ABSTRACT

PATIENT HANDLING ERGONOMICS

by
Paul Reichert

The incidence of musculoskeletal injuries among healthcare workers has been well documented in the medical and ergonomic literature. The epidemiological evidence demonstrates high injury rate among nurses, nurse's aides, therapists and other medical workers who frequently handle patients. The biomechanical research has shown large compressive forces developed in the lumbar spine performing various patient handling transfers that exceed the National Institute of Occupational Safety and Health's recommended guideline. One of the most strenuous patient handling tasks is transferring the patient from bed to the chair and vice versa.

One of the objectives of this thesis is to design and conduct a laboratory experiment to determine whether six experienced physical therapists and physical therapy assistants can accurately and consistently assess the patient's functional level based on a widely used grading system for a non-dependent patient. An additional objective is to measure the lumbar spinal compression forces during the assisted transfers to investigate whether they pose a risk of injury to the lumbar spine for healthcare workers. In the past, the reliability of this functional grading system and the biomechanical risk of performing assisted transfers has never been evaluated. The hand coupling forces and the therapist's perceived exertion was recorded and analyzed to verify the therapist's accuracy using the grading system on a patient. A small, able-bodied male, posing as a patient, was

transferred from bed and from wheelchair using a gait belt.

The therapists were consistent in their grading of the assistance level for the transfer from the bed with an average R^2 value of 0.62 and an overall correlation coefficient of 0.95. For the transfers from the wheelchair, the gradings were not well correlated with the respective values of 0.34 and 0.41. This low correlation was attributed to the mismatch between the varying anthropometry of the therapists with respect to the fixed lower height of the wheelchair.

The spinal compression forces at L5/S1 assessed for one large male therapist and one small female therapist were under the recommended safe level of 3400 N. The maximum spinal compression force was 2100 N using a static biomechanical model. The transfers, under the same experimental conditions, were extrapolated to 50th and 95th percentile bodyweight patients, with and without gait belts. Results revealed that the gait belt transfers continued to remain under the safe lumbar load levels. For larger patients requiring higher levels of assistance, the transfers performed without the gait belt ranged from 3555 to 4143 N, which is over the recommended safe limit. These biomechanical findings should assist healthcare workers in deciding whether to handle patients with manual or mechanical technique.

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by
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PATIENT HANDLING ERGONOMICS

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This thesis is dedicated in memory of my beloved father, who always appreciated my achievements and inspired my pursuit for knowledge.

This thesis is also dedicated to my loving family for their continuous support and patience for days when “daddy needed to study”.

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CHAPTER 1

INTRODUCTION

Patient handling can be defined as the manual assistance given to a patient by a healthcare worker to complete a functional task. The amount assistance on behalf of the healthcare worker is dependent upon the patient's size, functional, cognitive, and medical capabilities. Examples of a typical patient handling task are lifting a patient from the hospital bed to chair - flat surface to a seated surface, from hospital bed to stretcher - from flat surface to another flat surface, and from toilet to chair - seated surface to another seated surface.

The Bureau of Labor and Statistics (2000) continues to report a high incidence of nonfatal injuries and illnesses among nurses and nursing aides. The major cause of injury is overexertion, where the nurses and nursing aides do not possess the strength to perform the tasks required during the manual handling of patients. This strength to job mismatch leaves the worker vulnerable to strains and sprains, usually of the lumbar spine. Other studies have also demonstrated the high incidence of injury to nursing staff related to the strenuous nature of the work. Among the routine occupational tasks performed by the health care workers, assisting dependent or partially dependent patients during transfers between bed and wheelchair has been identified as one of the major occupational tasks that can overload the lower back structure.

Above average rate of occurrence of lower back pain among the health care workers has been established by several recent large-scale surveys. Hignett (1996) summarized many studies associated to work-related back pain in nurses. Cited studies found that frequent patient handlers had a three to seven times higher prevalence rate versus infrequent handlers, and 36% of low back injury occurrences were associated to patient handling. Healthcare workers have been at risk primarily due to the strenuous work related to patient handling (Pheasant and Stubs, 1992; De Looze, et al. 1998).

Physical therapists are additional healthcare workers that perform frequent patient handling tasks. The survey by Holder et al. (1999) of 623 physical therapists and physical therapy assistants and their work related musculoskeletal disorder (WMD), found 62 and 56 percent, respectively had low back pain at some point in their professional carrier. The three most stressful activities reported to cause injury was transferring, lifting and responding to sudden movement of patients. Based on a survey of 928 therapists, Bork et al. (1996) reported, 45 percent had had a history of WMD in the lower back with the most likely cause being lifting or transferring dependent patients. A Canadian survey of 311 physical therapists (Mierzejewski and Kumar, 1997) also noted higher incidence rate of lower back pain than the general population. Activities including patient handling, stooping, lifting, carrying pushing and pulling were frequently described as the cause of the injury by the therapists.

Knibbe and Knibbe (1996) evaluated nurses while bathing patients from a postural standpoint. They used Ovako Working Posture Analyzing System (OWAS) developed by Kharu et al. (1977) to quantify the number of harmful postures at the lumber spine. The harmful postures were identified as the number of degrees of trunk flexion assumed by the nurses. Performing nursing duties around a fixed height shower chair had the most harmful posture and a hi-lo bed was third. They established the frequency of harmful postures adopted around the patient in grading the low back pain risks of the tasks.

Biomechanical studies have documented and quantified the risk of injury to the lumbar spine. Almost all of the studies discovered that most of the patients handling tasks performed in the healthcare setting exceed the safe National Institute of Occupational Safety and Health (NIOSH) recommendation for compressive forces of 3400 N at the lumbar spine (Waters et al., 1993). Therefore, healthcare workers who frequently handle patients are at high risk of developing an injury to the lumbar spine. The studies evaluated numerous patient-handling tasks typically performed in the field.

Using biomechanical modeling approach, several researchers investigated spinal loading and risk for back injury for different patient handling scenarios. Garg and Owen (1992a, and 1992b) studied the two-person manual lifting technique of transferring patients from bed to wheelchair. Winkelmolen et al. (1994) evaluated five manual techniques for moving patients up in the bed, and Marras et al. (1999) investigated various patient-lifting techniques. All of the above studies concluded that dependent patient transfers pose a significant risk of development of structural failure of the lower back.

Ergonomic controls used to reduce the physical demands of patient handling have proven successful in reducing injuries, lost time, compensation costs, improving job satisfaction, and employee morale. The engineering controls utilize various modern, mechanized devices designed specifically for the handling of patients. The equipment, when used correctly, has demonstrated significant reduction in physical demands. When the equipment is used in conjunction with a supportive infrastructure and a comprehensive administrative program, the program attributes are more substantial and long-term. Ergonomic controls implemented without proper equipment or a structured program will usually fail to gain the above benefits.

1.1 Problem Statement

In most of the biomechanical studies reported in literature (Garg et al., 1991; Garg and Owen, 1992a and 1992b; Winklemon et al., 1994; Ulin et al., 1997; Marras et al., 1999; Zuang et al., 1999) related to patient handling, the "patient" was a totally dependent, meaning that he or she cannot assist in their own mobility and was 100 percent reliant on the healthcare worker. The patients were treated as dead weight in the above studies, and usually an able-bodied person or an inanimate dummy simulated the patient in these experimental studies. All of these studies reported that the lower back stress levels in patient transfers exceeded far beyond the NIOSH safe limit.

This is not always the situation in the healthcare field. Most patients can assist the healthcare worker in their mobility, but do require some exertion of the worker in order to complete that activity. For the handling of dependent patients, therapists generally seek assistance. For non-dependent patients, the decision of getting additional help from the coworkers or using a mechanical aid lies on the judgment of the healthcare worker. Thus depending on the assistance level requirement for a patient, a therapist may over exert while performing a patient transfer. The therapist's strain in such activity depends on factors including patient's level of mobility and strength in completing the activity, patient's compliance level, and his or her body weight. Therefore, in many such cases, the physical strain of the handlers in assisting the patient may very well exceed the safe handling limit.

In health care industry, the assistance provided by the therapist is subjectively graded depending on the assistance level needed to stand the patient. This grading system is used to initially assess the patient's functional ability and to track the patient's progress in a rehabilitation program. It is used for continuity of care, so if another therapist or healthcare worker treats the patient, he or she will know the functional level of that patient and can estimate the amount of assistance that particular patient requires. The grades that require assistance on the therapists part breakdown as follows:

- Contact guard (cg)– Patient requires only therapist's tactile guidance to complete task.
- Minimal assistance (min.) – Patient requires assistance for 25% of the activity
- Moderate assistance (mod.) – Patient requires assistance for 50% of the activity
- Maximal assistance (max.) – Patient requires assistance for 75% of the activity
- Dependent (d) – Patient requires complete physical assistance

Therapists determine assistance levels by subjectively grading the patient's assistance requirement during specific patient handling tasks. The grading should primarily rely on the assistance level required by the patient and not the perceived effort level by the therapists during patient assistance. Perceived exertion or effort levels is expected be more affected by the effort needed by a therapist in relation to his or her strength, rather than the assistance level required by the patient. For example, it is possible a male therapist may find it less strenuous to assist a patient and specify the patient's assistance level to be minimal. For handling that same patient, a smaller female therapist may assign moderate assistance level. Whether it truly reflects the rehabilitation level of patient and with what level of accuracy is unknown. The accuracy level of such a grading system has never been investigated.

1.2 Research Objectives

The objective of this study is set to investigate the following two questions relating the assisted patient handling tasks - (1) can the patient handlers assess the level of assistance requirement during partially dependent patient transfers with acceptable degree of accuracy, (2) what are the back injury risks of the patient handlers during the assisted patient handling tasks? The specific research objectives are as following:

(1) Select a group of experienced patient handlers who will participate in this experimental study.

(2) Design and conduct an experiment on assisted patient handling tasks, which will include different assistance levels produced by a participating subject simulating a patient.

(3) Measure the force requirement during the patient handling trials and the perceived assistance levels by the patient handlers. Subsequently, analyze the perceived assistance and measured force to assess the consistency and accuracy of the perceived assistance levels by the handlers.

(4) Record the postures of the patient handlers during the patient handling trials and compute the spine compressive force at lower back from the measured hand forces during the trials. The computed lower back compressive force will be compared with

the available guidelines to determine risk of back injury of patient handlers during assisted patient handling tasks.

1.3 Research Significance

The results of the experimental study will evaluate the effectiveness the therapists' assessment capability of patient's rehabilitation status during the patient handling tasks. This type of assessment is prevalent in health care setting. The factors that may affect accuracy of such assessment could be valuable in improving the accuracy and consistency of such measures.

Quantification and identification of the back injury risks during assisted patient handling tasks will help to reduce the occupational back injury among the healthcare workers, which presently occurs at a very high rate. The results of the study can help in producing safe patient handling guidelines for assisted patient transfers.

CHAPTER 2

LITERATURE SURVEY

A survey of literature related to patient handling was performed to assess the risks encountered by healthcare workers who frequently need to manual lift patients. The epidemiology literature reviewed documents the extensive prevalence of musculoskeletal injuries sustained by the health care workers. The literature on biomechanical investigation has documented the high forces and the awkward postures adopted during the manual handling of patients. Some of the biomechanical studies have also evaluated the reduction of these forces and improvements in posture, after ergonomic engineering controls have been implemented. Lastly, the ergonomic interventions related to patient handling have been presented to illustrate the effectiveness of administrative and engineering controls in reducing occupational injury prevention in patient handling.

2.1 Epidemiology of Back Injury of Health Care Workers

The Bureau of Labor and Statistics (BLS) (2003) reported that in the year 2000 nursing aides had the third highest incidence rate for nonfatal injuries involving days away from work only surpassed by truck drivers and laborers. Registered nurses rank tenth (see Figure 2.1). The BLS also reported nurses aides rank second in injuries with days away from work involving musculoskeletal disorders nurses ranked sixth in 2000 (see Figure 2.2).

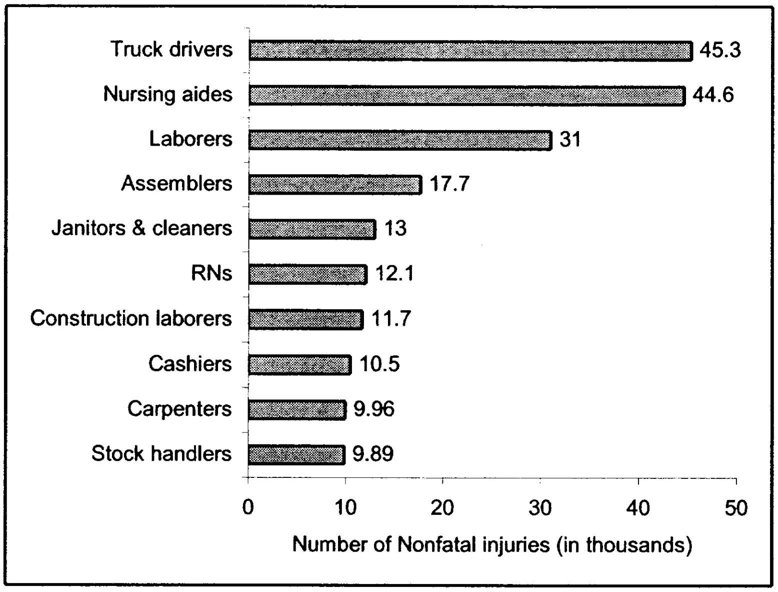


Figure 2.1 Nonfatal injuries and illnesses for ten largest number of cases involving days away from work in 2000.
(Bureau of Labor and Statistics 2003)

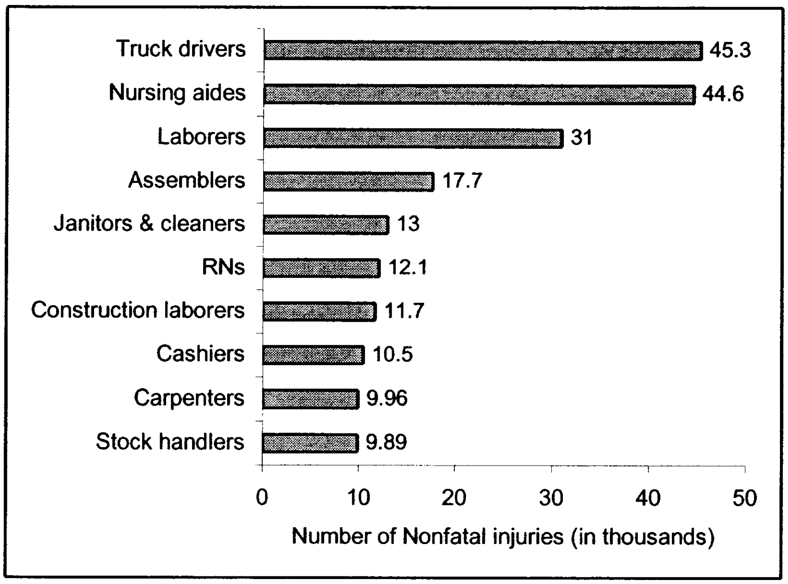


Figure 2.2 Injuries with days away from work involving musculoskeletal disorders in 2000.
(Bureau of Labor and Statistics, 2003)

The BLS cited the most frequent source of injury were overexertion for both the nurses and the nurse's aides. Out of all musculoskeletal disorders, overexertion injuries accounted for 45% and 58% for nurses and nurse's aids, respectively in terms of days off from work.

The incidence of occupational low back pathologies in the healthcare field has been well documented in the ergonomic literature. Hignett (1996) summarized many studies associated to work-related back pain in nurses. According to his survey frequent patient handlers had a three to seven times higher prevalence rate versus infrequent handlers, and 36% of low back occurrences were associated to patient handling. Meittunen et al. (1999) concluded that patient transfers were the second most frequent cause of occupational injury and the highest compensable at the Mayo Medical Center. Registered nurses and licensed practical nurses comprised 72% of the overall injuries and this was attributed to the frequency of patient handling. The most stressful patient handling techniques identified were sliding a patient up in bed, transferring a patient from bed to stretcher, transferring a patient bed to chair, and repositioning patient in bed. Garg (1999) reported that most nursing homes have an 80 percent turnover rate among nursing aides. This turnover rate was attributed to the high physical demand placed on the aides.

Physical therapists are healthcare workers who also perform frequent patient handling tasks that require lifting. The survey by Holder et al. (1999) of 623 physical therapists and physical therapy assistants, found that 62 and 56 percent, respectively had low back pain at some point in their professional career. The three most stressful activities reported to cause injury were transferring, lifting and responding to the sudden movement of the patient. Twenty-five and 23 percent of the injuries to physical therapists and physical therapy assistants respectively were associated with lost time. Bork et al. (1996) also revealed a high prevalence of low back pain in physical therapists. In their survey of 928 therapists, 45 percent had had a history of a work related musculoskeletal disorder (WMD) in the low back with the most likely cause being lifting or transferring dependent patients. Mierzejewski and Kumar (1997) surveyed 311 Canadian physical therapists, and found physical therapists had a higher incidence of low back pain than the general population. Activities frequently described by the therapists as the cause of their injuries included patient handling, stooping, lifting, carrying, pushing, and pulling. Molumphy et al. (1985) found that therapists reported, "lifting with sudden maximal effort and bending and twisting" as some precipitating factors in his survey of 344 respondents.

Knibbe and Knibbe (1996) evaluated nurses while bathing patients from a postural standpoint. They used the Ovako Working Posture Analyzing System (OWAS) to quantify the number of "harmful" postures at the lumbar spine. The harmful postures were identified as the number of degrees of trunk flexion assumed by nurses. Performing nursing duties around a fixed height shower chair had the most harmful posture and a hi-lo bed was third. This is an example of the high frequency of harmful postures adopted around patients.

2.2 Patient Handling Biomechanics

High spinal compressive force at the lower back has been identified as the leading risk factor for occupational lower back pain (Chaffin et al., 1993). The National Institute of Occupational Safety and Health (NIOSH) has recognized that the spine compressive forces of maximum 3400 N at the L5/S1 disc as the safety cut-off value. At or below this level, at least 75% of male and 99% of female worker populations should be safe from structural failure at the lower back (Waters et al., 1993).

Garg et al. (1991) evaluated specific patient handling activities and found that a two person manual lifting technique of transferring patients from bed to wheelchair were in excess of 4223 to 4557 N of compressive force at the L5/S1 disc. Going from wheelchair to bed the average force was computed to be 4395 N. They used force dynamometers to measure the hand forces and videotape to measure the posture. They studied various patient transferring methods for a dependent patient from bed to wheelchair and from wheelchair to bed. The methods included two-person manual lifting, gait belt, walking belt, and mechanical lifting device. In collecting the biomechanical data, they stated that they attached the force dynamometer to the slings or belts depending on the method, but did not clarify where they attached the force dynamometer during the manual method or how they accounted for this measurement.

Garg and Owen evaluated 38 nursing aides job in the field with actual patients in their 1992a study. The authors used a static biomechanical model to estimate the spinal compressive forces. Their biomechanical assessment for going from wheelchair to bed and from bed to wheelchair was 4887 N and 3680 N, respectively for a 50-percentile patient weight. The estimated forces for a 90-percentile patient ranged from 4272 N to 5638N. Transfer from wheelchair to bed had the peak forces. A critical assumption made in this study was that the estimated force of transferring the patient by two nursing aides to be half of the patient's body weight. This assumes that all of the patients are completely dependent, which in fact may not always be the case. Some patients are capable in assisting the healthcare worker in their own mobility. Therefore, the hand coupling and lumbar compressive forces may have been overestimated.

The study also revealed that the nursing aides used manual transferring methods 98 percent of the time and mechanical devices only 2 percent. The reasons given by the nursing aides for not using the mechanical devices were, they were not available, they took too long to use, lack of staffing, lack of skill in using the mechanical devices, patient safety and personal choice. They performed a time study on the mechanical versus the manual method and found the respective times to be 180 seconds and 18 seconds. The nursing aides also reported difficulty pushing the mechanical devices secondary to the small diameter of the wheels, and the device tending to sway during the propulsion of it. In terms of postural stress to the lumbar spine, Garg and Owen also observed the nursing aides frequently adopting flexed trunk postures during their patient handling tasks as the mean trunk flexion for most patient handling tasks exceeded 30 degrees with the 57 degrees being the mean for transferring a patient from wheelchair to bed. The authors concluded that the strength requirements for the job exceeded the strength capabilities for most if not all worker, and body mechanics and lifting technique training alone did not reduce the workers physical demands or incidence of injury.

Garg and Owen continued to study nursing aide jobs in their 1992b field and laboratory study of ergonomic intervention. The laboratory part of the study investigated the biomechanical forces of patient handling tasks before and after ergonomic implementation. The field study also evaluated before and after interventions using perceived exertion ratings. The authors found high lumbar spine compressive forces during manual lifting methods averaging 4751 N using a static biomechanical model. The large compressive force for manual lifting the patient was greatly reduced with the use of a walking belt to 1964 N, which enabled the nursing aide to pull the patient instead of lifting. The horizontal pulling of the patient greatly reduces the stress on the aide's lumbar spine in contrast to the vertical lifting. They did state that they used a three-dimensional static biomechanical model to estimate the lumbar spine compressive forces, but failed to document how they measured the load of the hand forces and the method of obtaining the nursing aides' posture. The ergonomic interventions did improve the work by decreasing the biomechanical loads, perceived exertions, and injury rates. The authors also reported the nursing aides had high acceptance rates, 81 to 96 percent, with using the mechanical devices over the manual method, 42 to 53 percent.

Laboratory study by Winkelmolen et al. 1994 evaluated five manual techniques for moving patients up in the bed and revealed that lower back compressive forces for all of the lifts for a 75 kg patient ranged from 3869N to 4487N. They used ten female subjects to serve as nurses and two volunteers to be passive patients. The methods included the evaluation of five different two-person manual techniques to lift patient up in a hospital bed by using three-dimensional camera setup with body markers to record the postures. The compressive forces were calculated using the Arbouw Foundation biomechanical software. A similar assumption was made in this study in regards to measurement of the hand coupling forces. The authors assumed the forces were equal to half of the patient's body weight, which may have overestimated the back compressions. It is unlikely that the nurses actually lifted the entire patient. The authors stated that the Australian technique had the lowest perceived exertion rating and the lowest biomechanical lumbar compression force, but still exceeded the NIOSH's recommended load level of 3400 N. They concluded that the study further supported the use of mechanical devices in the field. It may be of importance to note that in greater than 12 years of personally handling patients; none of the techniques evaluated have ever been witnessed or performed by the author of this thesis. The most common method utilizes a draw sheet under the patient so that two healthcare workers can grip the sheet and slide the patient up in bed. This technique was not evaluated in this study.

Zhuang et al. (1999) studied methods for transferring patients in the laboratory setting using nine nurse's aides and two elderly volunteers posing as passive patients. The study evaluated and compared manual and mechanized transfers moving the patient from supine to sitting in a chair. The methods employed a three-dimensional motion analysis utilizing four cameras and 12 reflective body markers. They also used two force plates and the University of Michigan's 3-D Static Strength Prediction Program™ (3D SSPP) software to estimate the back compression forces. The two-person manual method revealed back compression forces for a 77.3 kg patient at 3676N. The stand-up lift, a type of patient handling device, revealed a force of 3635N, which was not much better that the manual method. This is an important finding as one would intuitively think that using this type of mechanized lift would decrease the compressive forces, but it did not. This type of device only lifts the patient from one sitting surface to another sitting surface and neglects to assist the patient from supine to sit, which produced considerable spinal stress in the study. The basket-sling and the overhead lift devices significantly lowered the spinal stress to 3081N for the heavier patient. This stress was created during the rolling of the patient in bed to place the sling under the patient.

Ulin et al. (1997) used two nurses to team transfer two paraplegic patients and compared three manual and three mechanical methods. Force gages measured the hand coupling forces during rolling, positioning patients on the sling, and pushing the wheeled mechanical lift, while the nurses wearing body markers were videotaped to record their postures. Perceived exertions were also obtained from the nurses. The authors did not use the force gages to measure the forces during the transfer as they estimated the forces based on a percentage of the patient's bodyweight. Two nurses simultaneously transferred the patient with one nurse performing the majority of the task ranging from 50 to 100 percent and the other assisting from 10 to 50 percent. Since the coupling forces were estimated, the back compression forces are also estimated and possibly significantly inaccurate. When lifting in the lead position, the average compressive forces in the nursing subjects lifting totally dependent 95 kg and a 56 kg patient from bed to wheelchair were 6521 and 6501N, respectively.

The main finding in this study was that even when handling patients in teams of two, it is still considered unsafe. In contrast, the estimated compressive force while using a mechanical lift ranged between 1531 and 1608 N, which is well below the safe limit. The authors did not measure the force of the inherent task of turning a patient in bed to place the sling under the patient when using a mechanical lift. Turning the patient can be a physically stressful task and should have been considered.

Marras et al. (1999) performed a comprehensive study on common transfers performed in healthcare using 17 subject, 12 of whom were experienced in handling patients and the remaining were inexperienced. The authors designated one "standard" 50 kg patient to serve as a medium sized patient throughout the study. The method used to determine the back stress was the Lumbar Motion Monitor (LMM), which is a goniomentric exoskeleton of the spine that measures instantaneous trunk movements. Electromyographic (EMG) signals were measured for the subjects back muscle activity. The authors investigated various one and two-person bed to wheel chair transfers. The results found that one-person transfer technique had a ten-percent higher spinal compressive force (1300 to 1700N) versus two person techniques. The use of a two person transfer with a gait belt did not reduce the risk of injury for the person on the left side of the patient, which had the same forces as the one-person transfer technique. The person on the right side did have lower anterior-posterior shear forces. The mean compressive force for a one-person transfer all ranged from 5964 to 6717N depending on the type of transfer. The two-person transfer compressive forces each ranged from 4314 to 4948N. While the two-person transfer performed with the gait belt ranged form 4895 to 4571N. Thus, the use of a gait belt in this study did not significantly reduce the risk of back injury in contrast to Garg and Owens' (1992b) findings, which they found to significantly reduce the back stress. This conflicting finding may be due to of the two different biomechanical assessment methods used in the studies. Garg and Owens used a static biomechanical model and Marras used the LMM and EMG.

One misconception common in the healthcare industry the Marras study did disprove is that a two-person technique does not decrease the back stress by half. Table 2.1 summaries the back compression forces during the lifting and the lowering phases of the bed to chair transfer.

Table 2.1 Lumbar Compression Forces During the Bed to Chair Transfers

Transferred from	Lifting	Lowering
Bed	6408 N	5744 N
Wheelchair	5964 N	5424 N

Overall, the lifting of the patient revealed higher compressive forces versus lowering. Marras concluded that "none of the lifting techniques would be considered safe to use in a hospital setting for either one or two-patient handlers" as they all exceed the NIOSH guideline. The authors also evaluated repositioning techniques for moving a patient up in bed. The results revealed a 9171 N compressive force for one person moving the patient up in the bed. Marras stated that "90 percent of the work population would be expected to have vertebral endplate fractures" at the lifting loads of that magnitude. Two-person results ranged from 5655 to 6570N were the test subjects physically handled the patients. The use of a draw sheet to slide the patient up in bed reduced the stress on the lumbar spine as the compressive forces ranged from 3819 to 3902N. The patient in this study was relatively light compared the average weight for a 50 percentile male/female at 74.5kg (Eastman-Kodak, 1983). Accordingly, a heavier patient would have greater associated risks in handling. Marras recommended the use of mechanical devices for handling patients in healthcare to reduce the risk of injury.

In a newer study, Nelson et al. (2003) assessed various patient handling techniques performed by nurses and nursing aides using a control and an intervention group. The control group did not use any administrative or engineering controls to perform the techniques. The intervention group used various ergonomic controls to assist in the completion of the task. The goal of this laboratory study was to determine which ergonomic intervention significantly reduced the biomechanical stress. The authors did not use a human subject as the patient; they chose a mannequin that weighed the same as 90th percentile male so that the subject was consistent between the two groups. The data was collected by a three-dimensional electromagnetic tracking system with surface EMG. The subject's anthropometrics, demographics, and perceived discomfort ratings were also recorded. Nine tasks were evaluated including transferring from bed to stretcher, transferring from bed to wheelchair, and pulling patient up to the head of the bed, which are summarized in Table 2.2. The authors use new technology that is not available on the market as of the writing of their study. One intervention used with the ceiling device, incorporates the sling into the bed linen or the patient's gown. The other technology involves a new type of bed that prevents the patient form sliding down in the bed.

Table 2.2 Summary Results of Nelson et al. (2003)

Task	Ergonomic Control(s)	Improved Results
Transferring from bed to stretcher	Use of transfer chairs (chairs that convert to a stretcher). Use of friction reducing device.	Subjective improved comfort Reduced pulling force (48%) Reduced erector spinae muscle activity (25%) Reduced shoulder muscle activity (33%)
Transferring from bed to chair	Ceiling mounted device*	Subjective improved comfort Reduced lumbar spine moment (54%) Reduced left shoulder muscle activity (69%) Reduced right shoulder muscle activity (45%)
Pulling patient up to the head of the bed	Tilted head of bed down by 10° Bent patient's knees Use of beds with shearless pivots preventing the patient from sliding down in the bed.^	Shoulder moment reduced an average of 40%. Applied forces reduced by 31%

*Utilized new technology therefore did not account for rolling the patient.
^Utilized new technology

2.3 Ergonomic Interventions in Patient Handling

The unique problem with patient handling is not overcoming heavy weight as in industry moving an inanimate object, which can be done with industrial hoists, cranes, forklifts, etc. A nursing aide has to move a heavy, living being of awkward size and shape considering their physical condition. The patient's physical condition may present with orthopedic, neurological, cognition, and/or deficits. Patients can also be contracted, confused, and/or combative resisting the healthcare worker further hindering and adding additional physical stress to the transfer. In addition, the consequences of dropping or mishandling a patient can be severe.

Clearly, a comprehensive ergonomic approach is required to reduce and eliminate the job demands, as this is the Occupational Safety and Health Administration's (OSHA) recommendation. Occupational Safety and Health Administration's (2003) Nursing Home Guidelines include references and recommendations to assist facilities in implementing ergonomic controls. The guideline can be applied to the hospital setting. This guideline was instituted as a result of the high injury rates nationally, the documented the lifting hazard of manual handling of patients in the literature, and the effective ergonomic controls that have proven successful.

Previous attempts in controlling patient handling injuries have focused injuries on body mechanics training only. Galinsky et al. (2001) reported in their article on home health care personnel ergonomic challenges, that body mechanics training alone is not been effective in reducing injury rates or severity in healthcare workers as a whole. They alleged that ergonomists are still unclear which lifting posture is the safest, although offer the following guidelines:

1. Getting close to the patient as possible
2. Maintaining spine in proper position
3. Bending knees
4. Keeping feet apart with one foot forward to limit the back from twisting
5. Use gentle rocking motion to make use of momentum
6. Push or pull patient rather than lift

They concluded, that good body mechanics reduces stresses on the back, however, if the job is intrinsically unsafe, no amount of training on 'safe lifting techniques' will make the job safe.

Generalizing that proper body mechanics will be an effective control in the health care setting is questionable. Patient Safety Center's (2001) Ergonomic Technical Advisory Group has written a comprehensive resource guide entitled Safe Patient Handling and Movement. The guide describes an ergonomic assessment in the health care setting, the use of patient handling algorithms based on the patient's functional assessment and size, and determining the appropriate patient handling equipment required, developing a "no lift" policy, implementing a lift team, and evaluating program effectiveness. The guide also dispels numerous common myths and provides facts about patient handling.

The Patient Safety Center reports one common myth that safety personnel have been teaching correct lifting mechanics for years, but questions whether the biomechanical research that has been performed mainly on men lifting boxes with handles in the vertical plane translates to the healthcare setting. In the nursing environment, most nurses are female, patients do not have handles, the mass of the load is asymmetrical, and most lifts are not performed in the vertical plane. The authors conclude that safe lifting technique is of limited value, as experts cannot agree which posture is the safest. The lifting, pushing, and pulling tasks performed by the nursing are widely variable and not isolated to postures assumed lifting a box from floor to waist level. Another common myth discussed is physically fit nurses have a decreased chance of being injured. The reviewed literature on nurse's back strength, cigarette smoking, obesity, and drug/alcohol consumption do not support this rationale for decreasing injury rates.

As stated in the Patient Handling Biomechanics section, Marras' 1999 and Ulin's 1997 study also revealed that a two-person lifting team does not reduce the risk of injury to safe levels with or without a gait belt. Both workers are subject to high spinal compressive forces when lifting dependent patients even when handling a relatively light patient. Therefore, team lifting is an ineffective ergonomic control.

Yassi et al. (2001) implemented a "no strenuous lift" program with mechanical patient handling equipment in a healthcare institution and revealed an interesting finding. After the first six months of the trial, the authors found a significant decline in the use of the mechanical devices and an increase in the frequency manual handling. The authors attributed this situation to the lack of ongoing training, changes in the patient characteristics, and/or change in workplace dynamics. This suggests that an ergonomic program that simply consists of providing employees with mechanical equipment without formalized, ongoing program may fail to reduce injury rates.

Research has revealed successful ergonomic interventions have incorporated a comprehensive program that includes: management and employee commitment;

formalized policies and procedures; standard operating procedures; a participatory, multidisciplinary team approach; various mechanical patient handling equipment; proactive surveillance of the program's effectiveness by monitoring employee's feedback and injury rates; and equipment maintenance. All of these factors have proven satisfactory results in improving employee comfort and morale, decreasing injury rates and workmen's compensation costs.

Hignett (2001) recommends some strategies in changing the hospital (nursing) culture by ensuring safe behaviors are accepted, and old habits of strenuous manual lifting are reduced or eliminated. The culture can be created by formal policies and procedures and/or by unwritten beliefs, ideals, peer influences, and adopted safe or unsafe practices. The model advocates an iterative "top down and bottom up" approach. Top down approach is analogous to "macroergonomics", where the overall process and company structure is reviewed to ensure it has a system capable of supporting an ergonomic program. The management must accept the ergonomic process into its organizational structure. This structure not only includes the written program on patient handling, but also includes ergonomic input on building design, purchasing, training, and risk management of work-related musculoskeletal injuries. Building and floor design are often overlooked in the facility's construction and is a vital aspect in ensuring the proper layout so adequate space is allotted to carry out necessary functions. Purchasing needs educating and advising in the procurement of furniture and mechanical equipment to ensure the acquired products incorporate efficient and practical ergonomic design.

The "bottom-up" approach is the "microergonomics" approach where the operational issues are evaluated at the worker level. The "bottom-up" approach is conducted at the nursing unit level, where the ergonomic training and proactive surveillance is performed. Again, ergonomic training is not the principal component, but is an important element. The training involves not only body mechanics and general awareness, but also a participatory problem-solving approach on the importance and rationale for safe patient handling. Key members for instituting, changing, and maintaining a supportive culture are the nursing unit, managers, staff, and safety department. The nurse managers and charge nurses are responsible for the daily enforcement of safe policies and procedures. The safety team is responsible for performing audits at defined intervals ensuring the program's effectiveness and compliance.

The Patient Safety Center's safe patient handling guide describes ergonomic assessment in the health care setting, the use the of patient handling algorithms based on the patient's functional assessment and determining the type appropriate patient handling equipment, developing a no lift policy, implementing a lift team, and evaluating program effectiveness. The authors of the guide report that a successful patient-handling program is not based on the technical aspects of providing mechanized equipment alone, but on the management's ability to motivated healthcare staff's participation in evaluating the patient, problem solve the situation, and use the appropriate piece of equipment according to the institution's policies and procedures.

CHAPTER 3

EXPERIMENTAL METHOD AND DATA COLLECTION

3.1 Participants

Six experienced physical therapists and physical therapist assistants (2 male assistants, 1 male therapist, and 3 female therapists) volunteered in this study. Table 3.1 lists the subject anthropometrics and demographics. They were screened for recent history of low back pain, other acute injuries, or conditions contraindicated. Informed consents were obtained from all of the participants. The mean patient handling experience of the participants was 6 years (range: 1 to 20 years). One able-bodied male hospital staff participated as "patient" in the experimental trials. He was a compliant person with normal balance, weighing 59 kg. The participant used as a patient was deliberately chosen to be lightweight, to reduce the risk of injury during the experimental trials. All participants volunteered for this project and were unpaid.

Table 3.1 Anthropometric and Demographic Data of Participants

Subject	Height (cm)	Weight (kg)	Experience (yrs)	Sex	Position
1	168	89	5	M	PTA
2	183	100	2	M	PT
3	155	51	1	F	PT
4	166	57	20	F	PT
5	183	81	1	M	PTA
6	147	56	6	F	PT
Average	167	72	6	-	-

Note: PT = Physical Therapist; PTA = Physical Therapy Assistant

3.2 Experimental Setup

The experiment was conducted at the physical therapy department of The General Hospital Center at Passaic, N.J. The experimental setup consisted of a typical adjustable height hospital bed (Hill-Rom mobilization table) and a standard hospital wheel chair (Figure 3.1 a & b). A Smith-Nephew nylon gait belt was worn the patient at the waist level. Two Warner Instrument's force gages (model FDK 60) were attached laterally to the gait belt to record the hand forces during the transfers. The force gages were tested with a known weight and proved accurate and reliable and no calibrating was necessary. The mechanical force gages recorded the maximum axial forces transferred through the gages. Gait belts are assistive devices used to place "handles" on the patient to improve the coupling and control during transfers. The gait belt secured to the patient's waist with the force gages measured the coupling force as the therapist performs the transfer.

(a) (b)

Figure 3.1 Experimental setup for patient transfer trials: (a) transfer from wheel chair, (b) transfer from adjustable height bed.

The posture of each therapist during the simulated patient transfer was recorded using a video camera (Sony, model # CCD-TR33). The video camera was positioned at a right angle to the participants with body markers applied to each therapist to facilitate determination of the joint angles. Approximately one-inch diameter reflective markers were attached to the appropriate joint locations of the patient handlers prior to the experimental trials (Figure 3.1a and b). The bony landmarks labeled were the:

- Acromion at the shoulder
- Lateral epicondyle at the elbow
- Styloid process at the wrist
- Greater trochanter at the hip
- Lateral condyle at the knee
- Lateral malleolus at the ankle

Only one camera was needed for this study, as the upper body posture was essentially symmetrical around the sagittal plane. The video recording was also used to determine the pull force angle from horizontal that was applied by the therapists during patient transfers.

3.3 Experimental Procedure

To simulate the assisted transfers, the participant posing as the patient was coached to simulate his assistance level requirement during the lifts at three approximate levels: minimal - corresponding to 25% of assistance level, moderate - corresponding to 50% assistance level and maximum - 75% of assistance level. Appendix A contains the standardized patient instructions used in the study. Each patient handler performed 18 lifts from the bed and 18 from the wheel chair. Six lifts at each level of exertion were performed for a total of eighteen from the bed and eighteen from the wheelchair. The experimental design is shown in Table 3.2. The sequence of the assistance levels was randomized in each session. Eighteen index cards designated with numbers - one, two and three corresponding to minimal, moderate, and maximal, respectively were shuffled to produce a random order of the transfers assigned. At the beginning of a lift, one randomly chosen card was flashed to the patient to produce the required assistance level for the handler. The cards were kept out of sight of the handler, to avoid his or her anticipation about the assistance level. The handlers were instructed verbally to transfer the patient from a sitting position to a standing position, using the handles attached to the force gages. To randomize the order of the trials, three of the therapists were randomly assigned to initiate the transfers from the bed and then to proceed to wheelchair and the remaining three vice versa.

Table 3.2 Design of Experiment for Patient Transfer Trials

Surface	Number of trials at the level of assistance			Total # of trials
	Minimal	Moderate	Maximal	
Bed	6	6	6	18
Wheelchair	6	6	6	18
			Grand Total	36

No instructions were provided to the handlers about the posture to be assumed, except to perform the trials in a comfortable posture typically assumed when working in the field. The written instructions given to the patient handlers on the experimental procedure prior to starting are provided in Appendix A. Before the starting the lifts from bed, each handler was asked to adjust the height of the bed, according to their preference. There was no provision of height adjustment for the wheelchair. The handlers were blinded to the readings of the gages. At the end of each transfer, the handler rated the assistance level on a scale of 1 to 10. At the end of the experimental trials, the anthropometric data of the subjects were noted, including gender, height, and weight. Workplace dimensions were recorded included height of bed and wheelchair. Rest intervals were provided between the transfers on as needed basis. Each experimental session took about two hours on an average for each handler.

CHAPTER 4

RESULTS AND ANALYSES

The first part of this chapter presents the results and analysis of patient transfers experiment for (1) left and right hand forces recorded during the experiment, (2) how closely the patient could mimic the desired level of assistance, and (3) how closely the handlers could perceive the assistance levels in relation to the actual hand forces. In the later part of the chapter the computation and analysis of the lower back biomechanical forces is discussed.

4.1 Hand Forces, Patient Simulation and Handler's Perception

Table 4.1 illustrates an example of raw data recorded from one of the patient handler during a transfer from bed. The complete set of raw data for all six handlers for both lifts from bed and from wheelchair can be found in the Appendix B. The first column of Table 4.1 is showing the assistance requested to the subject posing as patient, the second and third column contains the left and right force gage readings (in Newton) during the lift, and the fourth column contains the total forces. The last column contains the corresponding handler's perception in one to ten scale about the assistance level required by the patient.

Table 4.1 Sample Data for a Subject During Patient Transfer Trial from Bed

No.	Assistance level	Force gage readings		Total force	Per. exert.
		Left hand	Right hand		
1	3	134	143	276	6
2	2	105	116	221	5
3	3	147	134	281	7
4	1	107	98	205	3
5	1	103	111	214	2
6	3	147	160	308	8
7	2	134	152	285	6
8	2	127	152	279	7
9	2	123	140	263	6
10	3	160	156	316	9
11	1	89	94	183	2
12	3	156	167	323	7
13	1	111	105	216	3
14	3	143	156	299	8
15	1	107	109	216	4
16	2	107	100	207	5
17	1	98	98	196	1
18	2	94	85	178	4

4.1.1 Difference Between Left and Right Hand Forces

It has been previously stated in the experimental methods and data collection chapter that the patient lifting task was essentially in a symmetrical with respect to the body axis. As a result, it was expected that the hand forces developed by the two hands would exhibit similar magnitudes. An inspection of the difference between the left and right hand force data for all handlers showed that the difference was insignificant. The following matched paired *t*-test reached the same conclusion.

Test hypothesis H_0: $\mu_d = 0$
Alternate hypothesis H_1: $\mu_d \neq 0$
Test statistic $t = \dfrac{\bar{d}}{s_d / \sqrt{n}}$

Where, μ_d = mean of the difference between the left and right hand forces
$\bar{d}$ = average difference of left and right hand forces
s_d = standard deviation of the difference in left and right hand force, and
n = number of data points.

The results of the matched pair *t*-test are shown in the Table 4.2. The *p*-values of the tests for transfers from bed and from wheelchair conditions were 0.746 and 0.233, respectively. Thus at $\alpha = 0.05$ level, H_0 could not be rejected. This test concluded that the mean differences between the left and right hand forces were not significantly different from zero. Hence, in the subsequent data analysis, the two hand forces were added together and used as a measure of total forces required during patient transfers.

Table 4.2 Matched Pair *t*-Test Results for the Difference between Left and Right Hand Forces

Type of lift	Number of pairs of data points (n)	Average difference ($\bar{d}$)	Standard deviation of difference (s_d)	Test Statistic $t = \dfrac{\bar{d}}{s_d / \sqrt{n}}$	*p*-value for a two tailed test. *d.f.* = *n-1*
From bed	108	-0.47	14.940	-0.325	0.746
From wheelchair	108	1.93	16.709	1.199	0.233

4.1.2 Simulation of Assistance Level by the Patient

The summary statistics of the total hand forces generated at minimum, moderate and maximal assistance levels simulated by the participant patient are presented Table 4.3. An increasing trend is noticeable in the mean hand forces generated from minimal to moderate and from moderate to maximal level of assistance, both for the transfers from bed and from wheelchair. The standard deviations of the measurements were quite large in comparison to the means, hence the hand forces developed for each assistance level varied widely for the same level of assistance. The 95% confidence intervals (CI) of the means for different assistance levels indicated that the means were distinctly different between minimal and maximum levels. But the 95% CI's for the means for the moderate level transfers were overlapping with both minimal and maximal level CI's. This indicated that the mean hand force generated for the moderate assistance level was not distinctly different than either the minimal or maximal assistance levels. Thus from the experimental data, it could be concluded that, even though the participant posturing as patient increased the assistance requirements for minimal, moderate and maximal levels, on an average, but there was a considerable variation between each type of transfers and some of the mean hand forces were not significantly different.

Table 4.3 Summary Statistics of the Effects of Assistance Level on Hand Force Generated

Type of transfer	Assist. Level	n	Mean	SD	SE	95% CI
Bed	Minimal	36	168.9	45.75	7.63	153.4 to 184.4
	Moderate	36	190.9	52.43	8.74	173.2 to 208.7
	Maximal	36	227.6	59.29	9.88	207.5 to 247.6
Wheelchair	Minimal	36	207.5	50.31	8.38	190.5 to 224.5
	Moderate	36	223.3	56.29	9.38	204.2 to 242.3
	Maximal	36	262.6	56.03	9.34	243.6 to 281.5

4.1.3 Perceived Assistance Levels and Hand Forces

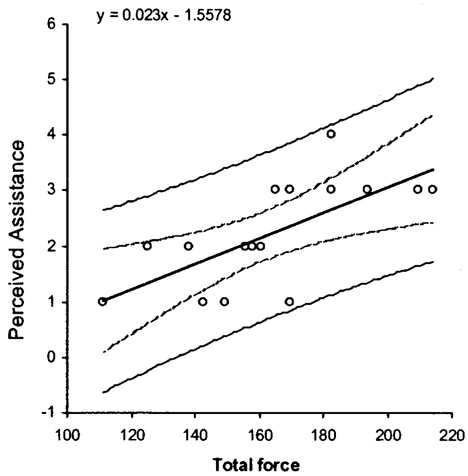
Linear regression analysis was performed 12 times from bed and from wheelchair separately, for each handler's perceived assistance levels. The hand force was used as the independent variable for the transfers. Analyse-it® (version 1.69) statistical software was used to perform the regression analyses. The details of the regression analysis are included in Appendix C. Figures 4.1 and 4.2 contain the plots of the individual perceived assistance scores (1-10) and hand forces (Newton), along with the regression line and 95% confidence intervals for transfers from the bed and transfers from the wheelchair, respectively.

All p-values for the regressions were less than 0.05 except for the case of the subject four, for the transfer from wheel chair. A p-value more than 0.05 indicated that no significant effect of hand force could be found on the perceived assistance score.

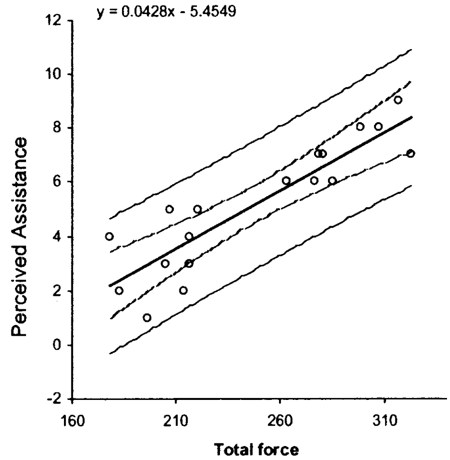
The hand forces, perceived assistance scores, and the respective R^2 values are summarized in Table 4.4. The average R^2 values of the regression relations were 0.62 and 0.34, for the transfers from bed and transfers from wheelchair, respectively. An average R^2 value more than 0.5 indicated that the perceived assistance level was a good indicator of hand force. Typically low average R^2 values for the transfers from the wheelchair indicated that their perceived assistance scores were not correlated well with the hand forces recorded during these transfers.

Table 4.4 Summary Statistics of Perceived Assistance Scores (1-10), Hand Forces and R^2

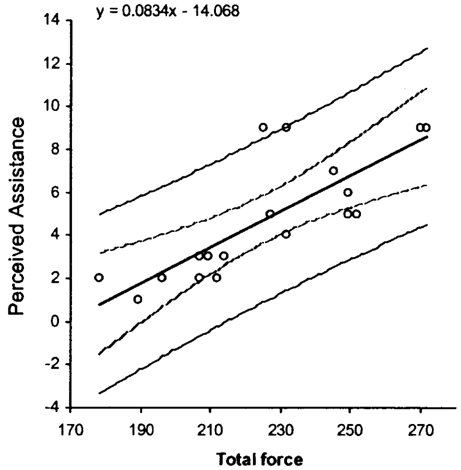
Subjects	Transfer from bed					Transfer from wheelchair				
	Forces (N)		Perceived Asst.		R^2	Forces (N)		Perceived Asst.		R^2
	Mean	SD	Mean	SD		Mean	SD	Mean	SD	
1 M	162	28	2.2	0.92	0.48	296	44	4.7	1.13	0.57
2 M	248	49	5.2	2.33	0.80	238	35	5.1	1.47	0.26
3 F	226	27	4.8	2.80	0.63	204	46	5.2	2.98	0.29
4 F	127	19	5.5	2.33	0.69	198	31	5.1	1.47	0.01
5 M	253	34	3.9	2.01	0.45	276	33	5.0	1.91	0.58
6 F	159	25	5.2	2.09	0.71	174	46	6.5	1.54	0.34
Avg	196	30	4.5	2.08	0.62	231	39	5.3	1.75	0.34



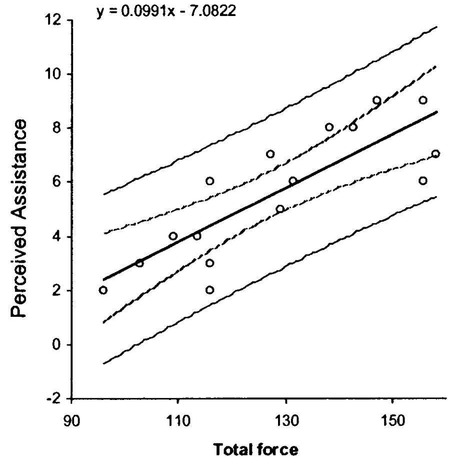
Subject 1



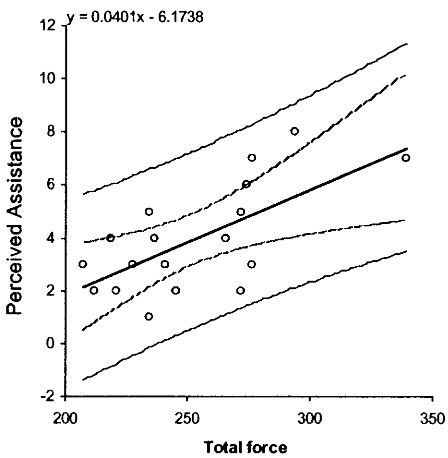
Subject 2



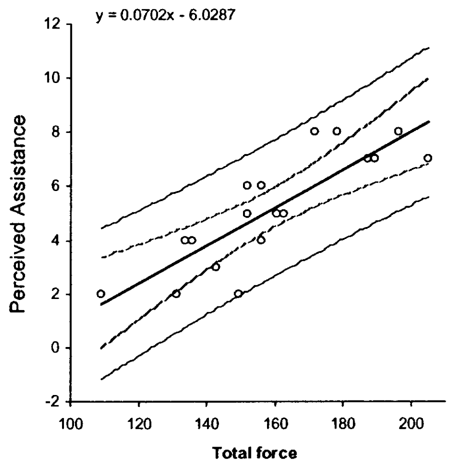
Subject 3



Subject 4



Subject 5



Subject 6

Figure 4.1 Effect of hand forces on the perceived assistance in 1-10 scale: Transfers from bed.

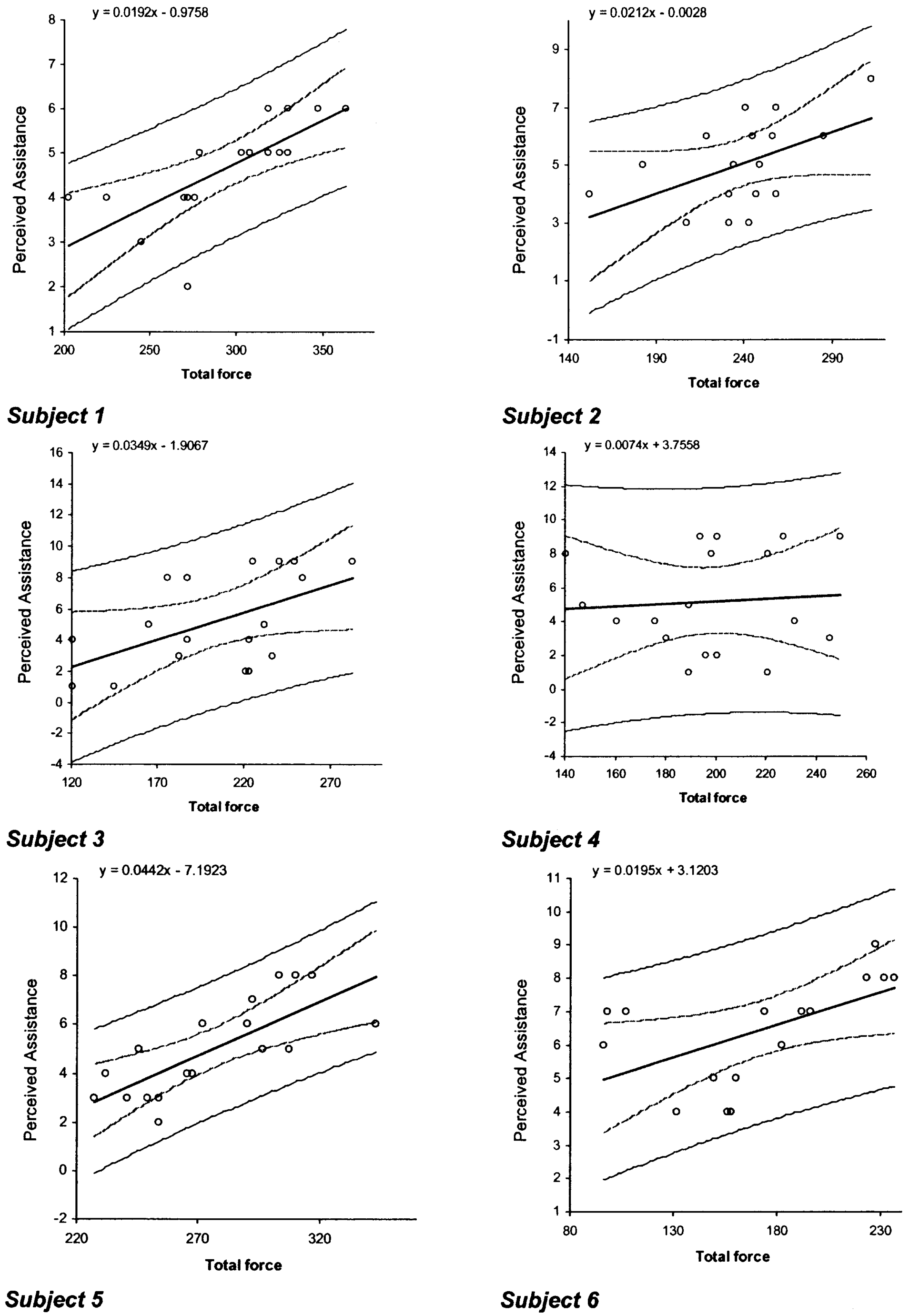


Figure 4.2 Effect of hand forces on the perceived assistance in 1-10 scale: Transfers from wheelchair.

A three-factor analysis of variance was performed using SAS statistical software package. The variation of hand forces was analyzed for three main factors – type of lift, subjects, and perceived assistance levels. The main purpose of this analysis was to determine whether the perceived levels of assistances were consistent with the hand force developed during the transfers among all the handlers. The ANOVA model consisted of the following three main factors. Type of lift factor had two levels – lift from bed and lift from wheelchair, subject factor had six levels, and perceived assistance had nine levels (none of the participant used level ten). The ANOVA output for the F-test is shown in Table 4.5. The details of the test can be found in Appendix D.

Table 4.5 F-Test on Hand Forces Developed During Patient Transfers

Source	*DF*	*Type I SS*	*Mean Square*	*F-Value*	*Pr>F*
Perceived Assistance	8	105571	13196	19.85	<.0001
Subject	5	363016	72603	109.24	<.0001
Type of lift	1	34089	34089	51.29	<.0001
Subject*Per__Asst._	35	129714	3706	5.58	<.0001
Type*Per__Asst._	8	29438	3680	5.54	<.0001
Type*Subject	5	28591	5718	8.6	<.0001
Type*Subject*Per__Asst	19	10744	565	0.85	0.6433

Analysis of the variance indicated that all the main effects were significant. The significant effect of perceived assistance pointed out that mean hand-forces were not the same for the different perceived assistance levels. The significant effect of subject factor indicated that mean forces exerted by the subjects were not same for all subjects. Similarly the significant 'type-of-lift' factor proved that the mean forces developed during transfers from bed and transfers from wheelchair were significantly different. The interaction factors were also significant except the triple interaction between type, subject and perceived assistance. Significant interactions established that the change in mean hand forces were not similar at the different combinations of subject's type of lift or perceived assistance levels.

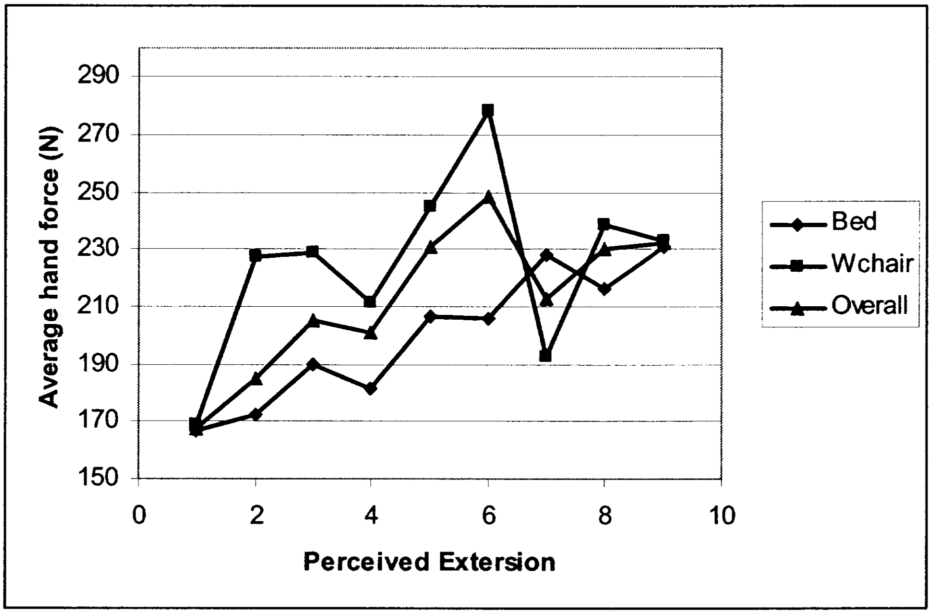


Figure 4.3 Average hand forces at different levels of perceived assistance.

Table 4.6 Average Hand Forces in Terms of Percent of Dependent Transfers

Perceived Assistance Levels	Hand forces (N) for transfers from			% of max 405 N
	Bed	Wheelchair	Overall	
1	167	169	168	41%
2	172	228	185	46%
3	190	229	205	51%
4	181	212	201	49%
5	206	245	231	57%
6	206	278	248	61%
7	228	193	213	52%
8	216	239	230	57%
9	231	233	232	57%

The average hand forces for all subjects at different levels of perceived assistance are shown in Figure 4.3 and presented in Table 4.6. The correlation coefficients between the perceived assistance levels and the average forces for transfers from bed, wheelchair and combined trials (overall) are presented in Table 4.7. Average hand forces generally showed an increasing trend with the level of assistance. The increase in the average hand forces was consistent for the transfer from beds with a correlation coefficient of 0.95 with the perceived levels of assistance. For the transfers from wheelchair this trend became erratic especially at the higher levels of exertion. The average hand forces were higher for the level five and six compared to that of levels seven, eight, and nine. Consequently a lower correlation coefficient (0.41) resulted for this set. When the averages were calculated based on all trials, the overall hand force data showed a correlation coefficient of 0.81. Wide variations of the average forces are noticeable for the transfers from wheel chair (Figure 4.3).

Table 4. 7 Correlation Coefficients Between Perceived Level of Assistance and Actual Hand Forces

		Perceived Level	*Hand forces*	
			Bed	*Wheelchair*
Perceived Level		1.00	0.95	0.41
Hand forces	Bed	0.95	1.00	0.34
	W.chair	0.41	0.34	1.00

For the combined transfer types, the average hand force values were compared to maximum average hand force of 405 Newton (See Table 4.6). This force value was recorded for 100% dependent transfer trials during the data collection. During these trials, the force gage readings were recorded while a strong male handler transferred the patient, without any assistance from the patient. The percent of maximum force varied from 41% to 57%, for variation in perceived level of assistance from 1 to 9.

To further investigate the relationship between the perceived assistance levels and the combined hand force for all trials, a Tukey's 95% joint confidence intervals on the contrasts of means were computed (details are included under SAS output in the Appendix D). The contrasts of the mean hand forces for the transfers at different level of perceptions are presented in Table 4.8. The first row and the first column contain the perceived assistance levels. Each cell of the contrast matrix contains the difference of the mean forces between the column level and row level. Significant difference in means at $\alpha=0.05$ is marked with an asterisk. An examination of the table revealed that not all levels were significantly different from each other. For example, the contrast of means between levels three and one was 37.1 N, which was statistically significant at $\alpha=5\%$. But the contrast of the mean forces between level seven and level four was 12.2 N, but it was not significant at $\alpha=5\%$. Generally, up to the level six the contrasts were significantly different and positive. However, after the level five, the contrasts became somewhat inconsistent. Some of the contrasts for level seven, eight and nine were negative. It means that the mean forces developed at perceived level seven, eight and nine were less than level six.

Table 4.8 Contrasts of Mean Hand Forces ($\mu_i - \mu_j$) at Different Perceived Assistance Levels

Perceived assistance level (i)	Perceived assistance levels (j)								
	1	2	3	4	5	6	7	8	9
1	0								
2	17.0	0.0							
3	37.1*	20.2	0.0						
4	33.0*	16.1	-4.1	0.0					
5	63.2*	46.3*	26.1*	30.2*	0.0				
6	80.6*	63.6*	43.5*	47.6*	17.3	0.0			
7	45.2*	28.3*	8.1	12.2	-18.0	-35.4*	0.0		
8	62.8*	45.9*	25.7*	29.8*	-0.4	-17.8	17.6	0.0	
9	64.7*	47.7*	27.5*	31.6*	1.4	-15.9	19.4	1.8	0.0

Note: An asterisk indicates statistically significant contrast of mean from Tukey's 95% joint confidence interval

4.1.4 Discussion

From the statistical insignificant difference between right and left hand force gages' readings, it was concluded that the experimental patient transfer tasks were essentially symmetrical in nature. Based on this result, the total hand force values were used in further analyses. An average hand force was used in computation of lower back compressive force during the patient transfer in the biomechanical model. The participant patient's ability to simulate the assistance levels was not included in the objectives of the study. Nevertheless, analyzing patient simulation data, it was found that, on an average, the patient simulated the assistance level requirements consistently, even though some of the mean forces required for the different levels of transfers were not significantly different from each other.

Majority of the patient handlers were quite consistent in grading the assistance levels for the transfers from the bed with an average R^2 value of 0.62. Similar high correlation coefficient of 0.95 was obtained when combined data for all handlers were used. For the transfers from wheelchair, the subjective grading levels showed poor consistency – an average R^2 value of 0.34 and correlation coefficient for the combined data of 0.41. One probable reason for such inconsistency might be due to the following reason. When transferring from the wheelchair, patient handlers had to bend the torso considerably more compared to the transfers from bed. The bed height adjusted by the patient handlers ranged from 22 to 28 inch from the floor, whereas the fixed height of the wheelchair was 18 inches. As repeated bending torso in itself is strenuous, this effect might have confounded the perception of the level of assistance that was needed for the patient during the experimental trials. Thus, if we disregard the transfers from wheelchair, then it can be concluded that the patient handlers are sufficiently consistent in grading the lifts according to the assistance requirement by the patient.

The assistance scales used to assess the rehabilitation level in healthcare are minimal, moderate and maximal assistance levels, which should approximately correspond to 25%, 50% and 75% of assistance requirement for a dependent lift. Measured hand forces did not correspond to these proportions. The handlers rated 41%-51% of the dependent transfer hand forces between levels one and three. Similarly, 49%-61% of maximum hand forces were rated between levels four and six. The average hand forces were between 52%-57% for the perceived levels of seven and nine.

Thus the experimental results find that even though the handlers can differentiate between patient's assistance levels, but the perceived assistance levels do not conform to the measured hand force levels. The minimal assistance transfers, such as those perceived at levels 1 to 3, should have been approximately 25%, but were underestimated significantly by the handlers resulting in 41%-51% of the dependent transfer hand force.

The moderate assistance transfers were closer to the desired 50% however; the maximal assistance transfers overestimated the actual hand force.

4.2 Biomechanical Analysis

This section analyzes the biomechanical forces at the lower back computed from the experimental handling of a non-dependent patient. The results are discussed and extrapolated for a larger patient since the experimental patient was relatively small. The risks of back injury associated with the extrapolated force are discussed.

4.2.1 Computation of Biomechanical Force

A large male and a small female therapist's posture were measured directly from the video using the subject's reflective landmarks and a goniometer. The goniometer is a tool designed to measure joint angles in degrees and was aligned with the depicted subject's reflective markers to derive their postures. These two subjects were chosen for this analysis to reflect the maximum and the minimum effect due to their differences in anthropometry and sex.

University of Michigan's 3D SSPP biomechanical software was selected for quantification of the back compressive force at the lower back. This software has been widely used in similar studies. The biomechanical model used in this software is well validated from the directly measured spine forces in live subjects. The software uses a three dimensional static biomechanical model, and does not take into account the dynamic forces, which arises due the accelerations and decelerations of the body segments masses during manual work. As the patient transfer tasks were inherently slow, it was anticipated that the component of the back compressive force from the dynamic loads will be minimal.

The therapist's joint angles along with their height and weight were inputted into the University of Michigan's 3D SSPP Biomechanical Software. The software computed the body segment masses, center of mass locations and segment link lengths from the predictive equations embedded in the software. The experimental right and left hand coupling forces were combined prior to input into the software, as this was a requirement of the software in two-dimensional mode. The two dimensional approach was justified from our previous study result, that the difference in the left and right hand forces were insignificant.

Additionally, the following assumption was made during the biomechanical analysis. The maximum trunk flexion was assumed to be synchronous with the peak force measured. This assumption was made because the limitations of the experimental procedure, as the force gages only measured the peak forces. Use of the mechanical force gages did not allow recording of the instantaneous forces during the transfer. However, this combination of maximum trunk flexion and peak force effectively provided the worst-case scenario. Both increase in torso flexion and hand force tend to increase the back compressive force.

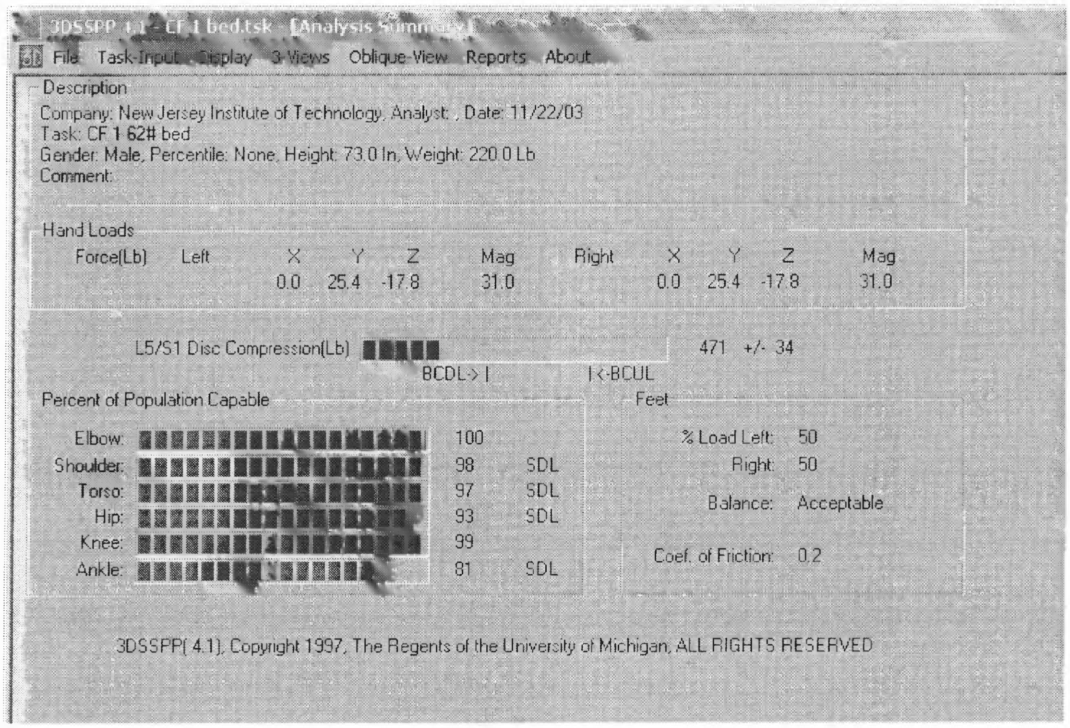


Figure 4.4 Example analysis report from the University of Michigan's 3-D SSPP biomechanical software.

Figure 4.4 illustrates a sample analysis report from the biomechanical software for subject number two. The analysis report not only provides the magnitude of the L5/S1 disc compression force, but also provides the estimates joint moments at elbow, shoulder, torso, hip, knee and ankle joints. These estimates are given in terms of percent of population that can safely withstand such moments at each of the joints. In general, most of the transfers performed in this study had a relatively high acceptance rate of the population capable, although these estimates were not reported systematically as this was beyond the scope of the experiment.

An exploratory analysis revealed that for none of the patient transfer trials, the back compressive forces exceeded the NIOSH cut off limit of 3400 N. Subsequently, the transfers with perceived assistance levels six or more were analyzed for the selected two subjects. The hand forces, joint angles, the angles of pull, and the spinal compression forces for 12 selected lifts are computed and summarized in Tables 4.9 and 4.10, for the two handler subjects. The body segment angles are the angle sustained by the axis of the segment with right horizontal, and counterclockwise being positive.

The angle of pull was determined from the video recording, which was the angle sustained by the axis of the force gage from the horizontal during the pull. The peak spinal compression forces for a large male and small female therapist were found to be 2100 N and 1732 N, respectively.

Table 4.9 Input Data and Resulting Spine Compressive Force at L5/S1 Level for a Large Male Handler

Transfer trial	Combined hand forces (N)	Measured joint angles (degrees)					Load pull angle (degrees)	Spine Compression force (N)
		Lower leg	Upper leg	Trunk	Upper arm	Forearm		
WC# 1	183	80	110	73	-72	-35	-35	1972
WC# 2	218	80	112	75	-88	-29	-42	1924
WC# 7	241	78	115	78	-90	-33	-35	1507
WC# 9	250	77	117	75	-85	-44	-44	1822
WC# 12	259	74	116	81	-83	-37	-40	1547
WC# 14	312	77	123	75	-88	-29	-40	2100
Average	**244**	**78**	**116**	**76**	**-84**	**-35**	**-39**	**1812**
BED# 1	276	78	122	72	-86	-27	-35	2098
BED# 3	281	81	115	78	-85	-32	-35	1665
BED# 6	308	80	120	75	-84	-32	-35	1902
BED# 10	317	83	118	75	-88	-30	-33	1797
BED# 12	323	85	118	75	-85	-29	-33	1886
BED# 14	299	85	115	80	-82	-30	-33	1610
Average	**301**	**82**	**118**	**76**	**-85**	**-30**	**-34**	**1826**

Note: wc = wheelchair

Table 4.10 Input Data and Resulting Spine Compressive Force (N) at L5/S1 Level for a Small Female Handler

Transfer trial	Combined hand forces (N)	Measured joint angles (degrees)					Load pull angle (degrees)	Spine Compression force (N)
		Lower leg	Upper leg	Trunk	Upper arm	Forearm		
WC# 8	241	85	142	77	-85	-10	-22	1211
WC# 13	232	85	135	79	-88	-22	-25	913
WC# 14	236	82	130	85	-86	-25	-26	684
WC# 15	254	82	135	85	-85	-25	-26	724
WC# 16	250	85	135	80	-80	-25	-26	1207
WC# 17	283	88	141	85	-85	-15	-18	748
Average	**249**	**85**	**136**	**82**	**-85**	**-20**	**-24**	**915**
BED# 3	245	84	135	80	-90	0	-40	1733
BED# 12	250	82	135	88	-90	0	-35	1289
BED# 14	270	86	140	80	-90	0	-35	1720
BED# 16	272	86	135	88	-90	0	-40	1626
BED# 17	250	86	135	88	-90	15	-35	1626
BED# 18	252	86	135	85	-90	5	-35	1516
Average	**257**	**85**	**136**	**85**	**-90**	**3**	**-37**	**1585**

Note: wc = wheelchair

4.2.2 Discussion of Results

In this laboratory study, the patient with low body weight (59 kg) was deliberately chosen to avoid the risk of back injury to the participant handlers. As a result, the compressive forces at the L5/S1 disc did not reveal any posture and associated patient-handling load as to be hazardous for development of occupational back pain. All of the spinal compression forces were below the NIOSH recommendation of 3400 N, which was expected from the study design.

The male handler had average spinal compression forces during the bed transfers at 1826 N and during the wheelchair transfers at 1812 N. The average force levels came out to be quite close for the two types of transfers. In contrast, the female therapist averaged 1585 N from the bed, but only 915 N from the wheelchair. The reason for this difference is that the pull force angle during the female wheelchair transfers was closer to the horizontal, therefore resulted in lower spinal compression forces. Also, the forearm angle during the bed transfers was more horizontal causing more of the vertical lift component, therefore causing more force transmitted to the lumbar spine. This increased vertical component was caused by the bed height probably being too high for the female therapist. The wheelchair transfer heights were lower and the female therapist used more of a pulling action to transfer the patient.

In patient transfers in the real world healthcare setting, the patients are not only always light and compliant; but also the handlers often do not use gait belts during this activity. Instead, the handlers often support and apply vertically upward force under arm to assist the patient to stand up. The angle of pull for the gait belt transfers averaged 30° for small female therapists and 36° for larger male therapists from the horizontal. Due to this inclined line of action, the force vector therefore was larger in the horizontal direction compared to that in the vertical downward direction. This resulted in the lower back compressive force to be small even though the hand coupling forces were significant. Had the forces been more vertical, the spinal compressive forces would have been greater. Without the use of the gait belt, the direction of the hand forces is more vertical. Completely vertical forces significantly increased the spinal compressive forces. This is usually the case when transferring patient without a gait belt in which the therapist grasped the patient from under the axillae.

In the experiment, force of the dependent lift was 70 percent of the patient's body weight (i.e., the patient's weight was 59 kg and the dependent lift force was 40.9 kgf.). Other biomechanical studies (Garg and Owens, 1992a; Ulin et al., 1997) assumed that the hand coupling forces were equal to the patient's body weight while performing a stand pivot transfer. This was overestimated, as the patient's whole body is not completely lifted. The patient's legs remain on the ground throughout the transfer; therefore the weight of the legs is not part of the overall force.

The moderate and maximal assist averaged in our experiment was between 50 and 60 percent, respectively of the dependent transfer. Therefore, the hand coupling force was calculated from taking 70 percent of the total patient weight and then multiplying by the 60 percent maximal assist or the 50 percent moderate assist factors. These hand forces were then inputted into the biomechanical software to calculate the spinal compressions. Table 4.11 summarizes the peak experimental and extrapolated spinal forces for the moderate and maximal transfers using a gait belt and without the use of a gait belt.

Table 4.11 Spine Compression Forces With and Without Gait Belt

Transfer type	Patient weight (Kg)	Spinal compression (Newtons)		
		Gait belt	No gait belt	Percent increase
Moderate Assist	59	1746	2900	40
Moderate Assist	76	1835	3265	44
Moderate Assist	103	1964	3773	48
Maximal Assist	59	1809	3154	43
Maximal Assist	76	1907	3555	46
Maximal Assist	103	2058	4143	50

The patient body weights 59, 75.5 and 103 kg corresponded to the actual, a 50th percentile and a 95th percentile body weight for adult American population, respectively (Eastman-Kodak, 1983). These spinal compression values were derived from a typical experimental posture adopted and using the large male therapist's (subject two) anthropometrics.

The intent of these calculations is to determine which type of transfer is safe and which is above the 3400 N recommended value. None of the transfers performed with a gait belt was over the recommended value. Moderate assist transfers performed without a gait belt with a 50th percentile bodyweight patient had a predictive spinal compressive force of 3265 N, which is close to the safe maximal value of 3400 N. For similar transfers performed with a 95th percentile bodyweight patient, the compressive forces increased to 3773 N. Maximal assist transfers performed with a 50th and a 95th percentile body weight patients had values of 3555 and 4143 N respectively.

It appears that moderate assist transfers with a 95th percentile body weight patient and maximal assist transfers with a 50th and 95 percentile body weight patient do pose a risk in healthcare workers when performed without a gait belt. The percent spinal compressive force increased with a range of 40 to 50% (see Table 4.11). Thus, the patient transfer using a gait belt appeared to make this patient handling activity comparatively safer in terms of spinal compressive force. Therefore, patient handlers should be encouraged to use gaits belts when transferring large patients who require significant assistance.

CHAPTER 5

CONCLUSIONS

The following conclusions were reached from the laboratory study on assisted patient transfers from bed and from wheelchair using six experienced handlers.

(1) For the patient handling tasks, the left and right hand forces were found out to be essentially identical. Based on this result, and the handlers' postures from the video recording, it was concluded the experimental patient-handling task was essentially a symmetrical and two-dimensional in nature.

(2) The subject posing as a patient effectively simulated the assisted transfers. The hand forces corresponding to minimal, moderate and maximal assist level transfers were 169, 191 and 228 N respectively, for the transfers from bed. The respective figures for the transfers from wheelchair were 208, 223 and 263 N. This experimental procedure, for the first time, simulated the assisted patient handling experimentally. In the past, all experimental studies treated patient handling for dependent transfers.

(3) The patient handlers were more consistent in rating the patient assistance requirement when the transfers were from bed with an average R^2 value of 0.62 and an overall correlation coefficient of 0.95. R^2 value and the correlation coefficient for transfers from wheelchair were 0.34 and 0.41, respectively. It is probable that the fixed lower height of the wheelchair (18 inches) and varying anthropometry of the handlers confounded the perceived assistance scores. The variation in rating could potentially cause conflict between the healthcare workers. One therapist may assess the patient's function and determine the patient is safe to be handled with a manual

technique, while another therapist may recommend the patient be handled with transfer equipment. If the assessment is not accurate, a therapist or other healthcare worker may attempt to handle the patient manually and sustain an injury. Thus, a standardized upright posture should be adopted during the transfers for grading the assistance levels.

(4) The therapists systematically under estimated minimal assisted lifts and overestimated maximal assisted lifts. The assistance levels one, five, and nine, which were the lowest, middle and highest levels in a scale of one through nine corresponded to 41%, 57% and 57% of dependent transfer force. In practice, minimal, moderate and maximum is thought to be corresponding to approximately 25%, 50% and 75% of the dependent assistance level. This subjective rating scale is designed to assess the patient's functional capacity and how much assistance they require to complete a particulate task. However, it seemed that the therapists tended to rate the patient's assistance level based on his or her own strength capabilities.

(5) In terms of spine compression forces, assisted patient transfers for a light compliant patient was found to be safe. The maximum L5/S1 force registered was 2100 N, which was below 3400 N recommended limit. The spine compression force for the larger male handler was in general higher than that of a small female handler.

(6) When a gait belt was used for the patient transfers, the spine compression force did not exceed the NIOSH limit for light, medium (50^{th} percentile) or heavy (95^{th} percentile) patients for all assistance levels. But when gait belt was not used, for a patient with even 50^{th} percentile body weight, the spine compression force of 3555 N was generated which exceeded the permissible safe limits. For a heavy, 95^{th}

percentile patient, the back compressive forces were 3773 and 4143 N for moderate and maximal assist patients, respectively.

5.1 Research Implications

This study results will help educating healthcare workers in seeking mechanical assistance for handling patients who require maximal assistance especially if the patient is not small. The experiment reinforces the basic premise of the mobility rating scale. The therapists should not base the patient's mobility based on their own strength capabilities but on the patient's functional ability to complete a task. The study emphasizes the use of gait belts and having the patient sitting on a surface at their waist level may help to reduce the forces on the lumbar spine and consequently make the handling safer.

Limitations of this experiment included that the patient was transferred only from sit to stand, where a complete pivot transfer might have generated torsional or shear forces on the spine. Additionally, the patient in this study was compliant, cooperative, and had normal balance. In the field, some patients can be agitated and resistive, which may add more spinal forces. Another risk factor, repetition, was not considered in this experiment, which adds to the overall physical stress endured by the healthcare worker. A healthcare worker may perform up to 20 high-risk patient handling movements per day.

5.2 Future Scope of Research

Future research is needed to verify the unreliability of the functional mobility scale. Larger scale study would determine the validity of this experiment's results. Also, the lumbar forces should be reassessed using more accurate equipment. Force plates, electronic force gages and surface EMGs would enable more precise acquisition of data and determining the stress on the lumbar spine by recording the postures and the forces synchronously. This will determine when the peak forces occurred during the transfer and the healthcare is at the greatest risk. Future studies could also evaluate the entire motion of transferring the patient from bed to chair to capture the lumbar torsional and shear forces.

The experiment design could assess the transfers with and without the use of a gait belt. The perceived assistance levels could then be compared to determine if the gait belt truly made the transfers easier.

APPENDIX A

INSTRUCTIONS TO PARTICIPATING PHYSICAL THERAPISTS AND PATIENT

The following instructions were given to the participating physical therapists, physical therapy assistance, and patient prior to the start of the experimental trial.

Instructions to physical therapists (or assistant):

1. Greet "patient"
2. "Patient" is a compliant patient with normal sitting balance
3. You will be asked to simulate 36 transfers on this "patient". The patient will seated on either a hospital bed or a wheelchair. 18 transfers will be performed from each surface.
4. You may adjust the level of the bed ad lib and ask the patient to scoot to the edge of the surface, but do not change the orientation of the wheelchair or bed.
5. Assume a comfortable posture and grasp the force gages in each hand, when ready to perform the transfer.
6. When instructed, you will transfer the patient from sit to stand. Be sure to use smooth movement and do not jerk the force gages (to decrease false readings due to momentum).
7. Upon completion of that transfer, please hand the force gages to the researcher and be sure not to look at the readings. You will also rate the perceived transfer assistance level on a 1 to 10 scale.
8. Rest time will about 2 minutes between each level if needed, and then process will be repeated. If more rest time is needed, please inform the researcher.
9. Do not give any feedback to the patient, except if the transfer or any other procedure causes you discomfort. If discomfort is noted, please stop and inform the researcher.

Instructions to "patient":

1. You will be fitted with a gait belt around your waist.

2. You will be seated on the surface assigned Each therapist will be performing 36 simulated transfers on you. 18 from a hospital bed and 18 from a wheelchair. You will have approximately 2 minutes between each lift.

3. While sitting, you will be instructed by the researcher to simulate minimal, moderate, or maximal assistance. Also, keep arms at your sides and do not grasp the therapist.
4. Sit compliantly with normal balance.

5. Do not give any feedback to the therapist, except if the transfer or any other procedure causes you discomfort. If discomfort is noted the please inform the researcher.

APPENDIX B

RAW DATA TABLES

The following tables contain the raw data for each therapist. This data was taken from the patient handling worksheet and directly inputted into the spreadsheets. Forces, originally recorded in pounds, were converted to Newtons.

Table B.1 Raw Data for Subject One

No.	Transfer	Force gage readings for bed			Per. Asst.	Diff. L-R	Transfer	Force gage readings for wheelchair			Per. Asst.	Diff. L-R
		L	R	Total force				L	R	Total Force		
1	3	98	71	170	1	27	2	152	120	272	4	31
2	2	89	54	143	1	35	1	111	91	203	4	20
3	1	94	56	150	1	38	3	170	150	319	6	20
4	1	89	67	156	2	22	3	187	160	348	6	27
5	1	67	58	125	2	9	1	174	152	326	5	22
6	1	71	67	138	2	5	2	165	143	308	5	22
7	3	76	107	183	3	-31	1	123	103	225	4	20
8	1	76	62	138	2	14	3	187	160	348	6	27
9	3	98	71	170	3	27	1	134	111	245	3	22
10	2	74	85	158	2	-11	3	158	145	303	5	13
11	3	96	118	214	3	-22	2	178	152	330	5	26
12	3	76	118	194	3	-42	1	150	120	270	4	29
13	2	89	71	160	2	18	2	143	136	279	5	7
14	2	80	62	143	1	18	2	129	147	276	4	-18
15	1	62	49	111	1	13	3	170	160	330	6	9
16	3	125	85	210	3	40	3	194	170	364	6	25
17	2	105	78	183	4	27	2	170	150	319	5	20
18	2	94	71	165	3	22	1	138	134	272	2	5

Table B.2 Raw Data for Subject Two

No.	Transfer	Force gage readings for bed			Per. Asst.	Diff. L-R	Transfer	Force gage readings for wheelchair			Per. Asst.	Diff. L-R
		L	R	Total force				L	R	Total Force		
1	3	134	143	276	6	-9	3	80	103	183	5	-22
2	2	105	116	221	5	-11	3	107	111	218	6	-5
3	3	147	134	281	7	14	2	74	78	152	4	-5
4	1	107	98	205	3	9	2	114	120	234	5	-7
5	1	103	111	214	2	-9	2	105	103	208	3	2
6	3	147	160	308	8	-13	2	118	129	247	4	-11
7	2	134	152	285	6	-18	3	111	129	240	7	-18
8	2	127	152	279	7	-25	1	120	111	232	3	9
9	2	123	140	263	6	-18	2	134	116	250	5	18
10	3	160	156	316	9	5	1	118	114	232	4	5
11	1	89	94	183	2	-5	2	123	134	256	6	-11
12	3	156	167	323	7	-11	1	147	111	259	7	36
13	1	111	105	216	3	6	1	123	136	259	4	-13
14	3	143	156	299	8	-13	3	120	125	245	6	-5
15	1	107	109	216	4	-2	3	165	147	312	8	18
16	2	107	100	207	5	6	1	120	114	234	5	7
17	1	98	98	196	1	0	1	109	134	243	3	-25
18	2	94	85	178	4	9	3	134	152	285	6	-18

Table B.3 Raw Data for Subject Three

No.	Transfer	Force gage readings for bed			Per. Asst.	Diff. L-R	Transfer	Force gage readings for wheelchair			Per. Asst.	Diff. L-R
		L	R	Total force				L	R	Total Force		
1	2	105	91	196	2	14	2	76	69	145	1	7
2	2	107	100	207	2	6	1	71	49	120	1	22
3	3	125	120	245	7	5	2	89	31	120	4	58
4	1	103	87	190	1	16	2	94	82	176	8	11
5	1	111	103	214	3	9	2	89	76	165	5	13
6	1	107	100	207	3	6	3	107	80	187	8	26
7	1	94	85	178	2	9	3	125	100	225	9	25
8	1	116	96	212	2	20	3	134	107	240	9	27
9	2	120	111	232	4	9	1	98	89	187	4	9
10	2	120	111	232	9	9	1	103	80	183	3	22
11	2	116	111	227	5	5	1	123	100	223	4	22
12	2	123	127	250	5	-5	1	123	98	221	2	25
13	3	105	120	225	9	-15	2	125	107	232	5	18
14	3	129	140	270	9	-11	2	125	111	236	3	14
15	1	107	103	210	3	4	3	138	116	254	8	22
16	3	127	145	272	9	-18	3	134	116	250	9	18
17	3	120	129	250	6	-9	3	147	136	283	9	11
18	3	118	134	252	5	-15	1	118	105	223	2	13

Table B.4 Raw Data for Subject Four

No.	Transfer	Force gage readings for bed			Per. Asst.	Diff. L-R	Transfer	Force gage readings for wheelchair			Per. Asst.	Diff. L-R
		L	R	Total force				L	R	Total Force		
1	1	54	56	110	4	-2	3	98	123	221	1	-25
2	3	67	89	156	6	-22	1	96	94	190	1	2
3	2	54	76	130	5	-22	1	82	94	176	4	-11
4	3	91	67	158	7	25	1	67	74	140	8	-7
5	2	80	58	139	8	22	1	71	76	147	5	-5
6	1	49	54	103	3	-5	3	103	118	221	8	-15
7	3	85	58	143	8	26	2	94	107	200	9	-13
8	1	49	82	131	6	-33	2	89	105	194	9	-16
9	2	49	67	116	6	-18	3	100	131	232	4	-31
10	3	69	87	156	9	-18	1	94	87	180	3	7
11	2	51	62	114	4	-11	1	78	82	160	4	-4
12	1	49	47	96	2	2	2	89	107	196	2	-18
13	3	54	74	127	7	-20	2	82	107	189	5	-25
14	2	56	60	116	3	-4	3	111	134	245	3	-22
15	2	62	65	127	7	-2	2	87	111	198	8	-25
16	3	67	80	147	9	-14	3	103	125	228	9	-22
17	1	54	62	116	2	-9	3	125	125	250	9	0
18	1	45	58	103	3	-14	2	94	107	200	2	-13

Table B.5 Raw Data for Subject Five

No.	Transfer	Force gage readings for bed			Per. Asst.	Diff. L-R	Transfer	Force gage readings for wheelchair			Per. Asst.	Diff. L-R
		L	R	Total force				L	R	Total Force		
1	3	134	143	276	7	-9	3	143	174	317	8	-31
2	1	105	103	208	3	2	3	170	174	344	6	-5
3	2	114	120	234	5	-7	2	145	152	297	5	-7
4	2	111	107	218	4	5	1	114	118	232	4	-5
5	3	138	156	294	8	-18	2	120	125	245	5	-5
6	1	114	107	220	2	7	2	131	140	272	6	-9
7	1	107	105	212	2	2	1	123	131	254	3	-9
8	3	129	145	274	6	-16	3	152	158	310	8	-6
9	1	116	111	227	3	5	3	152	152	304	8	0
10	2	118	118	236	4	0	3	156	152	308	5	4
11	2	123	118	241	3	5	2	145	145	290	6	0
12	3	134	131	265	4	2	2	129	136	265	4	-7
13	1	125	120	245	2	5	1	125	129	254	2	-4
14	1	120	114	234	1	7	1	120	120	241	3	0
15	3	134	138	272	5	-5	3	150	143	292	7	7
16	2	134	138	272	2	-5	2	134	134	267	4	0
17	2	138	138	276	3	0	1	111	116	227	3	-5
18	3	160	178	339	7	-18	1	125	125	250	3	0

Table B.6 Raw Data for Subject Six

No.	Transfer	Force gage readings for bed			Per. Asst.	Diff. L-R	Transfer	Force gage readings for wheelchair			Per. Asst.	Diff. L-R
		L	R	Total force				L	R	Total Force		
1	3	89	98	187	7	-9	3	49	47	96	6	2
2	2	76	80	156	6	-5	1	54	54	107	7	0
3	1	62	71	134	4	-9	2	49	49	98	7	0
4	1	76	80	156	4	-5	3	116	111	227	9	5
5	2	71	71	143	3	0	1	65	67	131	4	-2
6	3	98	107	205	7	-9	2	89	103	192	7	-14
7	1	76	74	150	2	2	3	116	116	232	8	0
8	1	67	65	131	2	2	3	105	118	223	8	-13
9	1	67	69	136	4	-2	3	118	118	236	8	0
10	3	91	98	190	7	-7	1	71	78	150	5	-7
11	2	80	82	163	5	-2	2	80	94	174	7	-13
12	3	82	89	171	8	-7	1	74	82	156	4	-9
13	3	89	89	178	8	0	1	76	82	158	4	-6
14	2	76	76	152	6	0	3	107	125	232	8	-18
15	3	98	98	196	8	0	1	74	87	160	5	-13
16	2	80	80	161	5	0	2	85	98	183	6	-14
17	1	54	56	110	2	-2	2	85	89	174	7	-5
18	2	74	78	152	5	-5	2	94	103	196	7	-9

APPENDIX C

REGRESSION ANALYSIS OUTPUT

This section contains outputs from Analyse-it (version 1.69) software for the regression analyses for total force versus perceived exertion scores. The regression was performed for six subjects separately for transfers from bed and transfers from wheelchair. The tables give the sum of squares and the F scores. The graphs describe the distribution and the normality of the data.

Perceived Assistance vs. Total force

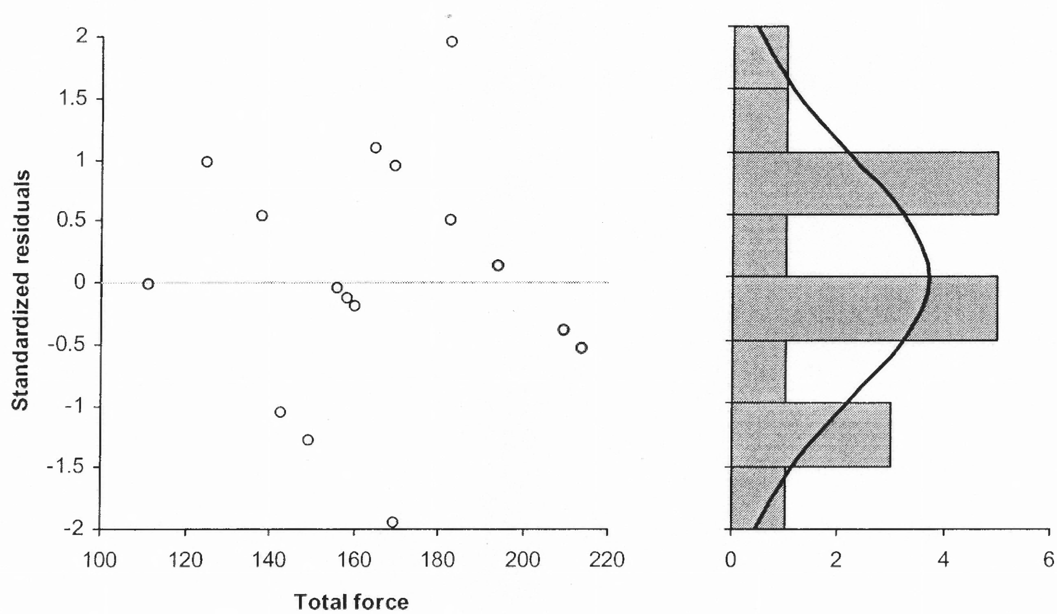
Subject 1 (Bed)

n	18

R^2	0.48
Adjusted R^2	0.44
SE	0.6890

Term	Coefficient	SE	p	95% CI of Coefficient	
Intercept	-1.5578	0.9901	0.1352	-3.6568	to 0.5411
Slope	0.0230	0.0060	0.0015	0.0102	to 0.0359

Source of variation	SSq	DF	MSq	F	p
Due to regression	6.904	1	6.904	14.54	0.0015
About regression	7.596	16	0.475		
Total	14.500	17			



Perceived Assistance vs. Total force

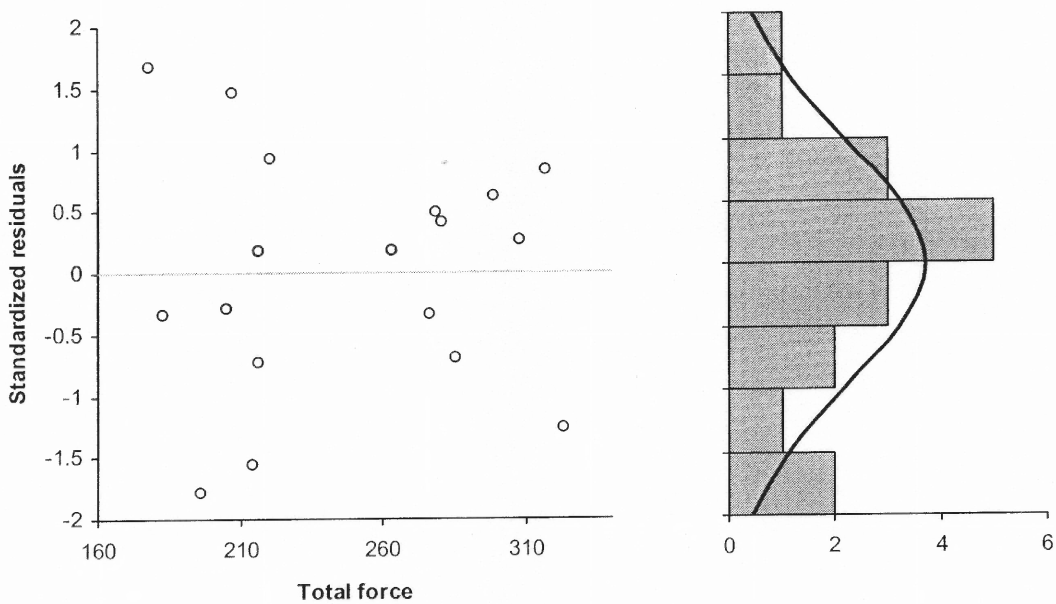
Subject 2 (Bed)

n	18

R^2	0.80
Adjusted R^2	0.78
SE	1.0883

Term	Coefficient	SE	p	95% CI of Coefficient	
Intercept	-5.4549	1.3720	0.0011	-8.3634	to -2.5464
Slope	0.0428	0.0054	<0.0001	0.0313	to 0.0543

Source of variation	SSq	DF	MSq	F	p
Due to regression	73.551	1	73.551	62.11	<0.0001
About regression	18.949	16	1.184		
Total	92.500	17			



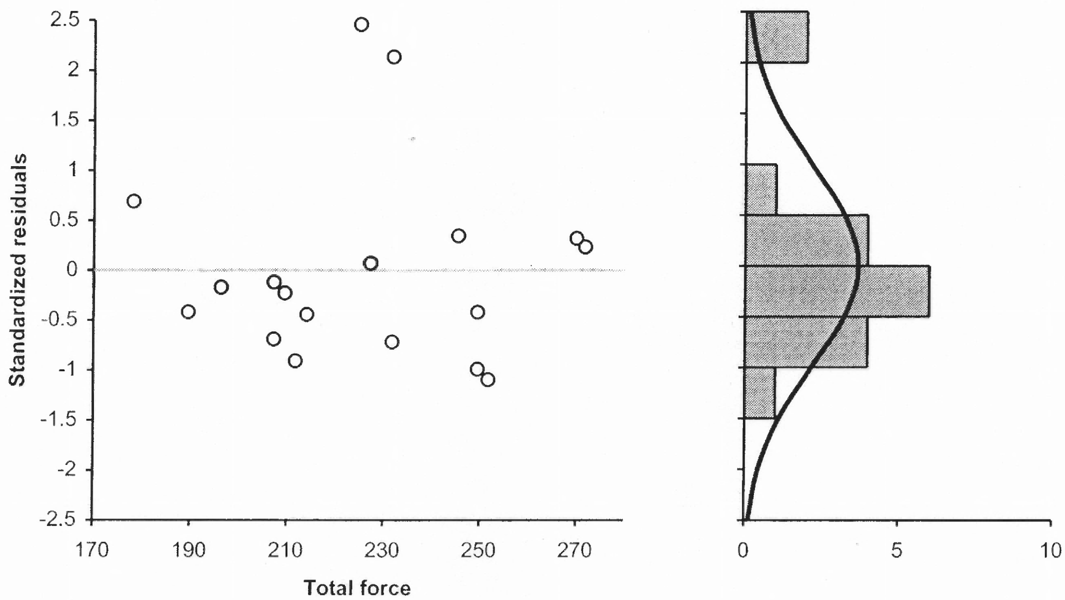
Perceived Assistance vs. Total force

Subject 3 (Bed)

n	18
R^2	0.63
Adjusted R^2	0.61
SE	1.7536

Term	Coefficient	SE	p	95% CI of Coefficient
Intercept	-14.0679	3.6313	0.0013	-21.7658to -6.3699
Slope	0.0834	0.0160	<0.0001	0.0495to 0.1172

Source of variation	SSq	DF	MSq	F	p
Due to regression	83.910	1	83.910	27.29	<0.0001
About regression	49.201	16	3.075		
Total	133.111	17			



Perceived Assistance vs. Total force

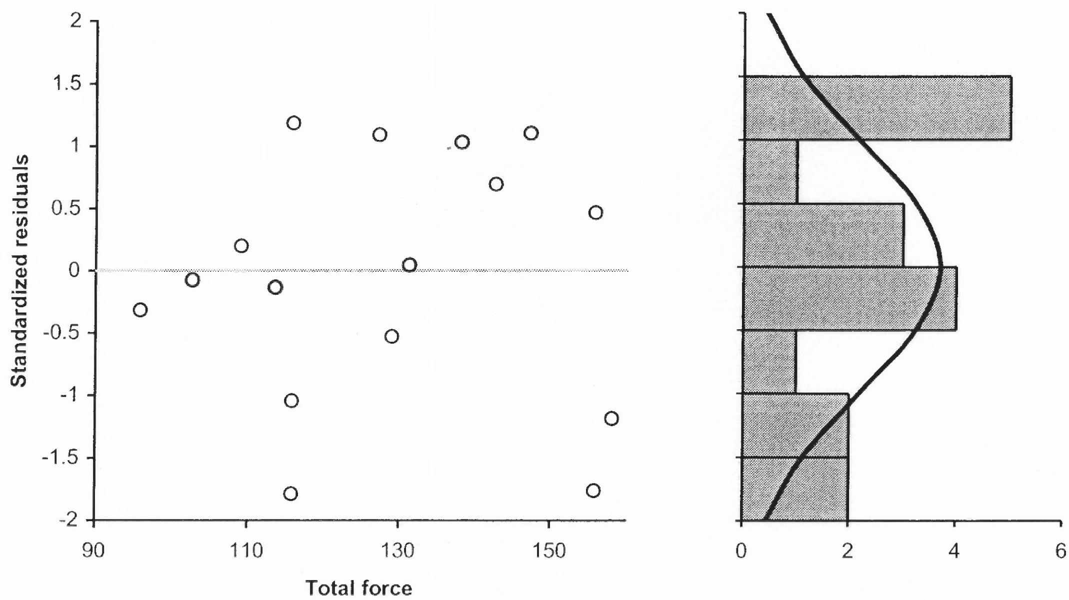
Subject 4 (Bed)

n	18

R^2	0.69
Adjusted R^2	0.67
SE	1.3463

Term	Coefficient	SE	p	95% CI of Coefficient
Intercept	-7.0822	2.1492	0.0046	-11.6383 to -2.5261
Slope	0.0991	0.0167	<0.0001	0.0636 to 0.1346

Source of variation	SSq	DF	MSq	F	p
Due to regression	63.502	1	63.502	35.04	<0.0001
About regression	28.998	16	1.812		
Total	92.500	17			



Perceived Assistance vs. Total force

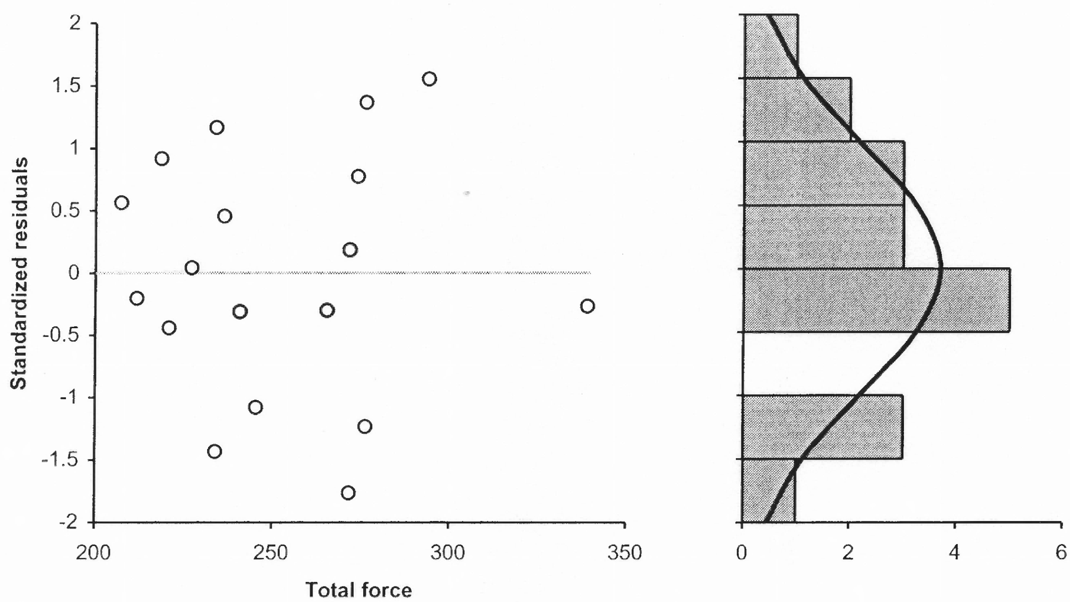
Subject 5 (Bed)

n	18

R^2	0.45
Adjusted R^2	0.42
SE	1.5387

Term	Coefficient	SE	p	95% CI of Coefficient
Intercept	-6.1738	2.8170	0.0436	-12.1456to -0.2019
Slope	0.0401	0.0111	0.0023	0.0166to 0.0635

Source of variation	SSq	DF	MSq	F	p
Due to regression	31.061	1	31.061	13.12	0.0023
About regression	37.884	16	2.368		
Total	68.944	17			



Perceived Assistance vs. Total force

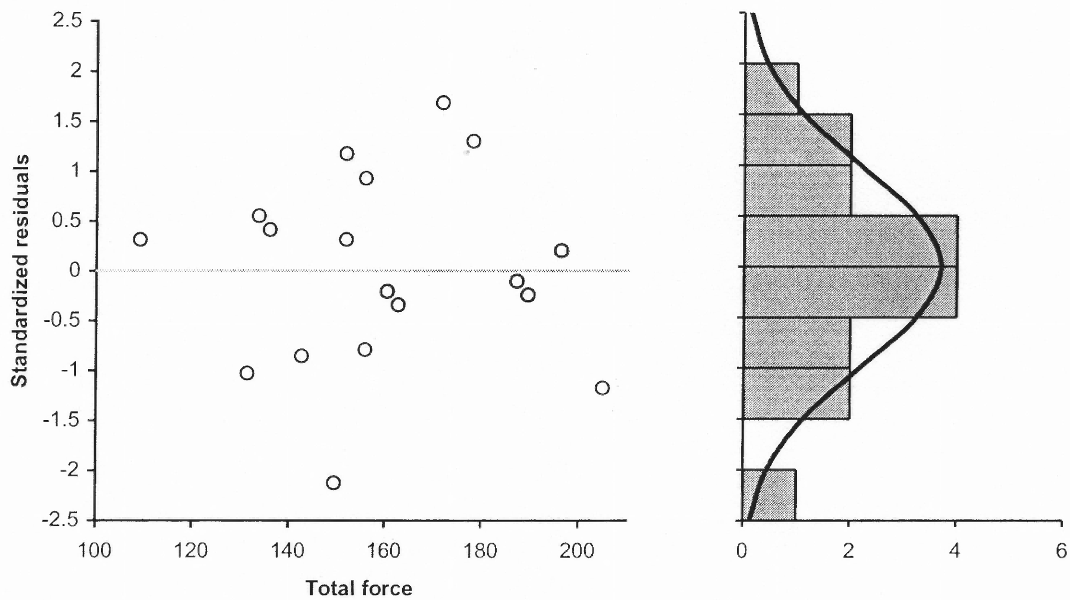
Subject 6 (Bed)

n	18

R^2	0.71
Adjusted R^2	0.69
SE	1.1653

Term	Coefficient	SE	p	95% CI of Coefficient
Intercept	-6.0287	1.8167	0.0043	-9.8800 to -2.1775
Slope	0.0702	0.0113	<0.0001	0.0464 to 0.0941

Source of variation	SSq	DF	MSq	F	p
Due to regression	52.774	1	52.774	38.86	<0.0001
About regression	21.726	16	1.358		
Total	74.500	17			



Perceived Assistance vs. Total force

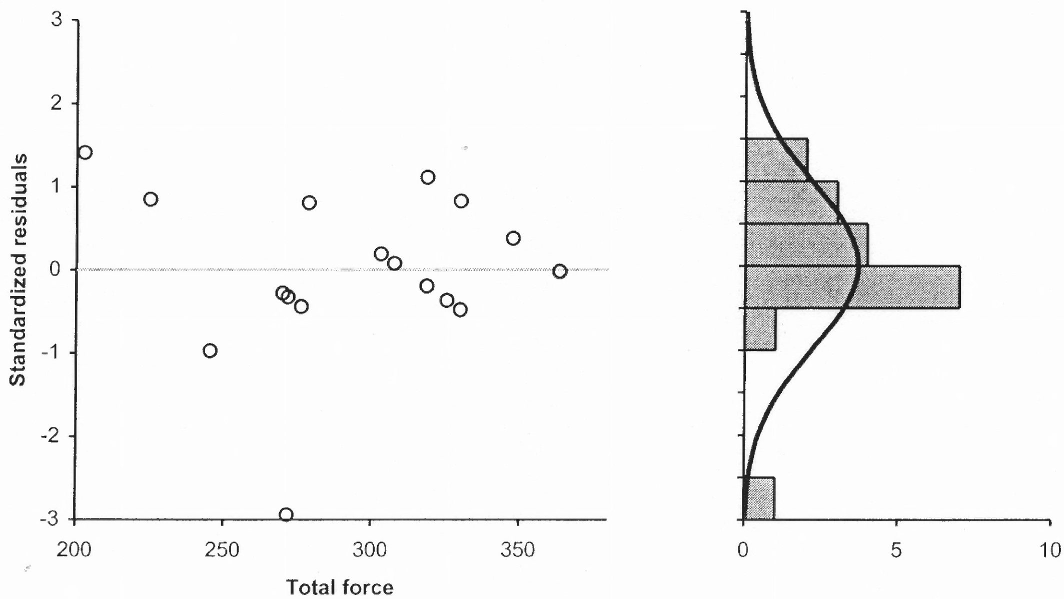
Subject 1 (Wheelchair)

n	18

R^2	0.57
Adjusted R^2	0.54
SE	0.7648

Term	Coefficient	SE	p	95% CI of Coefficient
Intercept	-0.9758	1.2579	0.4492	-3.6426 to 1.6909
Slope	0.0192	0.0042	0.0003	0.0103 to 0.0281

Source of variation	SSq	DF	MSq	F	p
Due to regression	12.253	1	12.253	20.95	0.0003
About regression	9.359	16	0.585		
Total	21.611	17			



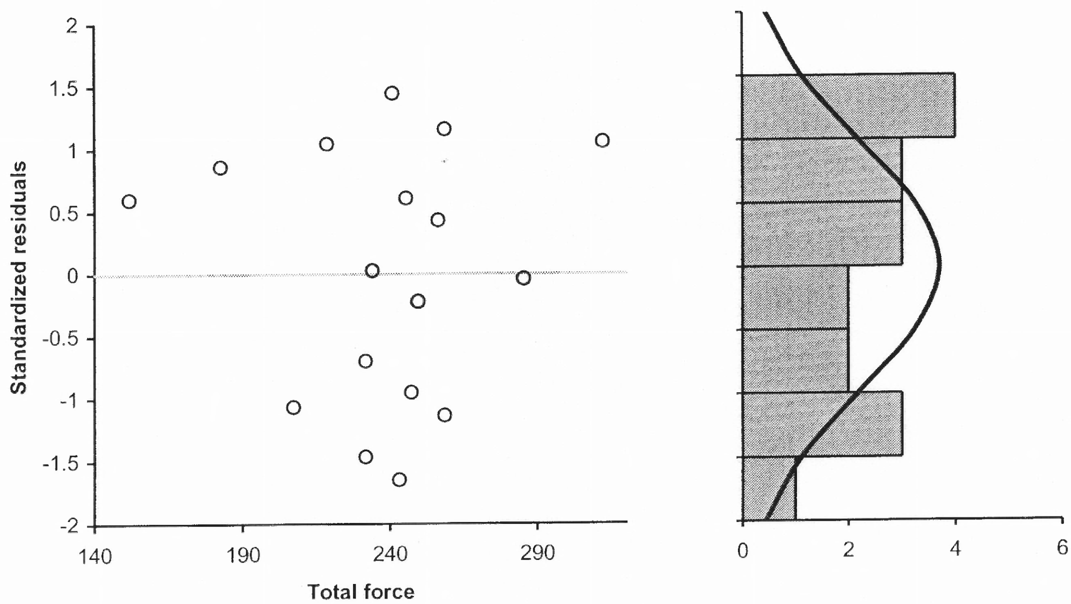
Perceived Assistance vs. Total force

Subject 2 (Wheelchair)

n	18
R^2	0.26
Adjusted R^2	0.21
SE	1.3088

Term	Coefficient	SE	p	95% CI of Coefficient
Intercept	-0.0028	2.1657	0.9990	-4.5939to 4.5883
Slope	0.0212	0.0090	0.0313	0.0022to 0.0403

Source of variation	SSq	DF	MSq	F	p
Due to regression	9.538	1	9.538	5.57	0.0313
About regression	27.407	16	1.713		
Total	36.944	17			



Perceived Assistance vs. Total force

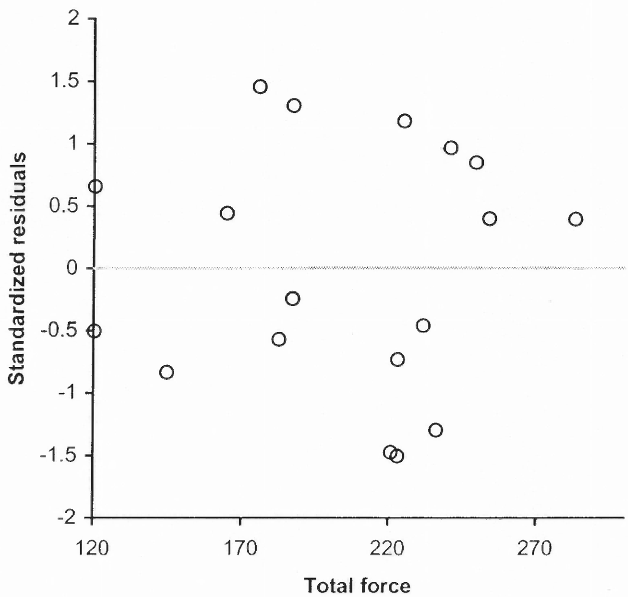
Subject 3 (Wheelchair)

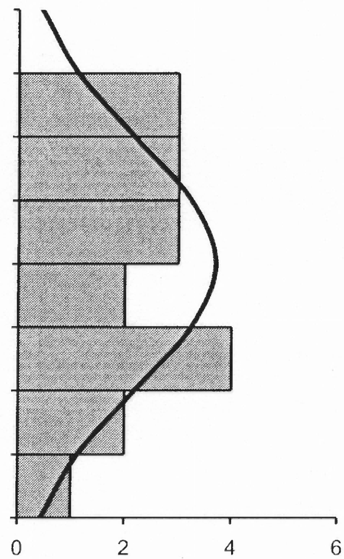
n	18

R^2	0.29
Adjusted R^2	0.25
SE	2.5840

Term	Coefficient	SE	p	95% CI of Coefficient
Intercept	-1.9067	2.8346	0.5108	-7.9158 to 4.1024
Slope	0.0349	0.0136	0.0203	0.0062 to 0.0637

Source of variation	SSq	DF	MSq	F	p
Due to regression	44.277	1	44.277	6.63	0.0203
About regression	106.834	16	6.677		
Total	151.111	17			





Perceived Assistance vs. Total force

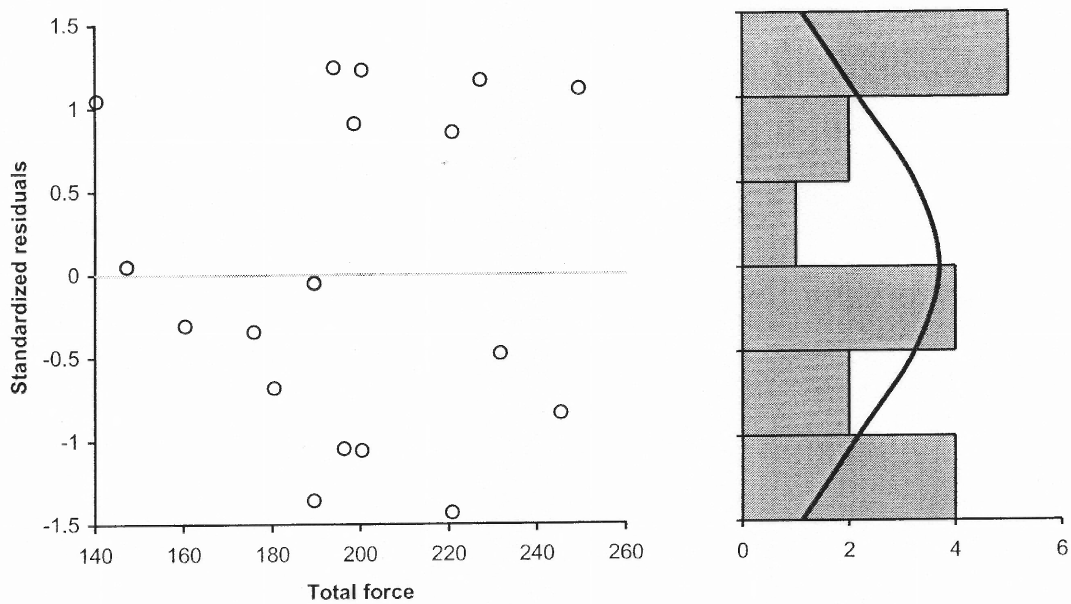
Subject 4 (Wheelchair)

n	18

R^2	0.01
Adjusted R^2	-0.06
SE	3.0641

Term	Coefficient	SE	p	95% CI of Coefficient
Intercept	3.7558	4.8254	0.4477	-6.4736 to 13.9851
Slope	0.0074	0.0241	0.7625	-0.0436 to 0.0584

Source of variation	SSq	DF	MSq	F	p
Due to regression	0.887	1	0.887	0.09	0.7625
About regression	150.224	16	9.389		
Total	151.111	17			



Perceived Assistance vs. Total force

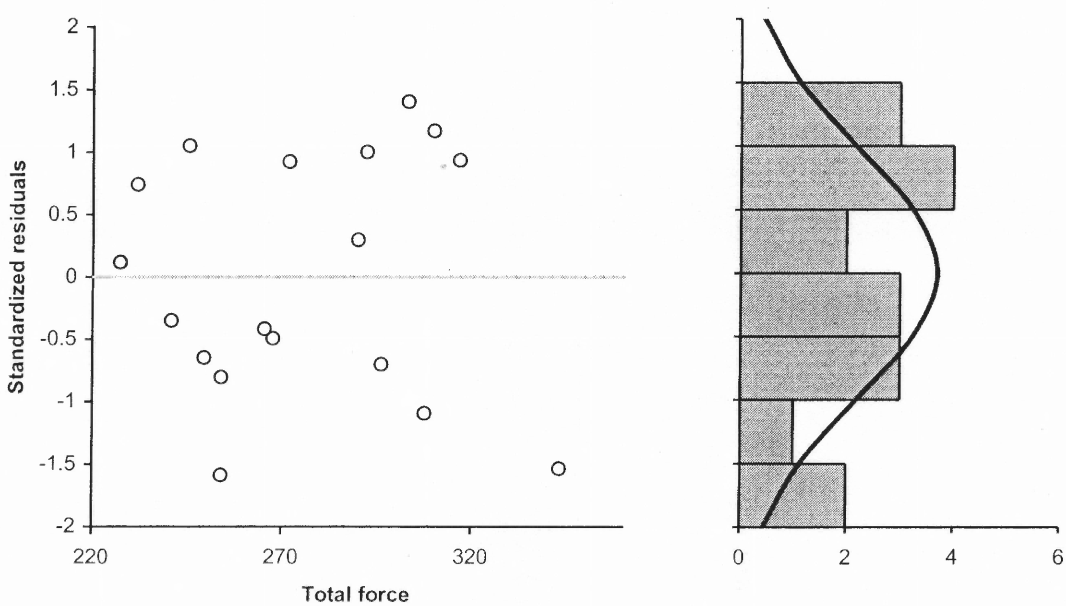
Subject 5 (Wheelchair)

n	18

R^2	0.58
Adjusted R^2	0.55
SE	1.2815

Term	Coefficient	SE	p	95% CI of Coefficient
Intercept	-7.1923	2.6316	0.0147	-12.7710 to -1.6137
Slope	0.0442	0.0095	0.0003	0.0241 to 0.0643

Source of variation	SSq	DF	MSq	F	p
Due to regression	35.724	1	35.724	21.75	0.0003
About regression	26.276	16	1.642		
Total	62.000	17			



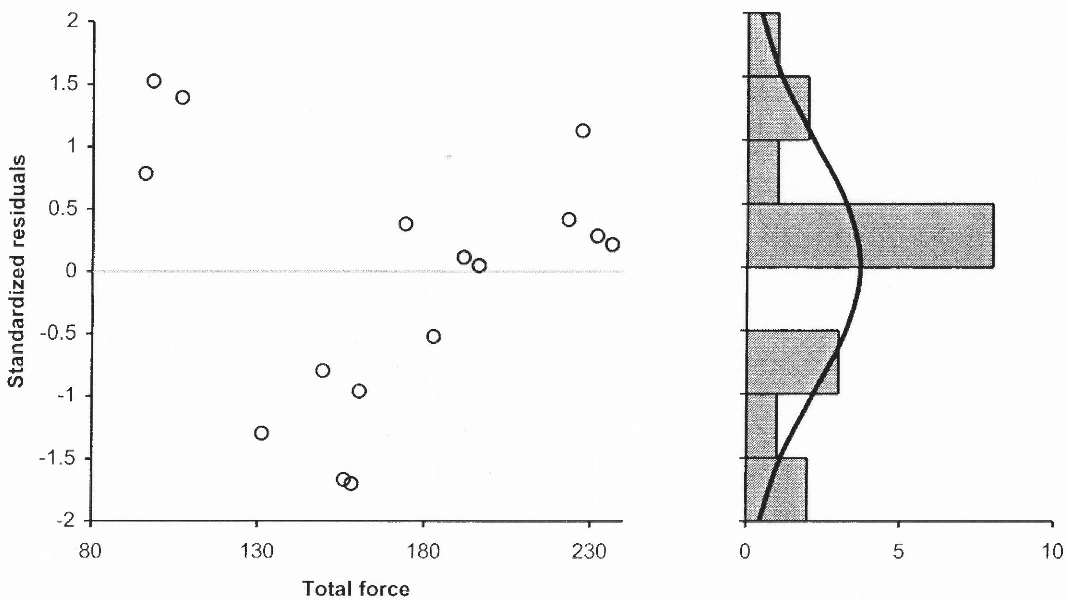
Perceived Assistance vs. Total force

Subject 6 (Wheelchair)

n	18
R^2	0.34
Adjusted R^2	0.30
SE	1.2934

Term	Coefficient	SE	p	95% CI of Coefficient
Intercept	3.1203	1.2183	0.0209	0.5376 to 5.7030
Slope	0.0195	0.0068	0.0112	0.0051 to 0.0339

Source of variation	SSq	DF	MSq	F	p
Due to regression	13.734	1	13.734	8.21	0.0112
About regression	26.766	16	1.673		
Total	40.500	17			



APPENDIX D

ANALYSIS OF VARIANCE (ANOVA) OUTPUT BY SAS STATISTICAL SOFTWARE

This section contains the details of the ANOVA on the experimental data. The printout shows the design of experiment, F-values of each factor and Tukey's 95% joint confidence intervals of the contrast of mean forces at different perceived level of assistance.

The GLM Procedure

Class Level Information		
Class	Levels	Values
Type	2	1 2
Subject	6	1 2 3 4 5 6
Per__Exert_	9	1 2 3 4 5 6 7 8 9

Number of observations	216

The GLM Procedure

Dependent Variable: Force Force

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	81	701163.4552	8656.3390	13.02	<.0001
Error	134	89063.0131	664.6494		
Corrected Total	215	790226.4683			

R-Square	Coeff Var	Root MSE	Force Mean
0.887294	12.07700	25.78079	213.4701

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Per__Assistance_	8	105571.2598	13196.4075	19.85	<.0001
Subject	5	363016.3469	72603.2694	109.24	<.0001
Type	1	34089.1131	34089.1131	51.29	<.0001
Subject*Per__Asst_	35	129714.2786	3706.1222	5.58	<.0001
Type*Per__Asst_	8	29437.7642	3679.7205	5.54	<.0001

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Type*Subject	5	28590.7153	5718.1431	8.60	<.0001
Type*Subject*Per__Asst	19	10743.9772	565.4725	0.85	0.6433

The GLM Procedure

Tukey's Studentized Range (HSD) Test for Force

This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Alpha	0.05
Error Degrees of Freedom	134
Error Mean Square	664.6494
Critical Value of Studentized Range	4.08904
Minimum Significant Difference	17.57

Means with the same letter are not significantly different.

Tukey Grouping		Mean	N	Subject
	A	264.255	36	5
	B	243.258	36	2
	B			
C	B	229.066	36	1
C				
C		215.051	36	3

Means with the same letter are not significantly different.				
Tukey Grouping		Mean	N	Subject
	D	166.566	36	6
	D			
	D	162.626	36	4

The GLM Procedure

Tukey's Studentized Range (HSD) Test for Force

This test controls the Type I experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	134
Error Mean Square	664.6494
Critical Value of Studentized Range	4.45923

Comparisons significant at the 0.05 level are indicated by ***.				
Per__Asst_ Comparison	Difference Between Means	Simultaneous 95% Confidence Limits		
6 - 9	15.938	-10.299	42.174	
6 - 5	17.345	-4.918	39.607	
6 - 8	17.763	-6.231	41.757	
6 - 7	35.360	11.070	59.650	***
6 - 3	43.459	21.356	65.561	***
6 - 4	47.550	25.742	69.358	***

Comparisons significant at the 0.05 level are indicated by ***.				
Per__Asst_ Comparison	Difference Between Means	Simultaneous 95% Confidence Limits		
6 - 2	63.626	40.820	86.431	***
6 - 1	80.587	51.847	109.328	***
9 - 6	-15.938	-42.174	10.299	
9 - 5	1.407	-23.758	26.572	
9 - 8	1.826	-24.883	28.535	
9 - 7	19.422	-7.553	46.398	
9 - 3	27.521	2.498	52.545	***
9 - 4	31.612	6.848	56.377	***
9 - 2	47.688	22.042	73.335	***
9 - 1	64.650	33.606	95.693	***
5 - 6	-17.345	-39.607	4.918	
5 - 9	-1.407	-26.572	23.758	
5 - 8	0.419	-22.399	23.236	
5 - 7	18.015	-5.114	41.144	
5 - 3	26.114	5.295	46.933	***
5 - 4	30.205	9.699	50.712	***
5 - 2	46.281	24.717	67.845	***
5 - 1	63.242	35.476	91.008	***
8 - 6	-17.763	-41.757	6.231	
8 - 9	-1.826	-28.535	24.883	

Comparisons significant at the 0.05 level are indicated by ***.				
Per__Asst_ Comparison	Difference Between Means	Simultaneous 95% Confidence Limits		
8 - 5	-0.419	-23.236	22.399	
8 - 7	17.596	-7.204	42.397	
8 - 3	25.695	3.034	48.357	***
8 - 4	29.787	7.412	52.161	***
8 - 2	45.862	22.515	69.210	***
8 - 1	62.824	33.651	91.997	***
7 - 6	-35.360	-59.650	-11.070	***
7 - 9	-19.422	-46.398	7.553	
7 - 5	-18.015	-41.144	5.114	
7 - 8	-17.596	-42.397	7.204	
7 - 3	8.099	-14.876	31.074	
7 - 4	12.190	-10.502	34.882	
7 - 2	28.266	4.614	51.918	***
7 - 1	45.227	15.810	74.644	***
3 - 6	-43.459	-65.561	-21.356	***
3 - 9	-27.521	-52.545	-2.498	***
3 - 5	-26.114	-46.933	-5.295	***
3 - 8	-25.695	-48.357	-3.034	***
3 - 7	-8.099	-31.074	14.876	
3 - 4	4.091	-16.241	24.424	

Comparisons significant at the 0.05 level are indicated by ***.				
Per__Asst_ Comparison	Difference Between Means	Simultaneous 95% Confidence Limits		
3 - 2	20.167	-1.232	41.566	
3 - 1	37.129	9.491	64.766	***
4 - 6	-47.550	-69.358	-25.742	***
4 - 9	-31.612	-56.377	-6.848	***
4 - 5	-30.205	-50.712	-9.699	***
4 - 8	-29.787	-52.161	-7.412	***
4 - 7	-12.190	-34.882	10.502	
4 - 3	-4.091	-24.424	16.241	
4 - 2	16.076	-5.019	37.171	
4 - 1	33.037	5.634	60.440	***
2 - 6	-63.626	-86.431	-40.820	***
2 - 9	-47.688	-73.335	-22.042	***
2 - 5	-46.281	-67.845	-24.717	***
2 - 8	-45.862	-69.210	-22.515	***
2 - 7	-28.266	-51.918	-4.614	***
2 - 3	-20.167	-41.566	1.232	
2 - 4	-16.076	-37.171	5.019	
2 - 1	16.961	-11.242	45.165	
1 - 6	-80.587	-109.328	-51.847	***
1 - 9	-64.650	-95.693	-33.606	***

Comparisons significant at the 0.05 level are indicated by ***.				
Per__Asst_ Comparison	Difference Between Means	Simultaneous 95% Confidence Limits		
1 - 5	-63.242	-91.008	-35.476	***
1 - 8	-62.824	-91.997	-33.651	***
1 - 7	-45.227	-74.644	-15.810	***
1 - 3	-37.129	-64.766	-9.491	***
1 - 4	-33.037	-60.440	-5.634	***
1 - 2	-16.961	-45.165	11.242	

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