning curve theory to the introduction of an ergonomic intervention, and illustrated the dominance of an active training method when training workers to use the intervention (particularly in the early stages of learning to use the device). The results emphasize the importance in considering learning curves when workers are learning to use new equipment, especially ergonomic interventions that can prevent MSDs from occurring. The results also show that the method of training given to workers can impact the initial performance of a task.

Learning Curve Analysis of a Patient Lift Assist Device

By

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Dedication

To all those upon whose shoulders I stand, my gratitude is eternal.

Biography

Stephanie Ann Reid was born the eldest daughter of Steven and Julie Reid on November 7, 1979 in Columbus, Ohio. Almost eight years into her life she was blessed to have a younger sister, Vanessa Lynn Reid. A member of a large biological and extended family, she was raised in an environment of love and support.

She attended The Wellington School in Upper Arlington, Ohio, where she graduated in June of 1997. She went on to further her studies at The Ohio State University in Columbus, Ohio, where she studied engineering. Stephanie was very active on campus, serving in Undergraduate Student Government as well as assuming leadership roles in various organizations. She was especially involved in the National Society of Black Engineers, serving as the National Secretary, Region IV Vice Chairperson, and Region IV Secretary. She also worked as an engineering intern each summer. As an intern at IBM in Rochester, Minnesota she worked on coding and guardband testing. With Eaton Corporation she focused on technical sales and divided her time between Beaver, Pennsylvania and Columbus, Ohio. Stephanie graduated with a Bachelors of Science in Industrial Engineering in June of 2002

After completing her undergraduate degree Stephanie joined Teach For America, where she was stationed in Atlanta, Georgia. Her assignment took her to F.L. Stanton Elementary where she taught fifth grade. The time Stephanie spent teaching children was extremely enjoyable, however the desire to complete graduate studies was still a very appealing option for her. Stephanie began working towards her Masters of Science

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1 Introduction

Recently more people have taken a greater interest in their health and a more proactive role in their healthcare. Most people want to know that if they are ever admitted into a hospital or health care setting as a patient, their caregivers are in the best condition possible, and are not dealing with aches and pains of their own. Unfortunately some of the work tasks within the health care setting can be the cause of aches and pains in these healthcare workers. One of the more strenuous tasks within the healthcare setting is patient transfer, moving a patient from location to location. In the hospital setting this task is usually done by nurses and nurse aides, and is traditionally done manually.

There has been a recent push to make the task of patient transfer safer for the worker (OSHA, 2002). A number of ergonomic interventions have been introduced to address the issue. Administrative controls like lift training and policies of two-person lifts have been implemented (e.g. Nussbaum & Torres, 2001). Engineering controls such as low-friction sheets and mechanical patient lift assist devices have also been used (e.g. Garg & Owen, 1994; OSHA, 2002). While these controls make the patient transfer task safer, they can require more time from the worker in terms of setup and implementation.

The health care setting is a very busy environment, with many temporal demands on the workers. Because of this rushed pace, some ergonomic interventions that make the patient transfer task safer for the worker are ignored for the traditional and strenuous manual lift. Because time is an asset in these settings, the manual lift often appears to be optimal. What is often not considered is the gradual reduction in time to complete these tasks using these devices due to the normal learning process. Learning theory states that

it will take a number of replications of a task before one reaches a steady state of time-to-complete. The initial time-to-complete value for a worker who uses the ergonomic intervention can be much higher than their steady state value, and these time-to-complete values follow a predictable function called a “learning curve”. This theory has not been considered when introducing and evaluating ergonomic interventions, and this process is the focus of the current work.

The following introduction first provides an overview of the ergonomics field and musculoskeletal disorders. The health care industry’s interest in ergonomics and preventing musculoskeletal disorders is next examined. Ergonomic interventions are evaluated in depth, focusing on the controls used in the patient transfer task of the health care setting. A differentiation is made between administrative controls and engineering controls. This information is followed by an overview of learning curve theory and the application of the theory when introducing ergonomic interventions. This will lead to the study objectives and a hypothesis is presented, specifically that hands-on training method is superior to the see-one-do-one training method when introducing an ergonomic intervention.

1.1 Overview of Ergonomics

Ergonomics is a branch of engineering that is devoted to fitting the task to the worker. Ergonomics is defined as the application of knowledge about human capacities and limitations to the design of workplaces, jobs, tasks, tools, equipment, and the environment (NAE, 2004). Ergonomics is a growing interdisciplinary field that Wilson (2002) more rigorously defines as the theoretical and fundamental understanding of human behavior and performance in purposeful interacting socio-technical systems, and

the application of that understanding to design of interactions in the context of real settings. Whether plainly or elaborately defined, ergonomics is a field that has true relevance in the current world. As systems become more elaborate, more thought has to be put into the dynamics of human interaction with the systems. The study of ergonomics can be separated into two categories. Cognitive ergonomics deals with people's mental interactions with systems, while physical ergonomics deals with people's physical interaction with systems. The focus of this study is on physical ergonomics, specifically a person's physical interaction with an ergonomic intervention. A more detailed discussion of the important issues in physical ergonomics is presented in the following sections.

1.1.1 Occupational Musculoskeletal Disorders

A subsection of ergonomics, called occupational ergonomics, deals with the physical injuries that can be caused by workplace tasks. Workplace induced injuries that impact the muscles, tendons, ligaments, joints, peripheral nerves, and blood vessels are known as occupational musculoskeletal disorders (MSDs). MSDs can develop when there is a mismatch between the physical requirements of the job and the physical capacity of the worker. A number of issues within the workplace can cause an MSD to develop: repetitive motion, rapid pace, forceful exertions, heavy lifting, non-neutral postures, vibration, insufficient recovery time, and mechanical pressure contractions (Punnett & Wegman, 2004). For example, workers that complete repetitive tasks can develop tension degradation in their ligaments, which can cause increased exposure to injuries as the workday progresses. Eventually the ligament degradation can lead to joint degradation, a predecessor to osteoarthritis (Solomonow, 2004).

MSDs have a large impact on our society. The U.S. National Institute for Occupational Safety and Health (NIOSH, 1997) found through reviews of workers compensation claims that the average cost of an occupational MSD ranged from \$8,000 to \$21,000. Utilizing the same workers compensation claims review method, Webster and Snook (1994) found that the compensable cost for the U.S. in upper extremity MSDs totaled \$563,000,000 in 1993. It is important to note in workers compensation studies, that compensable costs do not include factors such as rehabilitation costs and the recruitment and training of new workers, so the actual cost can be much higher. In a study that surveyed over 15,000 employees of a major U.S. company, the annual per capita costs of lower back pain were on the same scale of serious ailments such as heart disease and diabetes (Maetzel & Lee, 2002).

Musculoskeletal disorders (MSDs) can be inflammatory or degenerative conditions, and can be clinical syndromes such as tenosynovitis, or less standardized pain in a particular region of the body (Punnett & Wegman, 2004). Some common MSDs include sciatica, epicondylitis, carpal tunnel syndrome, and low back pain. The lower back, shoulder, neck, forearm, hand, and legs are the regions most commonly impacted by MSDs (Punnett & Wegman, 2004). Shoulder and back MSDs are very common for workers dealing with forceful exertions, non-neutral postures, and heavy lifting (Klein, et al., 1984), the kinds of exposures experienced by nurses and nurses aides. A self-reporting survey of 180 nurses in China found 57% reporting low back pain, 39% reporting shoulder pain, and 39% reporting upper back pain. The survey used the internationally accepted “Standardized Nordic Questionnaire” (Smith et al., 2004).

The back is a region in the body composed of the spine, muscles, and nerves. The spine is the major skeletal structure in the back and is composed of vertebrae (bones) separated by discs. Lower back pain can be caused by muscle strain, degenerative disc disease, spinal instability, or a herniated nucleus pulposus (herniated disc). Strain in the muscles can occur from overexertion and lifting in non-neutral postures. A herniated disc occurs when a tear in the outer layer of the disc allows the nucleus pulposus material to travel into the spinal canal and compresses the spinal nerves. Spinal instability is another condition and is usually brought on by aging (leading to a decreased intervertebral disc height), and is caused when one vertebrae is able to move in the transverse plane relative to its neighboring vertebra(e). This condition can be detected on an X-ray. It is interesting to note, however, that 80% of back pain does not have a known cause, and is referred to as non-specific localized lower back pain. There can be numbness, intense or dull pain, and weakness in the back from any of the lower back MSDs, and they are sometimes accompanied by a condition called sciatica. Sciatica is a radiating pain that begins in the low back and travels to the buttocks and down the legs, following a pathway of nerves in the body (Benetti & Marchese, 1996). In an analysis of workers compensation claims study in the U.S., back injuries accounted for 20% of all claims. Of those back injuries, 87% were classified as back strains and sprains (Klein, et al., 1984).

The shoulder is a complex joint connecting the humerus (bone of the upper arm) to the torso. Pain in the shoulder can originate from the tendons or the muscles that secure this bone in place and provide the motion of the humerus. Tendons are the connective tissues that connect muscle to bone. When tendons are subjected to heavy

and repetitive loading they may become inflamed due to increased friction and reaction forces in the body. The inflammation of tendons is a condition commonly known as tendonitis, although it is sometimes undiagnosed as shoulder pain. Muscle pain, another non-specific localized pain syndrome, can also occur in the shoulder (Buckle & Devereux, 2002). Because the shoulder is a joint, degenerative joint disease, known as osteoarthritis, can occur as a complication from problems in the tendons or muscles (Benetti & Marchese, 1996). There are specific risk factors that have been identified as contributing to or causing shoulder MSD's. These risk factors include working with hands above shoulder height, not taking rest breaks, and repetitive arm movements (Sommerich, et al., 1993). There is also a strong correlation between shoulder postures above 60 degrees of flexion or abduction, commonly referred to as non-neutral or awkward postures, and the development of shoulder MSDs (NIOSH, 1997).

1.2 Health Care

The health care industry has a special interest in occupational ergonomics, due to the physically demanding nature of the work. The industry has many tasks that are strenuous on the human body, including repetitive tasks and lifting heavy patients. For example, the task of manually folding and unfolding a wheelchair can be ergonomically problematic. In a workplace study of twenty health care workers the folding and unfolding tasks were found to have many bent and twisted postures associated with it, and the workers assumed the postures repetitively which carries a great risk of injury (White & Kirby, 2003). In another study on the use of the wheelchair in the health care industry, the transporting of the wheelchairs while empty was the focus. Twenty-three health care workers were evaluated in the laboratory setting and reported that the

wheelbarrow method of transporting was superior to the conventional transport method in back comfort, efficiency, and ease of task. The postures assumed in the wheelbarrow method were also found to be less bent over than in the conventional method (Woolfrey & Kirby, 1997). Ergonomics is also extremely important in the examination room. In a postural analysis of physical therapists in a large hospital, one third of the treatment time, equaling approximately 2 hours per day, was spent in a stooped posture. The stooped posture is a non-neutral one and is a reported risk factor in the development of low back MSDs (Fenety & Kumar, 1992).

Occupational injuries and illnesses are prevalent in the health care setting. Out of all industries with at least 100,000 nonfatal injuries and illnesses, hospitals came first in the rankings, followed by nursing and personal care facilities (BLS, 2003a). Data from the Bureau of Labor and Statistics (BLS, 2002) shows there was a 3.4 incidence rate of nonfatal occupational injuries that required days away from work, job transfer, or job restriction in the health services industry. While this is considerably higher than the 2.8 incidence rate for all of private industry, the picture looks much worse when specific areas within health care are explored. For hospitals the incidence rate is 4.1, and in nursing and personal care facilities the incidence rate is an astronomical 7.6. In 2001 there were 672,900 musculoskeletal disorders reported from hospital employees, and 694,200 from nursing care facility employees. In hospitals there were 50,700 shoulder injuries and 223,000 back injuries. The same high numbers were seen in nursing care facilities, with 48,500 shoulder injuries and 233,000 injuries for the back. While there was a 34.6 incidence rate of back injuries overall per 10,000 workers, the rate jumps to 66.1 for hospital employees and 106.7 for nursing care facility employees. This may be

correlated to the overexertion in lifting rates. The overall rate was 21.1, but for hospitals it increased to 36 and for nursing care facilities it rose even more to 71.1. There were 67,635 injuries with days away from work whose source was a health care patient. Out of those injuries 54,973 resulted in musculoskeletal disorders (BLS, 2003b).

1.2.1 Health Care Musculoskeletal Disorders

The data from the Bureau of Labor Statistics (2003b) shows us clearly that many of the occupational illnesses and injuries in the health care setting result in MSDs for the workers. An important risk factor for MSDs in the health care setting is overexertion. The rate of injuries from overexertion among health care workers was almost two times more than the overexertion injury rate among other private sector workers (BLS, 1997). In a 2004 study of Australian workers' compensation claims, 89% of the overexertion back injuries among nurses were found to be from patient transfer activities (Engkvist, 2004).

The patient transfer task is one of the most challenging tasks in the health care environment, as many MSD risk factors can be accumulated: non-neutral posture, heavy lifting, and rushed pace. In a 2004 interview study of 56 nurses, 87% had already experienced back pain. Most of the nurses indicated the actions of lifting a patient as being the most important reason for their back pain. (Karahana & Bayraktar, 2004). In another study of 21 geriatric nurses, nurses rated in a survey patient lifting, transfer, and turning as the most physically demanding of all work tasks. Heart rates were recorded for the full 8 hour shift in the study, and the most demanding tasks were also the tasks with the highest recorded heart rates, indicating a high intensity exertion of heavy weight. This study may also be an indicator that nurses are aware and can correctly perceive

when they are experiencing the most physical stress and exerting the most energy on a daily shift (Hui, et al., 2001). The occupation of nursing has a high prevalence of MSDs including neck, shoulder, arm, and low back pain. In a larger questionnaire study of 314 nurses in Japan the patient handling task was the most strenuous. It was noted as a cause of stress and injury not only on the lower back but also the neck, shoulders, and arms (Ando, et al., 2000).

1.3 Overview of Ergonomic Interventions

An ergonomic intervention can take a variety of forms but the overarching focus is on reducing MSDs in the workplace. An ergonomic intervention can make a significant difference on the risk factors that can contribute to the development of MSDs. A very significant risk factor in the development of MSDs of the low back is large force exerted on and about the spine. A 2003 videotape analysis study showed a 73% decrease in average spine compression by adding an extension handle to a frequently used hand tool. The study followed 15 framing/carpentry workers as they constructed the framing for a home, and showed the power that a seemingly small intervention can have on the mechanics of the body (Mirka, et al., 2003). The amount and frequency of stresses on the shoulders and back can also lead to MSDs. A modification of a harvesting bucket for 14 agriculture workers showed a significant lessening in the strains on the shoulders and back (Earle-Richardson, et al., 2005). The study observed harvesting postures in workers from two apple orchards before and after using the modified bucket that attached to the hips. The addition of another body part in bearing the load of the heavy apple bucket lessened the strain and 78% of the workers preferred the modification even though it added more time to their tasks. Pain symptoms are often indicators of underlying MSDs.

Training in correct computer workstation postures and subsequent redesign of the workstations to accommodate the postures resulted in a significant decrease in the pain symptoms of 20 newspaper workers. In particular, the pain symptoms of the neck, shoulders, and elbow and the shoulder flexion and shoulder muscle activity were lessened after the redesign of the workstations (Nevala-Puranen, et al., 2003).

1.3.1 Engineering Controls

An engineering control uses engineering techniques to reduce or totally eliminate the risk of exposure to conditions that may cause the worker harm. Engineering controls are the highest ranking in the system safety hierarchy of controls, and is the optimal option to explore when trying to make a workplace safer. An engineering control can be the redesign or introduction of a task tool, or the installation of an entire system. When designing engineering controls, it is important to evaluate how the control will interact with the user as well as the existing system. A properly designed engineering control will be easily understood by the user and flow into the existing environment. Engineering controls can be a type of ergonomic intervention that reduces ergonomic risks in the work environment. Proper ergonomic interventions to reduce MSDs are based on ergonomic guidelines that describe the appropriate exposure variables. A common ergonomic intervention that is also an engineering control is the redesign of tools to fit or assist the worker better in a task (Westgaard & Winkel, 1997).

1.3.1.1 Engineering Controls for Patient Handling

There are many engineering controls that have been introduced to the health care industry to use to make the tasks safer. Because the patient handling task is so strenuous on the body, there have been a number of interventions in this area (a number of these

devices have been shown in a publication by OSHA (2002) and many of the figures presented in the current manuscript make use of these figures). There is usually a level of patient dependency determination that is made in order to select the appropriate intervention. The health care worker has to determine if the patient can bear weight, if they are cooperative, if they can assist themselves, and if they have upper extremity strength. They also need to get an estimate of the weight of the patient, as some interventions have weight limits.

When moving a patient from a sitting to a standing position the nurse can use a powered sit-to-stand device. This device allows the patient to use the motor of the device to lift their sling encased torso from the seat while stabilizing their lower body, creating a standing posture. Figure 1 shows a patient using the device to move from a wheelchair to a standing position. The patient can also use a fixed stand assist device if they are able to assist themselves and have ample strength. The fixed device provides a stable handle for a patient to use to assist themselves in standing. A fixed stand assist device attached to the edge of a bed is shown in Figure 2.



Figure 1: Patient using a powered sit-to-stand device (OSHA, 2002).

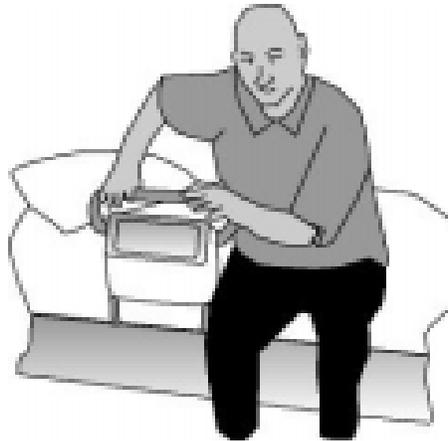


Figure 2: Patient using a fixed stand assist device (OSHA, 2002).

Ambulation devices can then be used to safely provide assistance to the patient in walking to a different location. They are used when the patient needs an extra sense of stability or needs assistance in walking. There are a number of ambulation devices, including canes, walkers, and ambulation belts. Figure 3 shows a patient using an ambulation device on rollers.

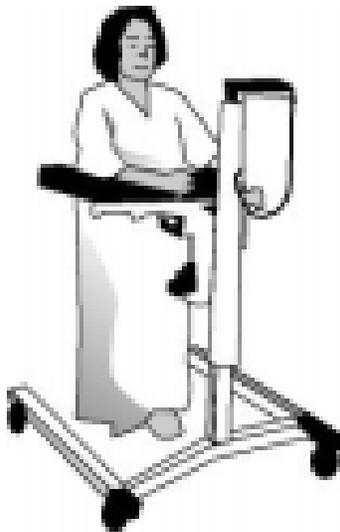


Figure 3: Patient using an ambulation device (OSHA, 2002).

If the patient is not able to bear their own weight, a portable or ceiling-mounted lift assist device used with a sling can transfer the patient from location to location. A ceiling-mounted device is shown in Figure 4.



Figure 4: Patient being transferred in a ceiling-mounted lift assist device (OSHA, 2002).

Generally ceiling-mounted devices are less preferred because they can limit the transfer location (OSHA, 2002). A more versatile choice is the portable lift assist device, shown in Figure 5.



Figure 5: Patient being transferred in a portable lift assist device (OSHA, 2002).

It was shown in a motion analysis and force platform study of nine nursing assistants that the mechanical lift assist devices that use a basket sling (like those shown in Figures 4 and 5) significantly reduce the forces on the back when preparing a patient to be transferred. The basket sling style lifts also completely eliminate the forces involved when transferring the patient from location to location, because the load is on the sling and not on the nurses back. The study also evaluated other lift assist devices that did not use the sling style, including the small sliding board (shown in Figure 6), which were found not to be as effective in reducing forces on the nurses backs (Zhuang et al., 1999).



Figure 6: Patient using the sliding board (Zhuang et al., 1999)

For lateral transfers there are low friction mattress covers, large slide boards, and vinyl roller boards, any of which can be used with a draw sheet to move a patient from a bed to a stretcher or other lateral surface. All of the lateral transfer devices are designed to make movement easier along a horizontal surface, either by adding rollers in the rollerboard case, or by reducing the coefficient of friction in the slide boards and low friction mattress covers case. The draw sheet is used to encapsulate and transfer the patient from location to location when using these interventions. A large sliding board is shown in Figure 7, and Figure 8 shows a patient on a low friction mattress cover being transferred with a draw sheet (OSHA, 2002).



Figure 7: Large sliding board (OSHA, 2002)

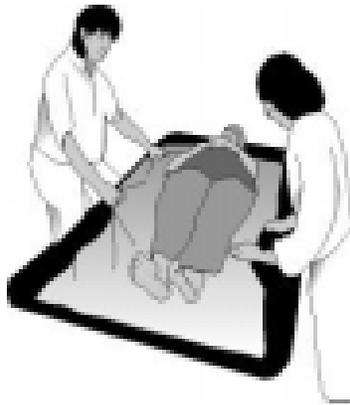


Figure 8: Patient being transferred on a low friction mattress cover with a draw sheet (OSHA, 2002).

Engineering controls for patient handling have been shown to be very effective when implemented. Garg & Owen (1994) found in their biomechanical analysis of 6 nurses using eight transfer methods that the portable lift assist device was perceived as most secure by the patients and least physically stressful by the nurses. The same study also looked at 57 nursing assistants before and after the introduction of portable lift assist devices, and saw the incidence rate of back injuries decrease from 83 to 43 over a 13 month time period. The number of lost or restricted days in the same time period went from 634 to 0 for those two units of the nursing home. In a study of four hospitals and five long term care facilities that introduced portable lift assist devices it was found that more frequent use can lead to a lower injury rate (Evanoff et al., 2003). The health care workers completed a survey following the implementation of the lift assist device program at their workplaces. The workers self reported frequency of use was 50% in the long term care facilities, while it was reported at a lower 34% in the hospitals. The number of lost day injuries dropped from 29 to 9 in the long term care facilities while the decrease in the hospitals was a smaller 65 to 55 lost day injuries.

1.3.2 Administrative Controls

Administrative controls are generally regulations from management whose purpose is to reduce or prevent risk of exposure to conditions that may cause the worker harm. Administrative controls are usually employed when engineering controls are not feasible in a situation, or as a substitute when waiting for an engineering control to be implemented. Different types of administrative controls include job rotation, training, limiting the exposure time, and slowing the work pace.

Proper task training is usually the first type of administrative control used. Training can come in a number of methods, and can be separated into passive and active training categories. Passive training does not involve the worker in the execution of the task, and includes methods such as watching a pre-recorded video or attending a lecture. Active training involves the worker in the execution of the task, and can occur in a large seminar setting or in small group interactions. It has been found that active methods are more successful than passive when dealing with ergonomic interventions (Westgaard & Winkel, 1997).

1.3.2.1 Administrative Controls for Patient Handling

The most common control for the high risk task of patient handling is administrative controls. Specifically, the use of two people transfers or team lifting is a popular policy. Five techniques of the two person lift were evaluated in a study of ten female nurses (Winkelmolen et al., 1994). The study collected perceived exertion ratings and biomechanical analysis on the assumed postures for the three asymmetrical and two symmetrical lifting techniques. The perceived exertion ratings were highest when the nurses completed the asymmetrical lifts. The higher biomechanical loads also

corresponded to the higher perceived exertion ratings. In environments where one person lifts are still acceptable, training in proper postures and methods is most popular (Garg et al., 1999). Training has been proven effective in correcting manual lifting postures. In a study of 24 nurses who were trained in correct manual lifting, it was shown that most assumed a more upright lifting posture after the training. This fact was illustrated by the 3.5 to 11.1 degree range of decreases in the elbow and knee angles of the nurses while transferring patients. The nurses also used more of a squat posture as opposed to a stooping posture, and held the patient closer to their body (Nussbaum & Torres, 2001). In another study of 55 nurses in a nursing home setting, training in manual handling was shown to decrease the incidence of lower back pain from 18 to 8 over a 12 month period. An overwhelming majority of the nurses, 94%, agreed that the training made the manual lifting task easier. The observed effort exerted and observed postures were also significantly better after training (Best, 1997). It is important to note that these administrative controls do nothing to reduce the total load of the patient handling task. However, they may divide the load of the patient and definitely reduce the likelihood of unnecessary non-neutral postures, both of which are risk factors in the development of MSDs.

The type of training used frequently in health care settings is the see-one-do-one method. This passive method allows a person to watch a task being completed, usually in the action of the workplace, and after watching they are expected to know how to complete the task. Formal training sessions are less frequently used, and most do not involve active training. In some cases one worker in the ward will attend the formal training, and this person is responsible for training everyone else in their ward on the

technique. Often this training will be in the see-one-do-one method, and interpersonal issues can impact the quality and quantity of the training that other workers on the ward receive. Although this is not the most effective way to train, it is the most efficient, and in a time rushed environment the focus is on providing health care and not training (Garg & Owen, 1994). Recently OSHA recommended that all types of manual patient handling methods be eliminated, recognizing the important issues that administrative controls were not solving in the area of patient handling (OSHA, 2002).

1.4 Challenges to Ergonomic Interventions in Patient Handling

Although there are a number of excellent ergonomic interventions addressing the issues of patient handling, the implementation of these tools in the workplace can be challenging. Administrators and nurses alike complain about the amount of time it takes to use the interventions, and offer that as a reason for manual lifts (Daynard, et al. 2001). In a study using a mechanical hoist, the average time was 1.5 – 2 minutes longer than the time it takes to complete a manual lift. The nurses in this study perceived that as too long, even though it was only 12-30 minutes, or 3-6% of their 8 hour shift if they had to lift a patient 8-15 times (Takala & Kukkonen, 1987).

Proper training also is of the utmost importance when using ergonomic interventions. If a nurse is not properly trained in the use of the lift assist device, the peak spinal loading can be significantly higher than normal (Daynard, et al., 2001). This higher load may be due to improper postures assumed while using the mechanical lift, so training must include proper usage and proper postures. Training on the mechanical lifts must also not be an afterthought, done on the job using the popular see-one-do-one technique (Takala & Kukkonen, 1987). It is extremely important for everyone to accept

the ergonomic intervention for it to be successful. When workers do not buy into the benefits of the intervention, there can be issues of non-compliance to policies suggesting the intervention be used (Westgaard & Winkel, 1997). In the case of the mechanical lift assist device, the forces on the spine can be significantly higher than normal if a nurse is noncompliant with using the lift (Daynard, et al., 2001).

The nature of people is sometimes to be resistant to change, which can also be a challenge to introducing an ergonomic intervention for patient handling. The intervention can be perceived as a new work task altogether, which can influence the way workers receive it. In a study that introduced a mechanical lift on three wards in a hospital, two of the key factors that influenced whether or not the lift was used were ward culture and ward management (Daynard, et al., 2001). Kan & Parry (2004) identified key issues in a study of three hospital wards that were critical to the staff accepting changes from the nursing leadership. These issues included group influence on the change, recognition of the natural resistance to change, and group acceptance of the leader. The feelings of the patient are also important, and anecdotal evidence shows an uneasiness on the patient's part in being transferred with novel devices. The patient may already be undergoing a great deal of trauma and the patient handling intervention can add to their feelings of stress and instability. It is important that these issues are taken into account when introducing an intervention to workers in the health care industry.

1.5 Learning Curve Theory

While the extra time that ergonomic interventions add to a task is well documented, what is often not considered in these studies is the aspect of learning curve. Learning in the context of completing a work task is defined as improvement with a

constant product design and constant tools and equipment (Konz & Johnson, 2000). Learning curve theory gives explanation to the concept of increased replications corresponding to decreased task time, and is extremely applicable in many industrial settings. In particular, in the health care industry it is useful in exploring the number of replications and time it would take a worker to develop a certain “efficiency” or skill with a task.

In order to calculate the rate at which a worker is learning to complete a task, the following standard equation is used:

$$Y_x = KX^{-N}$$

Where:

Y_x = production time for Xth unit

K = time required to produce first unit

X = total units produced

And N is an exponent leading to 2^{-N} = Learning Rate

Learning can also be separated into two categories, cognitive learning and physical learning. Purely cognitive learning tasks usually have a rate of 0.70 while purely physical learning tasks usually have a rate of 0.90. It is important to note that most tasks involve both cognitive and physical learning, although there can be a dominance of one of the types (Konz & Johnson, 2000).

Learning rate theory has been used to enhance a number of industries, and the manufacturing industry in particular embraces its significance to productivity levels. The engineering textbook by Konz & Johnson (2000) outline the procedures for fitting production times to the equation $y = ax^b$, and credit Wright as publishing the first learning curve data in 1936 for the aircraft manufacturing industry. The theory has been

incorporated into the assembly line balancing procedure, where components on a manufacturing assembly line are adjusted for maximum efficiency (Arditi, et al., 1998). There are documented learning rates for numerous manufacturing tasks. For example, the machining and fitting of small castings has a learning rate of 0.74, the assembly of a radio tube has a learning rate of 0.83, and operating the punch press has a learning rate of 0.89 (Konz & Johnson, 2000). Learning rate analysis is often used in health care to evaluate the effectiveness of medical procedures, or of the expertise levels of medical specialists in their respective fields. Often the success and failure rates of certain surgeries or new medical procedures are analyzed (Forbes, et al., 2002; Hraska, et al., 2003). Learning rate has also been explored in the ergonomics field. A study of productivity among sixteen subjects conducting a visual display task documented the learning rate for that task. The study also explored the relationship between break times and learning rates while completing the visual display task (Sparks & Yearout, 1990). However, in the case of introducing the mechanical patient lift assist equipment, or any other ergonomic patient transfer intervention in the health care industry, there have been no studies documenting the impact of learning rate. Because one of the most frequent objections to the use of mechanical lift assist equipment is added task time, it is imperative to understand and document the learning that occurs with this task.

1.6 Goal of the Study

The goal of this study is to incorporate learning curve theory into the process of introducing an engineering ergonomic intervention, while varying the administrative ergonomic intervention of training method. It is important to understand how the productivity of a hospital staff will improve when presented with a mechanical patient lift

ergonomic intervention. It is expected that the productivity (measured in time-to-complete task data) will follow a definite learning curve, and the characterization of this “learning rate” is one objective of this study. Another objective is to assess the impact of type of training method on this learning rate. It is hypothesized that a more hands-on training approach will allow subjects to have a significantly higher learning rate than subjects trained in the see-one-do-one method.

2 Methods

2.1 Subjects

Eighteen subjects were recruited from the university population through word of mouth and flyer advertising. The flyer advertising the study is shown in Appendix A. The group had equal numbers of male and female subjects, with ages ranging from 18 to 48 years. The average age was 27 years and the standard deviation for subject age was 6 years. The subjects were required to sign a university-approved Informed Consent Form, shown in Appendix B. Potential subjects were excluded from participation in the study if they had current or chronic back pain, had experience using mechanical patient lifting assist devices, or were less than 18 years of age. The subjects were all college students with no nursing experience (no experience lifting patients manually). The results are believed to be applicable in a health care setting wherein novice nurses/nurses assistants would have no experience using a patient lift assist device their first time encountering one, and therefore it is reasonable to assume that the learning process would be the same in this population of novice users as it would be for novice nurses or nursing assistants. Subjects in the study were compensated for their time with an Ergonomics Laboratory t-shirt.

Anthropometric data were taken from each subject at the start of the study. All measurements were taken by the researcher and are direct measurements. The anthropometric data for all subjects is shown below in a compiled format. The hip height was measured from the floor to the center of rotation of femur in the hip joint. The arm length was measured from the acromium process to the wrist. The spine length was measured from the L5S1 joint to the C7 joint.

Table 1: Anthropometric Measurements

	Mean (cm)	Std. Dev. (cm)
Stature	173.9	9.8
Hip Height	100.4	7.1
Arm Length	54.0	4.2
Spine Length	46.0	4.5

2.2 Equipment

2.2.1 Testing Equipment

The task performed in the study involved moving a patient from a hospital bed to a wheelchair by using a mechanical lifting assist device. The environment was set up to simulate a room within a hospital, so a standard sized hospital bed and wheelchair were used in the study. The height of the working surface of the hospital bed was 30". The mechanical lifting assist device used was the Arjo brand "Opera" model (Arjo, Inc, Roselle, IL). A side view of the Opera is shown in Figure 9.



Figure 9: Side view of mechanical lifting assist device

The bed is shown in Figure 10 and the wheelchair is shown in Figures 11 and 12. Both were rented from a local medical supplies rental company.



Figure 10: Hospital style bed



Figure 11: Side view of wheelchair



Figure 12: Front view of wheelchair

It is also important to note here the layout of the room. In order to simulate the conditions of a hospital facility a tile floor was used, which can be seen in the figures above. The space to work was also limited, as shown in the diagram of the lab space below in Figure 13. The length of the room was 132” and the width was 147”. The Bed was 86” long and 40” wide, the Opera was 46” long and 30” wide, and the chair was 26” long and 32” wide.

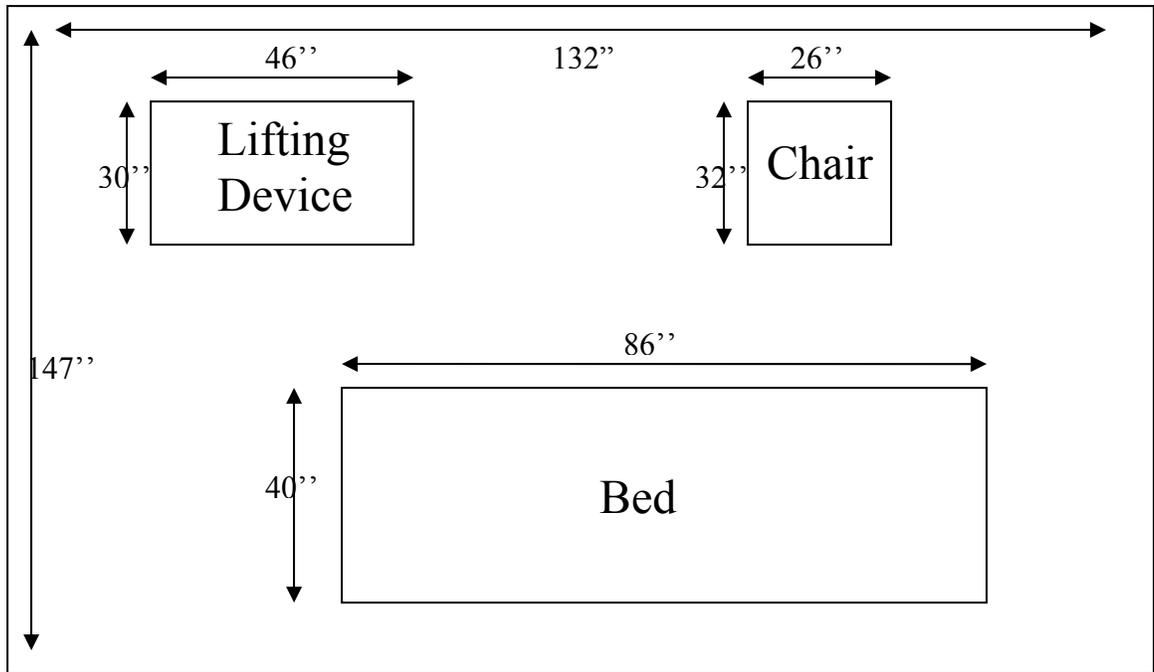


Figure 13: Dimensions of laboratory space

2.2.2 Data Collection Equipment

The time-to-complete task data were collected using a stopwatch that recorded accurately to the 100th second. Survey data were also collected (described in more detail in Section 2.3.2). The subjects were read the questions aloud by the researcher and asked to respond on a 1-5 scale. The survey questions measured the subjects' level of comfort and asked them to rate ease of use and applicability of the technology in a health care setting. Although the subjects did not have experience as a nurse within the health care field, the simulation of the hospital room and the rushed pace immersed them into the environment during their trials. The survey questions and scale are located in Appendix C.

2.3 Experimental Design

2.3.1 Independent Variables

There were two different types of training that was administered to the subjects. The subject either was trained in Method A or Method B. In Method A the experimenter completed the task while giving verbal explanations of each step of the task. The subject was allowed to watch while the experimenter completed the task. Training A gave a basic overview of the task and could be comparable to the see-one-do-one type of training that is often employed in current hospital settings. In Method B, the task was broken into steps, and the experimenter completed a step of the task with explanation, then allowed the subject to complete the step. The explanation given to the subjects in Method B was slightly more detailed, which coincided with the step-by-step training. Training Method B gave the subject a more hands-on experience with the equipment and task.

2.3.2 Dependent Variables

Quantitative measures related to the learning process and survey response data were the dependent variables in this study. There were two measures that were calculated from the time-to-complete data (calculations described in Section 2.5.1). The first was Learning Rate, which measured the decrease that occurred in the task performance time as a function of task repetition. The standard calculation for Learning Rate was used, using data point 0 (first time completing the task) and data point 10 (eleventh time completing the task) to estimate the learning rate. The second measure calculated from the time-to-complete data were measures of the immediate change in time-to-complete and were called Deltas, which measured the difference between the

time-to-complete at particular trial points. Delta 1 is defined as the difference between time-to-complete in seconds from trial 0 to trial 1. Delta 2 is defined as the difference between time-to-complete in seconds from trial 0 to trial 2. Delta 3 is defined as the difference between time-to-complete in seconds from trial 0 to trial 3. Another dependent variable, Trial 0, was taken directly from the time-to-complete data of data point 0. Trial 0 measures the time-to-complete in seconds for the subjects first time completing the task.

There were six survey questions (shown below). The responses to the survey questions were collected as integer values between 1 and 5. An answer of 5 corresponded to “excellent” or “absolutely”, and an answer of 1 corresponded to “poor” or “absolutely not”.

1. How effective do you think the training that you received today on how to use the mechanical lift assist device was?
2. How efficient do you think the training that you received today on how to use the mechanical lift assist device was?
3. How comfortable were you with using the mechanical lift assist device on your first independent trial?
4. How comfortable were you with using the mechanical lift assist device on your last independent trial?
5. As of right now, do you feel prepared to use the lift assist device in your day to day activities if you were in the medical profession?
6. Would you use the lift assist device in your day to day activities if you were in the medical profession?

2.4 Protocol

The study was completed in a single session that averaged 90 minutes per subject. The experimental protocol checklist that was used is shown in Appendix D. After arriving to the laboratory, the subject was introduced to the researcher and the mock patient (a real person). The subject was also informed of the purpose of the study. The

subject was then asked to sign the informed consent form. The informed consent form stated the requirements of the study and asked the subject to initial stating that they did not have back pain or experience using the lifting device, and were at least 18 years of age. The following script was used to explain the purpose of the study and request the subjects participation.

“Our study looks at how introducing an ergonomic tool impacts peoples learning and performance. We are evaluating how people learn to use a lifting device that is used to move hospital patients from their bed to a wheelchair or other hospital environments. First I am going to show you the task so that you will be familiar with it, then you will go through a training session where you will learn how to use the equipment, then you will complete the task on your own and repeat the task a number of times. At the end of the study you will be asked to answer a few questions, then you will receive compensation in the form of an ergonomics laboratory t-shirt. Before we get to the task, we have to take care of our documentation. I need you to read and sign our informed consent form, which gives us permission to proceed with you as our study subject.”

After the subject signed the consent form, anthropometric measurements were taken of the stature, hip height, arm length, and spine length. Next the subject watched the experimenter complete the task of moving the patient from the bed to the wheelchair using the device. This was called the orientation because it allowed the subject to see the task being completed from start to finish. The experimenter completed the task in silence, allowing the subject to observe from a close distance.

Next the subject was trained on how to complete the task, either in Method A or Method B. The scripts used for training was almost identical, however training Method B gave more detail and indicated nuances that would make the task easier. The scripts are shown below, with the additions for training Method B in boldface type.

“First we want to prepare the patient to be lifted. We want to lock our destination wheels and get closer to the patient by moving the guard rails. We also want to prepare the sling. We want to fold it lengthwise so that we can place it under the patient. **When we fold it we want to align the middle, and then crease the sling so that it will unfold neatly under the patient.**

Next we are going to put the sling under the patient. We are going to ask the patient to lay over on their sides so that we can put the sling under them. We want to push the sling as far as it will go, paying attention to the sling covering the head area. We always want to protect the head because it is the most fragile part of a body. **We are also going to look for alignment in the shoulders and hips, by looking at the lines of the sling. The shoulder should be at the top line, and the patients hips should align with the bottom line.**

Now we will ask our patient to roll onto their back, and place the guard rail back upright. Walking around to the other side, we will move the guard rail and ask the patient to roll the opposite direction. Now we are going to pull the sling through and be sure that it is cradling their entire body, and especially the head. **We also want to check the alignment points at the shoulders and hips.** We can now allow the patient to rest on their back.

We will prepare the patient to be connected to the lift by lifting each leg and pulling the leg straps inward toward the inside of the legs. When working we will work on the side that we are closest to, and not reach across the patient. Now the patient is ready to be lifted.

Now we want to position the lift for the patient. We want to position the lift so that the shoulder points on the lift are in alignment with the patients shoulders. When we are correctly positioned we can lock the lift wheels.

Now we want to lower the lift and attach the shoulder hooks. We want to **use the tilt control to adjust the connections and** listen for the snap. **It is sometimes easier if we pull down on the fabrics.** We want to walk around the patient and hook all four corners of the sling. If you are having difficulty you may want to reposition the lift **or adjust the tilt. Usually adjusting the controls works better than moving the actual lift.**

We can now lift the patient up in the reclined position. We then unlock the wheels of the lift and move the patient, positioning them over the wheelchair. We gradually lower and move the patient into an upright position. When they are lowered into the seat we can unsnap the hooks to free the patient from the lift. **It is best to use the fabric pulls for**

unhooking the sling from the lift. We can now move the lift back to its starting position.”

After training the subjects performed a “Trial 0”, in which they were able to ask the experimenter questions while completing the task. During Trials 1-10, the subjects were not able to ask questions. In each trial the subject was encouraged to go at a fast pace, and was told that their time-to-complete at the end of each trial as motivation to get faster.

After all the trials were completed, the subjects were asked to respond to the survey questions on a scale of 1 to 5. Following the survey, the subjects were given compensation for their time with an Ergonomics Lab t-shirt.

2.5 Data Processing

2.5.1 Learning Rate

There were two measures that were calculated from the time-to-complete data. The first was Learning Rate, which measured the decrease that occurred in the task performance time as a function of task repetition. The standard calculation for Learning Rate was used, using data point 0 and data point 10 to create the curve of the data. The equation and an example are shown below:

$$Y_x = KX^{-N}$$

Where: 2^{-N} = Learning Rate

Y_x = production time for Xth unit

K = time required to produce first unit

X = total units produced

N = exponent

For a subject with trial 0 time-to-complete of 397 seconds and a trial 10 time-to-complete of 221 seconds the Learning Rate is

$$221 = 397 (11)^N$$

$$\text{Log}(221/397) / \text{Log}(11) = N = -0.244$$

$$2^{-0.244} = 0.844$$

which is a Learning Rate of 84.4%

The second measure calculated from the data was Delta, which measured the difference between the time-to-complete at particular trial points. Delta 1 is defined as the difference between time-to-complete in seconds from trial 0 to trial 1. Delta 2 is defined as the difference between time-to-complete in seconds from trial 0 to trial 2. Delta 3 is defined as the difference between time-to-complete in seconds from trial 0 to trial 3.

2.5.2 Survey Data

There was no data processing of the survey data. The survey data were simply transferred from the handwritten sheets into a spreadsheet.

2.6 Statistical Analysis

The Analysis of Variance (ANOVA) technique was used to evaluate the effect of training method on the dependent variables Learning Rate, Trial 0, Delta 1, Delta 2, and Delta 3 using a statistical model. The assumptions of the ANOVA technique were tested using the graphical methods advocated by Montgomery (2001). The survey data was analyzed using the nonparametric Kruskal-Wallis test. Throughout the statistical analysis a p-value of less than 0.05 indicated a significant effect.

2.6.1 Assumptions Testing

The homogeneity of variance assumption, meant to ensure a constant variance of the residuals, was tested by plotting the residual values as a function of the predicted values. In order for the assumption to be satisfied the plot should not show any obvious patterns. The residuals should have no recognizable structure, and should be unrelated to any other variable, including the predicted response. Generally a slight departure is acceptable because the f-test is only slightly affected in the balanced fixed effects model (Montgomery, 2001).

The normality of residuals assumption, meant to ensure a normal distribution of the residuals, was tested by plotting the residuals of the model using a normal probability plot. In order for the assumption to be satisfied the plot should resemble a straight line. Generally, a slight departure or skew is acceptable since ANOVA is robust to the normality assumption (Montgomery, 2001).

The independence assumption, meant to ensure proper randomization of the experiment, was tested by plotting the residuals of the model as a function of trial order. In order for the assumption to be satisfied the plot should not have any recognizable pattern or trends. A violation of the independence assumption can be serious, so it is important to prevent the problem from occurring during the data collection process (Montgomery, 2001).

2.6.2 ANOVA for Learning Rate and Delta Data

The Learning Rate and Delta data were analyzed through a one-way analysis of variance (ANOVA). Throughout the analysis, a p-value of less than 0.05 served as an

indicator of significant differences between training method. The linear statistical model for the experiment was

$$y_{ijk} = \mu + \tau_i + \beta_{j(i)} + \epsilon_{(ij)k} ; (i = 1-2, j = 1-9)$$

This is a mixed model with τ being a fixed variable of training type and β being a random variable of subject.

2.6.3 Survey Data

The survey data were analyzed through a nonparametric Kruskal-Wallis ANOVA test. Again, a probability of less than 0.05 served as an indicator of significance between training method groups.

3 Results

The results are presented in three sections. Section 3.1 presents the results from the test of the analysis of variance assumptions. Section 3.2 presents the results from the statistical analysis of the performance data. Section 3.3 presents the results from the statistical analysis of the survey data.

3.1 Test of the Analysis of Variance Assumptions

The three analysis of variance assumptions were tested using the graphical methods advocated by Montgomery (2001). Refer to Appendix E for the graphs of these tests. The normality and independence assumptions were not violated. There were potential violations of the homogeneity of variance assumptions for the Trial 0 and Delta 1, Delta 2, and Delta 3 data, which can be seen in Figures 19, 21, 23, and 25. The homogeneity of variance concerns were corrected by applying a transform to these data. This was accomplished by adding a constant of 1 to the data, which moved the minimum value of the distribution from 0 to 1. This procedure is recommended by Osborne (2002) prior to using a natural log transformation on data that includes values of 0. The natural log transformation, described by Montgomery (2001), was then applied to the learning rate and delta data. The graphs of the residuals of the transformed data can be seen in Figures 20, 22, 24, and 26. The subsequent statistical results for the Trial 0, Delta 1, Delta 2, and Delta 3 data are based on these transformed values.

3.2 Performance Data

The results of the analysis of variance are shown in Table 2. We did not find a significant difference between training groups for Learning Rate, Delta 1, and Delta 2. The Learning Rate was 85.2% for the hands-on training and was 81.1% for the see-one-

do-one training (but this difference was not found to be statistically significant).

Significant differences were found between training groups for Trial 0 and Delta 3.

Table 2: Results of ANOVA for performance data

	F-Value	P-Value
Learning Rate	3.6826	0.0730
Trial 0	8.1488	0.0115*
Delta 1	4.3440	0.0535
Delta 2	0.2459	0.6267
Delta 3	10.2911	0.0055*

* represents statistically significant difference between training methods

There was a significant difference between training methods in the initial time-to-complete, and that difference slowly decreased as the subjects completed more trials. This difference can be seen below in Figure 14. Subjects trained in Method B, which allowed a more hands-on approach, had a much lower initial time-to-complete than subjects trained using Method A. The initial time-to-complete values are recorded as Trial 0. Trial 0 was found to be significant, and there was a 28% increase in Trial 0 values from Method B to Method A. Delta 3 was also found to be significant. Delta 3 is a cumulative measure of the difference in time-to-complete values, therefore it is not as sensitive to subject variability as Delta 1 and Delta 2. There was a 107% increase in Delta 3 from Method B to Method A. Figure 15 shows the difference between Method A and Method B for Trial 0, and Figure 16 displays the differences in training method for Delta 3.

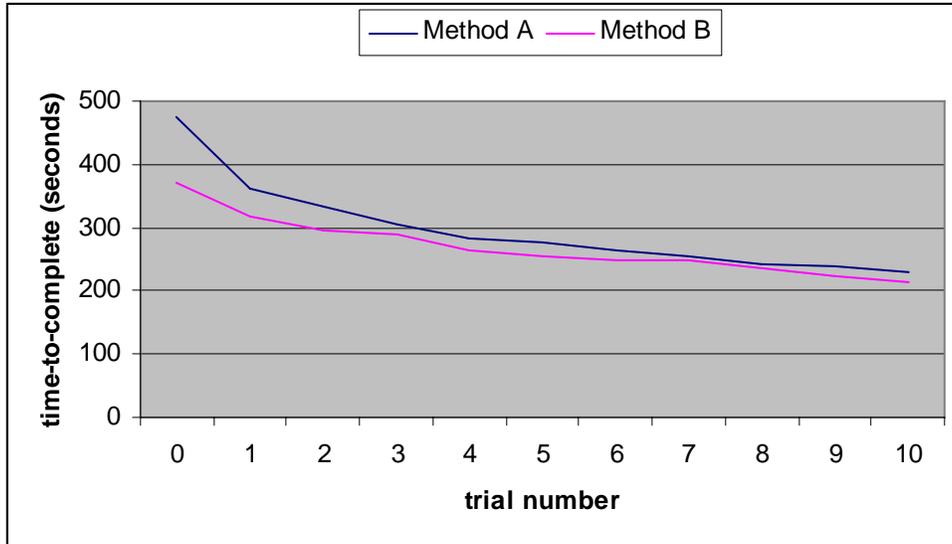


Figure 14: Time-to-complete per trial grouped by training method.

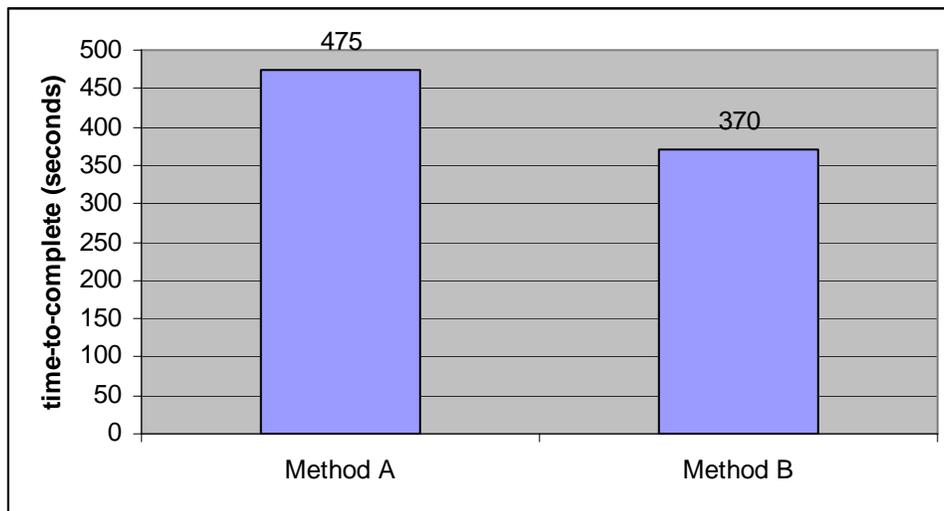


Figure 15: Trial 0 data grouped by training method

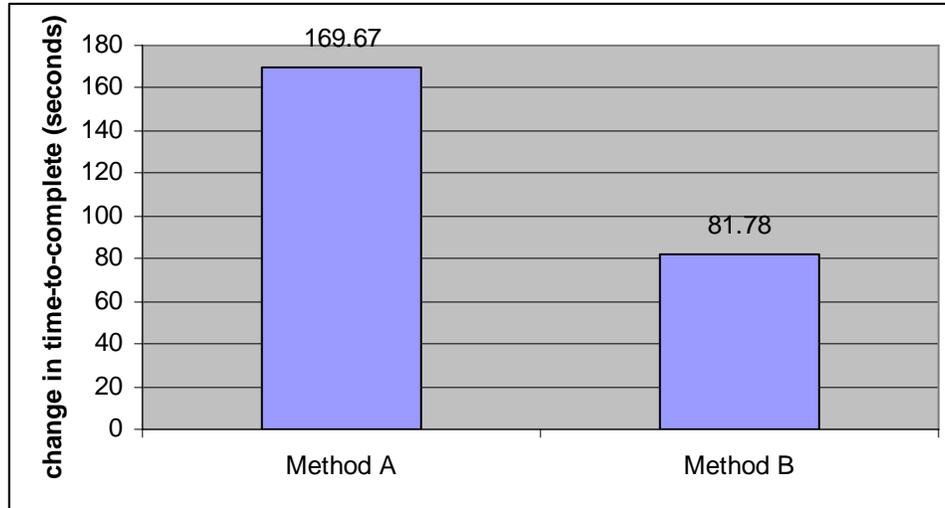


Figure 16: Delta 3 data grouped by training method

3.3 Survey Data

There was not a significant difference between training methods in all of the responses to the survey questions. However, for question 3 which addressed the subjects comfort with using the lift on their first independent trial (Trial 0), there was a significant difference found in the responses. The results of the Kruskal-Wallis test including the mean response value, the chi-squared test statistic and the corresponding probability value are displayed in Table 3. Figure 17 shows the mean response based upon training method. We see that responses were generally high for each question, with not much variability between training methods.

Table 3: Results of the Kruskal-Wallis test for the survey questions.

Question	Mean Response of Method A	Mean Response of Method B	Chi-squared Statistic	Pr > Chi-Squared
1	4.78	4.89	0.3778	0.5388
2	4.78	4.56	1.6794	0.1950
3	2.56	3.56	5.3530	0.0207*
4	5.00	4.78	2.1250	0.1449
5	4.89	4.78	0.3778	0.5388
6	4.33	4.89	2.4889	0.1147

* represents statistically significant difference between training methods

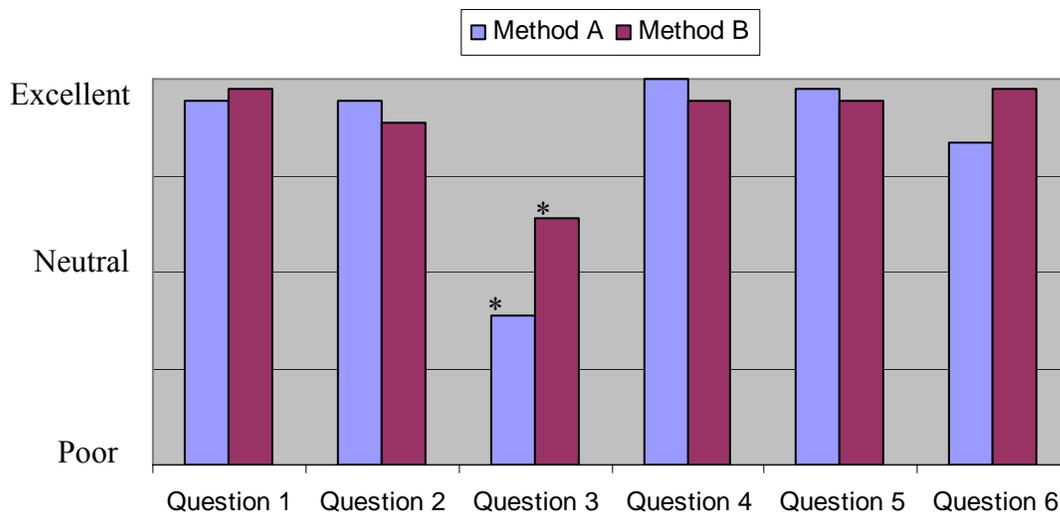


Figure 17: Mean response to survey questions based upon training method.

4 Discussion

4.1 Discussion of Results

The objectives of this study were to explore the possible application of learning curve theory in the process of introducing ergonomic interventions, and the impact of evaluating training technique on variables describing the learning process. The following subsections will explore these objectives on a variable-by-variable basis.

4.1.1 Learning Rate

Learning curve theory provides explanation to the observation that the more replications of a task a person completes, the more their time-to-complete values for that task will decrease. Learning rate is a measure of that theory, fitting the task time-to-complete values to the equation $y = ax^b$. Learning curve theory was effectively incorporated in the study, and the learning rate values were documented. The learning rate percentages shown for the task in this study ranged from 70% to 89%, with an overall average of 83.2%. The average learning rate percentage for the hands-on method of training was 85.2%, while the average for the see-one-do-one method was 81.1% (not a statistically significant difference).

The average learning rates for this task fall squarely in the middle of the cognitive and physical task range. Konz & Johnson (2000) estimate that purely cognitive learning tasks usually have a learning rate percentage of 70% while purely physical learning tasks usually have a percentage of 90%. The learning rates of the current study indicate that there is both cognitive and physical learning occurring in the patient transfer task, which is also the case in most tasks. It is also important to note the level of complexity of a task when evaluating learning rates. The complexity of a task can range from simple to

complex, and the level can impact the rate of learning. For example, a simple cognitive task can have a drastically different learning rate than a complex cognitive task. Complex tasks tend to have a lower learning rates than simple tasks. The learning rates of the current study also fall squarely in the middle of the simple to complex range, and is comparable to the tasks of sorting cards into compartments or using a power saw (Konz & Johnson, 2000). Table 4 from the Konz & Johnson text provides learning rates compiled from the literature for common tasks. Note how the complex assembly has a much higher learning rate than the simple screwdriver task.

Table 4: Common task learning rates (Konz & Johnson, 2000).

Learning Rate	Task Description
68	Truck body assembly
72	Complex 300 hour/unit assembly
80	Precision bench assembly
83	Power sawing
83	Sorting cards into compartments
84	Cigar making
88	Welding
90	Punch press operation
94	Pegs in pegboard
95	Screwdriver work

Although the difference in learning rate among training methods was not significant, the documentation of the learning rates is still extremely important. By using this empirical data, one can find the number of replications that it will take to get a user to a predetermined level of productivity. For example, for someone who completes their first replication of the task at 7 minutes or 420 seconds, using a learning rate of 0.83 we can confidently estimate that it will take them 8 replications to get to a 4 minute (240

seconds) time-to-complete level. Having access to this information can be extremely influential upon purchasing decisions, and can help procurement officers in making the best selection of ergonomic intervention for workers in their organization. Management can also complete a cost-benefit analysis and include learning rate in examining the cost of an ergonomic intervention to the benefits of using it.

4.1.2 Trial 0

Trial 0 shows the time-to-complete value for the first independent trial that the subjects completed with the lift assist device. The results for Trial 0 were found to be significant between training methods, showing the superiority of using the hands-on method. The Trial 0 values ranged from 265 to 616 seconds, with the average across training method at 423 seconds. The Trial 0 values for the hands-on training method was 370 seconds, while the values for the see-one-do-one method was 475 seconds.

Knowledge of Trial 0 values may be applicable in emergency situations when a person who does not usually transfer patients needs to use the lift assist device. The knowledge is also applicable in situations where new staff is hired.

The survey data also supported the significance between training methods for Trial 0. Question 3 of the survey, which asked the subjects to rate their level of comfort with using the lift on the first independent trial, also showed a significant difference between training methods. The subjects trained in the hands-on method were more comfortable than the subjects trained in the see-one-do-one method. Subjects trained in the see-one-do-one method responded with a mean score of 2.56, while subjects trained in the hands-on method responded with a mean score of 3.56. Responses for Question 3 were also the lowest of the entire survey, showing the subjects discomfort when

introduced to an ergonomic intervention. These low scores are important to note, and can indicate a general discomfort with using an ergonomic intervention for the first time. This discomfort can be coupled with a reluctance to change for nurses who previously used a different method of patient transfer, causing major problems for the introduction of the ergonomic intervention.

Garg & Owen (1994) revealed that very little formal hands-on training occurs in the health care environment due to the high demand of workers and the rushed pace. The type of training that usually occurs can be referred to as see-one-do-one, and does not give the trainee an active role in the learning process. It has been proven that active training will provide better results in completing tasks. For example, in a study of 48 subjects, it was found that active training methods resulted in better performance for the complex tasks. The study also found that the age of the subject was not a factor in these results, and the active training method left more information in memory than passive methods (Vakil, et al., 1998). Therefore, in the current study it was important to contrast the active and passive training methods in the introduction of the ergonomic interventions, and the difference in the methods was illustrated by the large differences in Trial 0 data.

4.1.3 Delta Data

The dependent variables under the name “Delta Data” showed the immediate impact of learning at the start of the trials. In specific, the dependent variable “Delta 1” shows how quickly a person is learning to use the ergonomic in the first two trials (i.e. change in productivity from first to second repetition), while the dependent variable “Delta 3” shows the same data for the first four trials. It is important to remember that

Delta Data is cumulative, and Delta 3 was found to be significant. Because Delta 3 is a cumulative measure of the difference in time-to-complete values, it may not be as sensitive to subject variability as Delta 1 and Delta 2. The variability inherent in the learning process may have impacted the Delta 1 and Delta 2 significance, while the cumulative nature of the learning process may have tended to “mute” these variability values for the Delta 3 measures.

4.2 Implications of Results

The results of the current study could provide valuable information to the health care industry. The results emphasize the importance in considering learning curves when workers are learning to use new equipment, especially ergonomic interventions that can prevent MSDs from occurring. It is important to note that learning can be a mixture of physical learning and cognitive learning. Physical learning involves actual muscle memory while cognitive learning involves incorporating a schema or procedure into the brain that is associated with completing a task. In the patient transfer task discussed here the learning was a mixture of physical and cognitive, with a large majority of the learning being cognitive. Within the cognitive learning there was room for creative thinking and incorporating procedural nuances to completing the task. Due to the repetitive nature of the task design, a small amount of muscle memory may have been occurring as well. Learning Curve theory has previously been used in surgical and procedural analysis. Forbes, et al. (2002) used learning curve theory to examine the progress of a surgeon and radiologist in performing endovascular abdominal aortic aneurysm repairs of ninety-six patients over a four year period. The learning curves in the study were based on procedural failure rates, and also incorporated an 80% reassurance level and upper 95%

alarm level. Hraska, et al. (2003) used the theory of learning curve to evaluate a new method of neonatal cardiac surgery involving 147 patients Slovakia and Slovenia using similar methods. The results of the current study are applicable across all areas of health care, and are directly applicable in the high risk task of patient transfer.

The National Institute for Occupational Safety and Health has recommended four health care settings that ergonomics research should focus upon in the early part of the new millennium: hospitals, nursing homes, home health care, and ambulances (NIOSH, 2001). The results are immediately applicable in the hospital, nursing home, and home health care setting where patients spend most of their time. The results provide a better understanding of the learning process and optimal training method when using the mechanical patient lift assist device. Although ambulance workers do not usually spend a lot of time with patients, they do complete the patient transfer task and could apply learning rates in their use of patient transfer equipment as well.

The findings also have a direct impact on the decisions of administrators in health care. The method of training given to workers directly impacts the time-to-complete and comfort they have when using the equipment for the first time. The method of training also impacts the workers learning rate when using the equipment. The results of this study imply that in order to make a nurse feel comfortable and learn how to use a piece of patient transfer equipment quickly, the hands-on method of training is superior to the see-one-do-one method, at least in the earlier phases of the learning process. Although the see-one-do-one method is prevalent in this industry, our results show that it does not give the nurses the optimal confidence when using the equipment for the first time. The method increases the amount of time the nurses will take to complete the task, especially

in the first several trials. Also since the item being moved is a human being, the health care worker industry has very little room for error, and it is important that the workers feel comfortable and confident in every task and procedure.

The mechanical patient lift assist device and other well designed interventions have been shown to reduce MSD's among health care workers, but a common reason given for their lack of use has been the negative impact on productivity. Many workers complain that the process for using them is too time consuming or slow (Evanoff, et al., 2003). Time is a precious commodity in the health care setting, so it is important for designers and manufacturers of these tools to address the temporal concerns of the end users. Possible means to increase the level of productivity of these interventions include using load absorbers and more efficient wheel systems to more easily move the mechanical lift assist device, which can become cumbersome once it is loaded with a patient. Also a more efficient design of the sling attachments would be helpful, as hooking and unhooking the sling from the lift assist frame can be a challenge. Creating rubberized handles to pull the hooks would also make the attachment process less stressful for the health care workers upper extremities.

While it is clear that the current intervention may have an impact on productivity, it is important to remember the true purpose of the patient lift assist intervention: preventing MSDs from developing in health care workers. These interventions are meant to protect the workers, and although productivity numbers may decrease as a result of their use, other measures of effectiveness are substantially improved. Zhuang, et al. (1999) showed that mechanical lift assist devices that used a basket sling to hold the

patient created a significant reduction in the forces on the back when preparing a patient to be transferred. The same study showed an elimination in the forces on the back when transferring the patient from location to location. Garg & Owen (1994) showed the incidence rate of back injuries decreased from 83 to 43 over a 13 month time period after introducing the mechanical lift assist device. The number of lost or restricted days in the same 13 month study went from 634 to 0. Takala & Kukkonen (1987) found that stooped and twisted back postures were assumed less often by nurses who used mechanical lift assist devices than by nurses who did not use the ergonomic intervention, and the differences in the two groups were found to be significant. Their study followed 70 nurses in a total of 5 hospital wards, and video analysis was used to collect the data. Chhokar, et al. (2003) studied the economics of using a similar ceiling mounted patient transfer intervention, and found the numbers of workers compensation claims decreased from 65 to 47 over a three year period in a 125 bed extended care facility. They also estimated that the introduction of the intervention saved the facility \$412,754 in direct workers compensation claims costs.

This study has illustrated that learning theory (and all of its quantitative measures and predictive capabilities) can be applied to the ergonomic intervention process, and is especially useful in considering how users will interact with the intervention. Learning rates can be characterized based upon their values. There can be a steep learning curve, which indicates a fast learning progression. For example, the use of bent handle pliers may have a steep learning curve in a user that is familiar with using a regular pliers, because there is not much of a change in the functionality of the task with the introduction of the ergonomic intervention. The same may be true for ergonomic spray

guns, screwdrivers, or other hand tools that are designed to keep the wrist in a neutral posture. The learning curve can also be shallow, which indicates a slower learning progression. For example, the use of a periscope when completing a pegboard task can have a very shallow curve, due to the large change in the functionality and interface of the task with the introduction of the ergonomic intervention (Lutz, et al., 2001). The use of a height adjustable work platform for upholstery and other tasks may have a medium curve, because there may be extra steps in the work task that need to be adjusted to by the worker, but the interface is still the same (Mirka, et al., 2002). Characterizing the learning rates and providing a predictive learning curve gives value to organizations considering introducing ergonomic interventions in their workplace. It can give the stakeholders a better idea of the impact the intervention will have upon productivity, both short and long term.

Although one challenge to implementing ergonomic interventions was explored in this study (reduced productivity) there are other limitations to introducing ergonomic interventions in the workplace that should be noted. First, there can be a strong resistance to change, a topic that Kan & Parry (2004) explored in the hospital workplace. They were able to identify three characteristics that needed to be in place for change to be accepted in the hospital workplace: group influence on the change, recognition of the natural resistance to change, and group acceptance of the leader. Second, there can also be issues of noncompliance with policies suggesting the use of the interventions when the benefits of the intervention are not accepted by the workers. Daynard, et al. (2001) showed that the forces on the spine can be significantly higher on a nurse if they are noncompliant with using a mechanical patient lift assist device. The study also showed

that compliance rates are greater for nurses that were presented with the ergonomic intervention of a patient lift assist device than with nurses that were simply trained to have better postures while lifting. Finally, it is important to note that patient handling is vastly different than material handling and individual sensitivities can arise in the process. Anecdotal evidence shows patient discomfort and feelings of instability when being transferred with some ergonomic interventions. There may be issues of modesty and disconnection with the caregiver that can arise when the patient is transferred, and these issues need to be considered when using the interventions.

4.3 Limitations to Research

There are some limitations of the generalizability of these results to the actual health care setting that should be noted. First, the research was done in a laboratory environment in contrast to the health care environment. Therefore there were no distractions that are often present in the health care setting, including people, noise, machinery, and other occupational demands. In the real health care setting there are numerous distractions that a nurse must filter when completing the patient transfer task. Therefore in the real world there may be slightly lower time-to-complete values due to these distractions. Secondly, the all eleven trials were done back to back, with breaks in between for the subjects comfort. In the real health care setting a nurse would not complete eleven patient transfer tasks back to back, and especially without other work tasks in between. Unless a nurse was under an extraordinarily high workload, they would not perform eleven patient transfer tasks in one daily shift. Therefore in the real world there may be some learning remission, which was not accounted for in the current study.

4.4 Future Research

Future research in this area could focus on classifying ergonomic interventions by their learning characteristics, including values such as learning rate and ratings of task complexity. Design alternatives for interventions can also be evaluated using the same measures. These classifications can be used in selecting appropriate ergonomic interventions for the workplace, and also be taken into consideration in the design of future ergonomic interventions. A study classifying interventions from simple to complex and documenting the learning rates would be ideal in expanding the ideas presented in the current study to the use of all ergonomic interventions.

The current work could also be expanded upon in the health care industry. This study could also be replicated in the actual health care setting, effectively eliminating the limitations to generalizability that are present in the current study. A study that allows nurses to complete the patient transfer task at a naturally occurring rhythm and in the rushed setting of a hospital or nursing home would be ideal. A study evaluating the learning rates of other patient transfer interventions would also help the health care industry in its arduous task of preventing MSDs.

5 Conclusion

It was found that learning curve theory can be applied to the process of introducing an ergonomic intervention, specifically the mechanical patient lift assist device. The evaluation of active and passive training methods were also relevant in the evaluation of learning, and the active method was hypothesized to have an advantage. Although the dependent variable Learning Rate was found not to be significant among training methods, the dependent variables Trial 0 (time-to-complete values for the first trial) and Delta 3 (change in performance over the first four trials) were significant. These significant values indicated a superiority of the active training method over the passive training method.

The passive method of training, called see-one-do-one, is a method that is prevalent in the health care industry. These results show us that the method of training selected is important when introducing an ergonomic intervention, and has an impact on the time-to-complete values and comfort ratings, at least the on first few replications of use. The current research is limited in its use of laboratory setting and time between replications. Future research can be done on the application of learning curve theory on other ergonomic interventions. The current study can also be replicated in the health care setting, effectively removing the limitations.

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Appendix A

Subjects Needed for Research Experiment

What: Subjects needed for research experiment at North Carolina State University. The study involves a 90 minute session. Participants will be compensated for their time.

Who: Healthy adults with no previous or current back pain. No previous experience with a specific hospital patient handling device.

When: Research will be performed in December 2004 and January 2005. Times are flexible and can be made to accommodate your schedule.

Contact: Stephanie Reid at sareid@ncsu.edu or 919-319-8392 to schedule your participation!

Appendix B

North Carolina State University INFORMED CONSENT FORM

Title of Study :

Learning Curve Analysis of a Mechanical Patient Lifting Assist Device

Principal Investigator

Stephanie Reid

You are invited to participate in a research study. The purpose of this study is to evaluate how the introduction of an ergonomic intervention impacts the performance of a person performing a patient handling task. You should not participate in this study if you have any chronic or current problems/discomfort in your back. If you do NOT have such an injury or disease, please initial here: _____ . You should not participate in this study if you have experience using mechanical lifting devices. If you do NOT have such an experience, please initial here: _____ .

INFORMATION

1. You will be given an explanation of the task and shown the task that will be performed.
2. Several measurements will be recorded including your weight, height, age, arm length, hip height, and nursing experience.
3. You will be trained on the patient handling task using the mechanical lift assist device.
4. You will be asked to repeat the patient handling task ten (10) times.
5. You will be asked to complete a brief questionnaire about your training experience.
6. After the experiment is complete, you will receive an Ergonomics Lab t-shirt as compensation for participation.
7. Total time for your participation is expected to take 1.5 hours.

RISKS

There is a very small risk of muscle soreness due to the physical nature of patient handling. If at any time during the experiment you feel discomfort let the researchers know and we will stop the experiment.

BENEFITS

The benefit associated with performing this study include better management of patient handling tasks and more workplace accomodation of ergonomic interventions.

CONFIDENTIALITY

The information in the study records will be kept strictly confidential. Each subject will be assigned a number, by which the subject's data and information will be referenced. This list and all other data will be stored securely and will be made available only to persons conducting the study unless you specifically give permission in writing to do otherwise. After the experiment is complete (data processed, statistical analysis performed, and report written) the list of the subject's names and numbers will be destroyed. The list is kept for the sole purpose of contacting the subject to find out if he/she would be willing to return if there are any problems with the data. No reference will be made in oral or written reports, which could link any subject to the study. All videotapes will be destroyed at the completion of the study.

COMPENSATION

For participating in this study you will receive an Ergonomics Lab t-shirt.

EMERGENCY MEDICAL TREATMENT

There is no provision for free medical care for you in the event that you are injured during the course of this study. In the event of an emergency, medical treatment may be available through the 911 emergency response service.

CONTACT

If you have questions at any time about the study or the procedures, you may contact the researcher, Stephanie Reid, at [919-319-8392]. If you feel you have not been treated according to the descriptions in this form, or your rights as a participant in research have been violated during the course of this project,

Appendix B

you may contact Dr. Matthew Zingraff, Chair of the NCSU IRB for the Use of Human Subjects in Research Committee, Box 7514, NCSU Campus (919/513-1834) or Mr. Matthew Ronning, Assistant Vice Chancellor, Research Administration, Box 7514, NCSU Campus (919/513-2148)

PARTICIPATION

Your participation in this study is voluntary; you may decline to participate without penalty. If you decide to participate, you may withdraw from the study at any time. If you experience any pain or discomfort you should inform the investigator, and you may terminate the process if the pain is severe. If you withdraw from the study before data collection is completed your data may be returned to you if you so desire.

CONSENT

I have read and understand the above information. I agree to participate in this study.

Subject's signature _____

Date _____

Investigator's signature _____

Date _____

Appendix C

Exit Interview Questions

Subject # _____

Directions: Rank each question with a high score of 5 corresponding to a response of excellent or absolutely and a low score of 1 corresponding to a response of poor or absolutely not.

1. How effective do you think the training that you received today on how to use the mechanical lift assist device was?
2. How efficient do you think the training that you received today on how to use the mechanical lift assist device was?
3. How comfortable were you with using the mechanical lift assist device on your first independent trial?
4. How comfortable were you with using the mechanical lift assist device on your last independent trial?
5. As of right now, do you feel prepared to use the lift assist device in your day to day activities if you were in the medical profession?
6. Would you use the lift assist device in your day to day activities if you were in the medical profession?

Appendix D

Subject # _____

Date _____

Start Time _____

End Time _____

Sex _____

Weight _____

Age _____

Height _____

Hip Height _____

Arm Length _____

Spine Length _____

Trial #	Completed?	Time
Orientation		
Training		
Trial 0		
Trial 1		
Trial 2		
Trial 3		
Trial 4		
Trial 5		
Trial 6		
Trial 7		
Trial 8		
Trial 9		
Trial 10		

 Training Type _____

Introduction	
Informed Consent	
Measurements	
Orientation	
Training	
Trial 0	
Trial 1-10	
Questionnaire	
Compensation	
Informed Consent Copy	

Appendix E: Graphs for the Assumptions of the Analysis of Variance

Test for Homogeneity of Variance

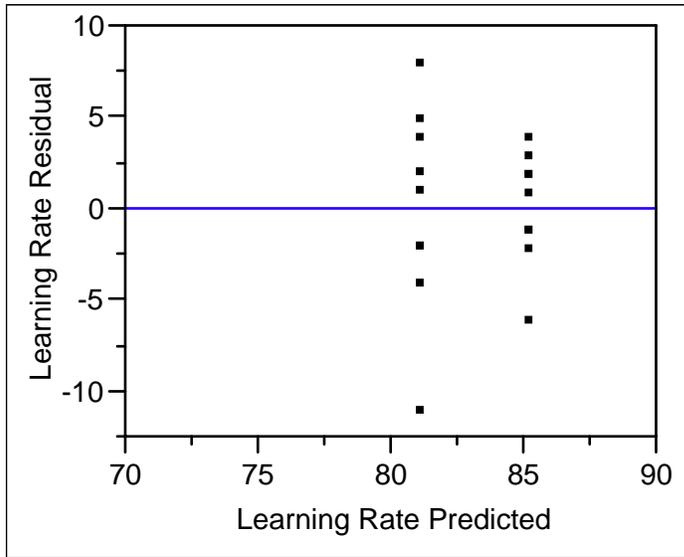


Figure 18: Scatter plot of the residuals as a function of the predicted values for the LearningRate.

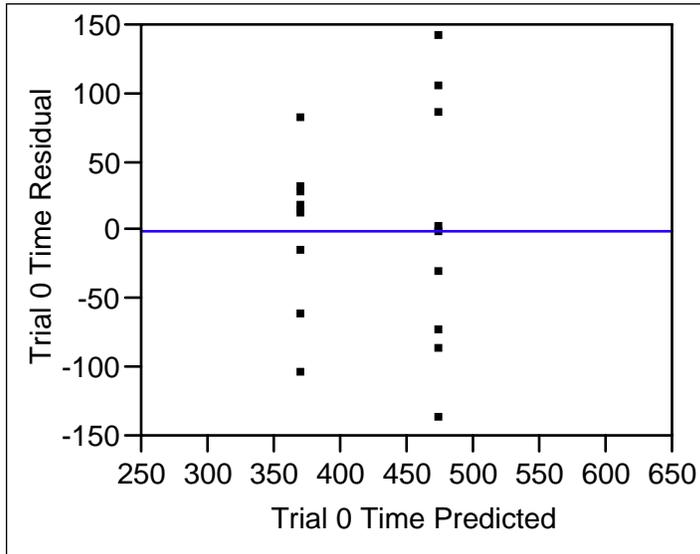


Figure 19: Scatter plot of the residuals as a function of the predicted values for Trial 0.

Appendix E: Graphs for the Assumptions of the Analysis of Variance

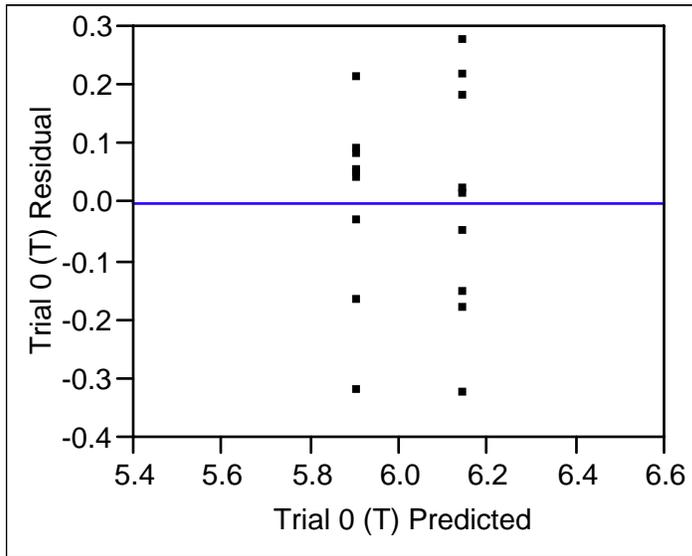


Figure 20: Scatter plot of the residuals as a function of the predicted values using the Trial 0 transformed values.

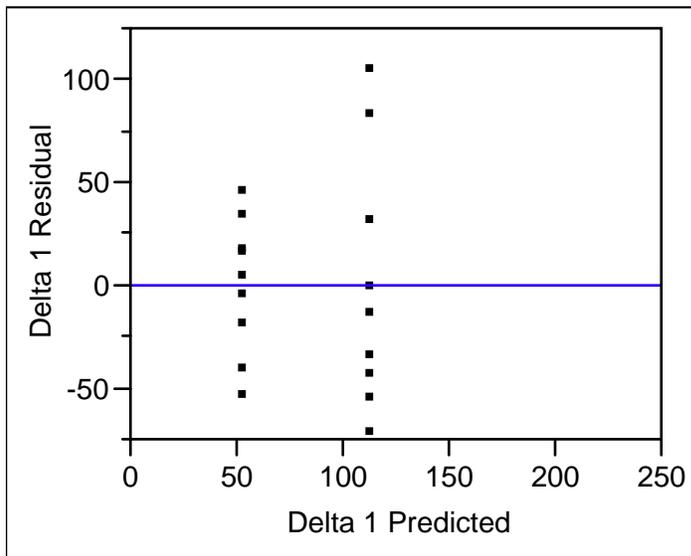


Figure 21: Scatter plot of the residuals as a function of the predicted values for Delta 1.

Appendix E: Graphs for the Assumptions of the Analysis of Variance

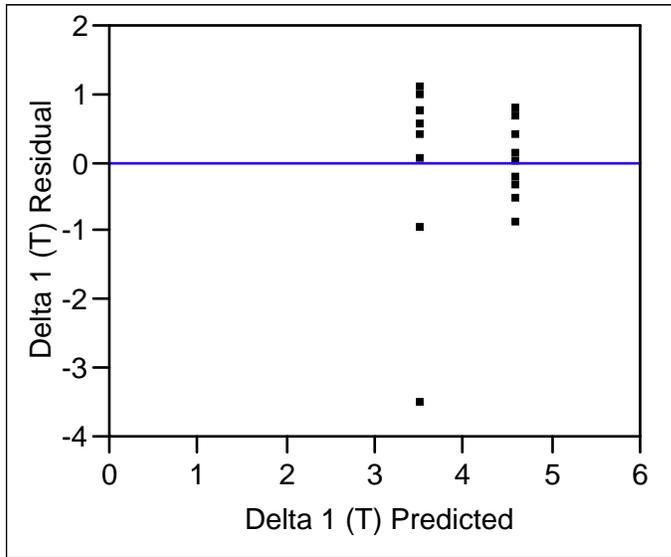


Figure 22: Scatter plot of the residuals as a function of the predicted values using the Delta 1 transformed values.

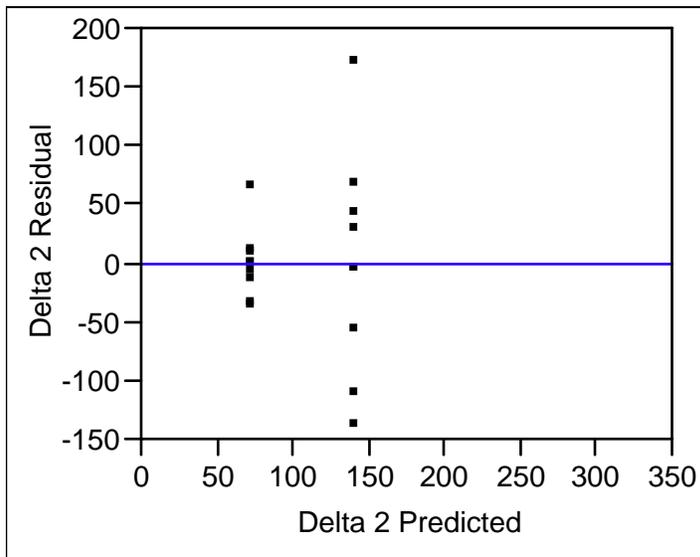


Figure 23: Scatter plot of the residuals as a function of the predicted values for Delta 2.

Appendix E: Graphs for the Assumptions of the Analysis of Variance

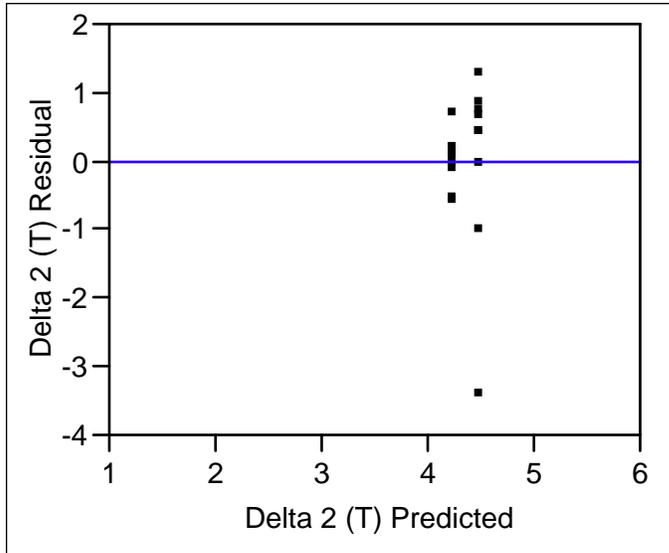


Figure 24: Scatter plot of the residuals as a function of the predicted values using the Delta 2 transformed values.

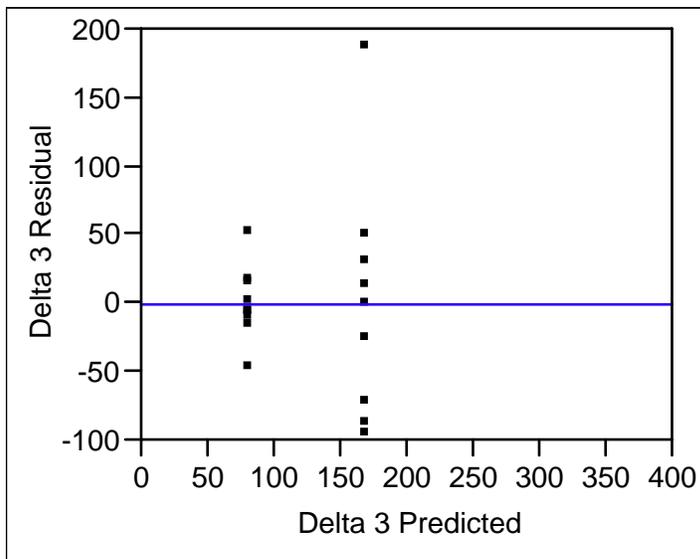


Figure 25: Scatter plot of the residuals as a function of the predicted values for Delta 3.

Appendix E: Graphs for the Assumptions of the Analysis of Variance

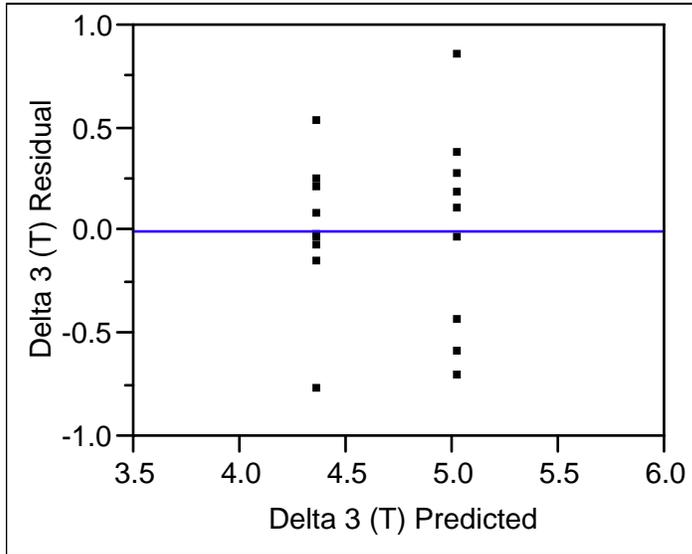


Figure 26: Scatter plot of the residuals as a function of the predicted values using the Delta 3 transformed values.

Test for Normality of Residuals

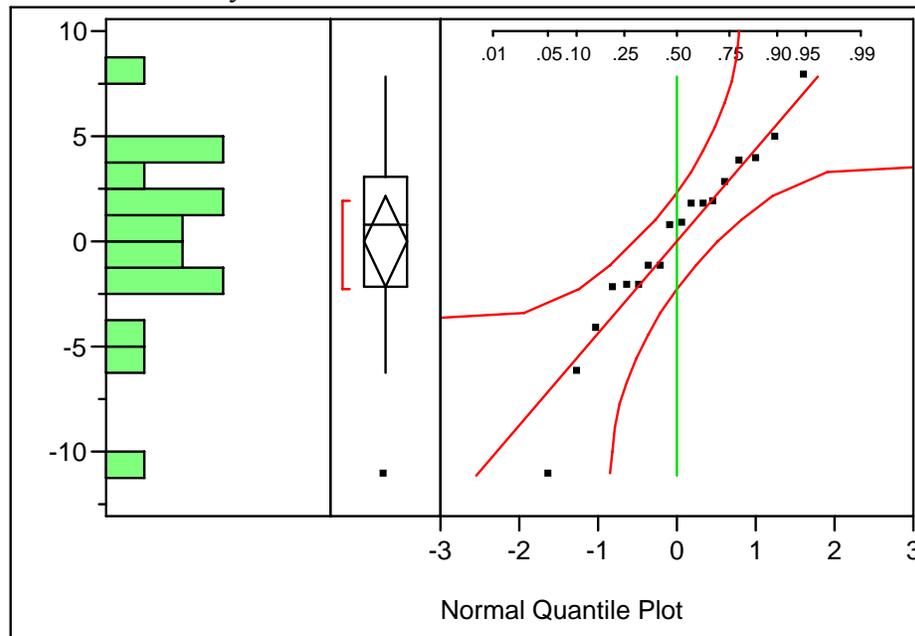


Figure 27: The normal quantile plot for the residuals of the Learning Rate.

Appendix E: Graphs for the Assumptions of the Analysis of Variance

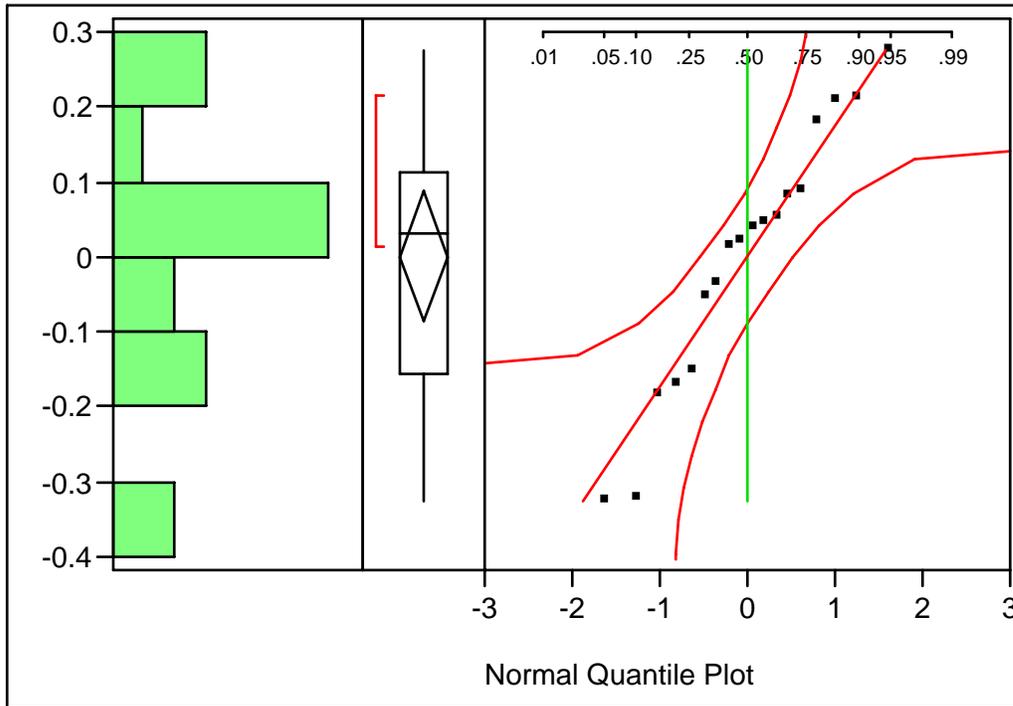


Figure 28: The normal quantile plot for the residuals of the transformed data of Trial 0.

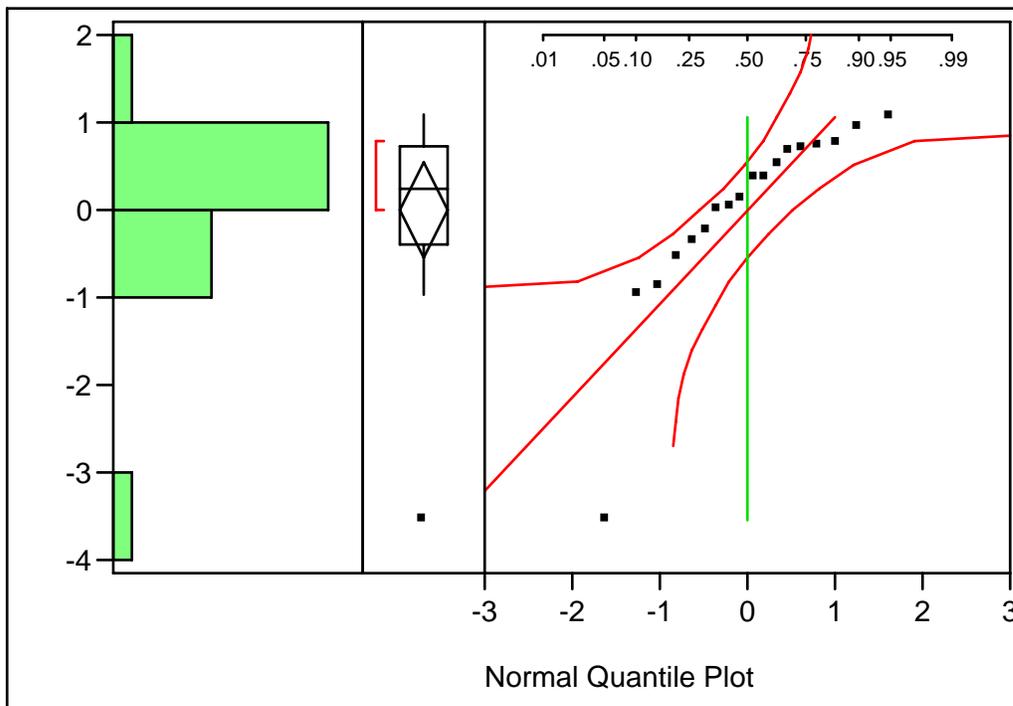


Figure 29: The normal quantile plot for the residuals of the transformed data of Delta 1.

Appendix E: Graphs for the Assumptions of the Analysis of Variance

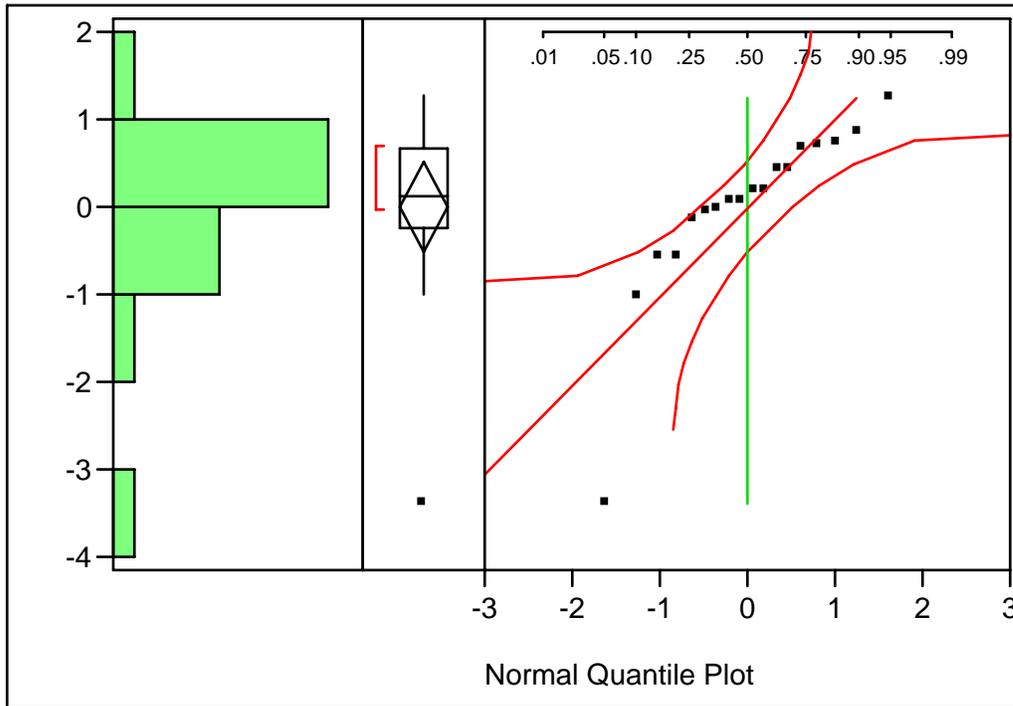


Figure 30: The normal quantile plot for the residuals of the transformed data of Delta 2.

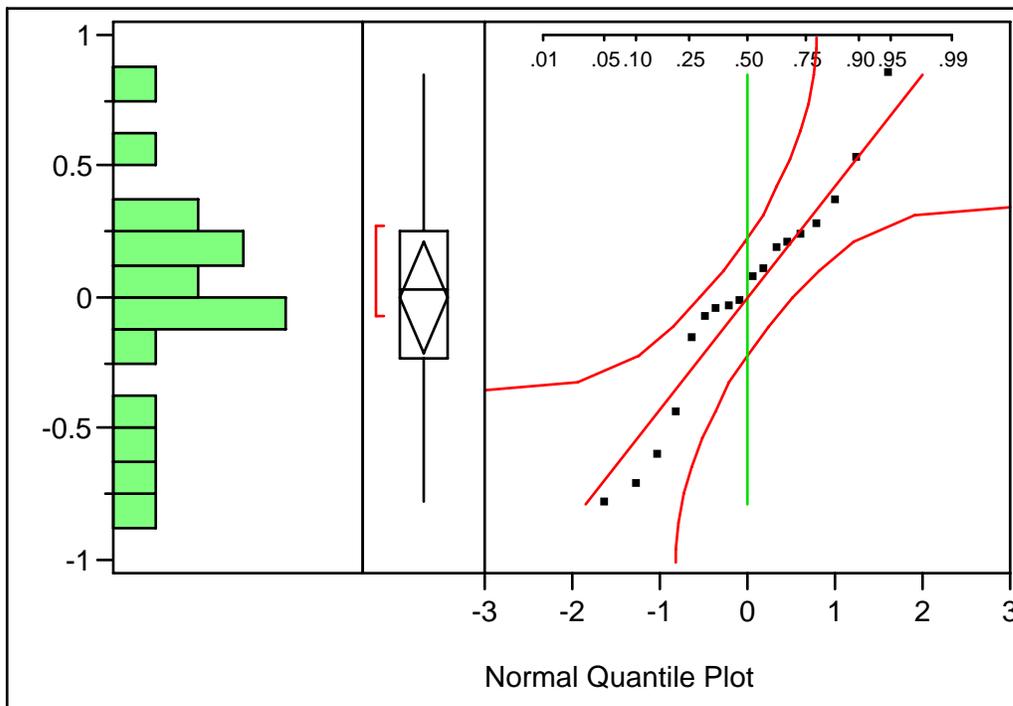


Figure 31: The normal quantile plot for the residuals of the transformed data of Delta 3.

Appendix E: Graphs for the Assumptions of the Analysis of Variance

Test for Independence

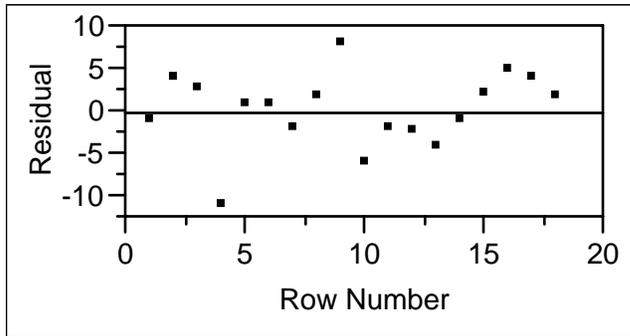


Figure 32: Scatter plot of the residuals of the Learning Rate.

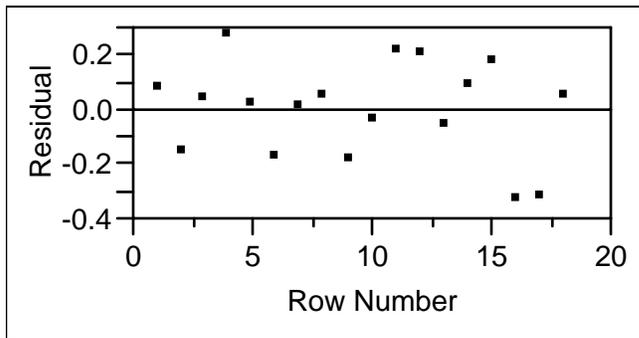


Figure 33: Scatter plot of the residuals of the transformed data of Trial 0.

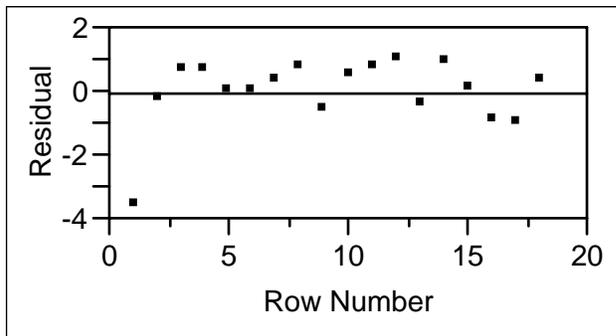


Figure 34: Scatter plot of the residuals of the transformed data of Delta 1.

Appendix E: Graphs for the Assumptions of the Analysis of Variance

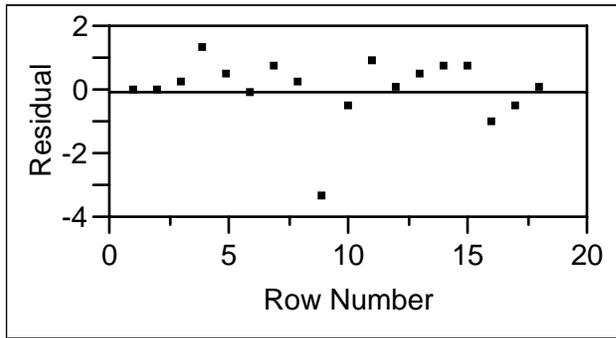


Figure 35: Scatter plot of the residuals of the transformed data of Delta 2.

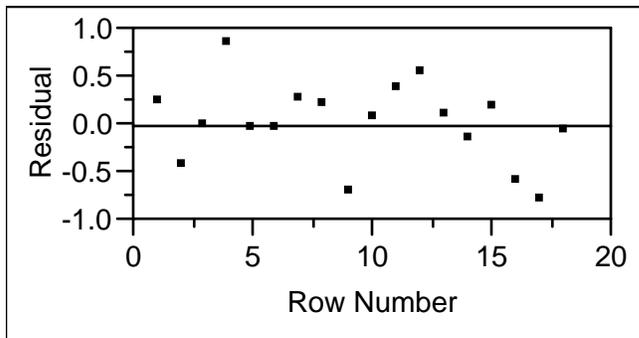


Figure 36: Scatter plot of the residuals of the transformed data of Delta 3.