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Learning curve analysis of a patient lift-assist device

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Abstract

One of the challenges facing ergonomists in the implementation of an ergonomic solution is addressing the concerns related to their impact on productivity. The focus of the current study was to (1) apply standard learning curve analysis to the learning that takes place as an individual works with a patient handling device and (2) compare the effects of two different training protocols on measures of learning. Eighteen subjects completed 11 replications of a patient transfer task after participating in either an "interactive" training protocol or "see-one-do-one" training protocol. The results show that the learning rate for this task was 83% with no difference as a function of training protocol. The results do indicate that the effect of Training Method was significant ($p<0.05$) for time to complete the first patient lift task (370 s for the interactive training vs. 475 s for see-one-do-one training). The results of the analysis of the survey data supported the objective results in that the only measure that was responsive to training type ($p<0.05$) was related to comfort level in performing the patient lift task for the first time. The results emphasize the importance in considering learning when introducing an intervention in the workplace, and showed that in this instance, training type had an immediate impact on productivity, but that this effect diminished over time.

Keywords: Intervention; Learning; Musculoskeletal

1. Introduction

Engineering controls are generally recognized as the most effective method to reduce or eliminate exposure to risk factors for the development of occupational musculoskeletal disorders. Unfortunately, engineering controls sometimes require a change in the methods employed by the worker to accomplish his/her work task, which can create deleterious effects in the short-term productivity of the worker. If this worker is paid on a production (i.e. piece-rate) system of compensation, this drop in productivity can lead to an immediately negative view of the intervention; and if the worker has control over such decisions, the intervention is often discarded. Management can likewise reject a potentially effective solution because of short-term negative impacts on productivity. This is unfortunate because while there may be a short-term negative impact on productivity, ergonomic solutions can often lead to long-term gains in productivity to go along with the improved safety that they bring to the job. These longer-term improvements in productivity can come from more efficient work methods that can lead to reduced levels of fatigue, higher-quality work output, and better worker morale. An important key to reaching these longer-term gains is to overcome this initial resistance from workers and management.

Engineering controls designed to reduce the risk associated with patient handling in the health-care industry are a particularly interesting case study in that they have been shown to be effective at reducing musculoskeletal loading (e.g. Garg and Owen, 1994; Zhuang et al., 1999; Keir and MacDonell, 2004; Santaguida et al., 2005) and incidence and severity of musculoskeletal injuries of nursing personnel (e.g. Evanoff et al., 2003; Trinkoff et al., 2003; Garg and Owen, 1992) but are often not utilized because of the increased task completion time (e.g. Takala and Kukkonen, 1987; Daynard et al., 2001). The OSHA publication entitled "Guidelines for Nursing Homes: Ergonomics for the Prevention of Musculoskeletal Disorders" is a resource to gain a perspective on the array of devices that have been developed to aid in the

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performance of patient handling tasks (OSHA, 2002) and two review articles nicely summarize the state of the literature (Hignett, 2003; Bos et al., 2006). In a study of the biomechanical effects of these devices, Zhuang et al. (1999) conducted a study that considered the effects of such devices on exposure to activities that were stressful to the low back in a group of nine nursing assistants. In this study they considered both basket sling and overhead lift devices and found that, as compared to the standard manual methods, the use of these devices reduced the number of stressful activities performed by the nursing assistants by two-thirds. These objective measures have been supported by studies that have considered the users perceptions of the overall safety of the patient handling task as well as the reduced compensation costs (Engst et al., 2005; Miller et al., 2006).

There have been a number of epidemiologic studies that have assessed the effectiveness of these devices. Garg and Owen (1992) conducted a prospective epidemiological study (140 beds and 57 nursing assistants) of an intervention that included hoists, walking belts and shower chairs. These authors found that the incidence rate for back injury prior to interventions was 83 per 200,000 work-hours and dropped to 47 per 200,000 work-hours after the intervention. They further note that the number of lost or restricted days was reduced from 634 to 317 per 200,000 work-hours over that same period. The results of a study of the effectiveness of mechanical lifts in acute care hospitals (31 units) and long-term care facilities (5 units) by Evanoff et al. (2003) show similar effects. In this study, the investigators examined measures of incidence and severity of musculoskeletal injuries pre- and post-intervention of mechanical lift-assist devices. The results of the combined analysis (i.e. acute care and long-term care combined) showed a reduction in the lost workday injury rate (injuries per 100 Full Time Equivalents (FTE)) from 3.04 pre-intervention to 1.71 post-intervention and the lost workday rate went from 37.1 days to 15.4 days per 100 FTE.

While there is ample evidence of the positive effects of these mechanical lift-assist devices, one common concern is the additional time required for their use (''additional'' in comparison with the one or two-person manual lift). The additional time can come from the time it takes to obtain and prepare the device for use, as well as the additional time to perform the lifting task itself. Device type (e.g. ceiling mounted vs. floor rolling) can have a significant impact on the ''obtain and prepare'' time. Several studies have indicated that users prefer the ceiling mounted systems because of the challenges posed with regard to maneuverability of the floor rolling systems in tight spaces. This preference does not come without additional costs, as this often requires the retrofitting of hospital rooms (not always possible e.g. Ronald et al. (2002)) to allow for the overheads track to be installed. Interesting cost–benefit analyses of the ceiling lift intervention can be found in Spiegel et al. (2002) and Chhokar et al. (2005).

In addition to this ''obtain and prepare'' time is the additional time that comes from the actual process of lifting the patient. This includes the time to properly place the patient in the sling and the additional time to properly move the patient to, and position the patient in, the destination. In a study of nurses on seven geriatric wards in five hospitals, Takala and Kukkonen (1987) found that the total extra time needed for the use of mechanical hoist systems was between 1.5 and 2 min per patient. When these data are extrapolated over a typical 8-h workday (8–15 patients per day), they estimate that the additional time amount to between 3% and 6% of the work shift. In summary, the literature indicates that lift-assist devices are effective at reducing biomechanical loading and injury rates, but may not be utilized because of an increase in the time to complete a patient transfer task.

While the extra time that ergonomic interventions initially add to a task can be easily documented, what is often overlooked is the gradual reduction in task completion time as the operator learns to integrate the solution into their standard work procedure. Learning in the context of completing a work task is defined as ''improvement [in productivity] with a constant product design and constant tools and equipment'' (Konz & Johnson, 2000, p. 524). Learning curve theory predicts decreased task time as the number of task replications increase, and has been shown to be applicable in many settings. In order to calculate the rate at which a worker is learning to complete a task, the following standard equation is used:

$$Y_X = KX^N \quad (1)$$

where Y_X is the production time for Xth unit; K the time required to produce first unit; X the total units produced; and N is an exponent leading to

$$2^N = \text{learning rate.} \quad (2)$$

Learning can also be separated into two categories, cognitive learning and motor learning. Purely cognitive learning tasks have been shown to have a learning constant (learning rate) of ~0.70, while the learning constant for purely motor learning tasks is ~0.90 (Dar-El et al., 1995). It is important to note that most tasks involve both cognitive and motor learning. There are documented learning rates for numerous manufacturing tasks. For example, the machining and fitting of small castings has a learning rate of 0.74, the assembly of a radio tube has a learning rate of 0.83, and operating the punch press has a learning rate of 0.89 (Konz & Johnson, 2000, p. 533). Because one of the most frequent objections to the use of mechanical lift-assist equipment is added task time, it is imperative to understand and document the learning that occurs with this task so that predictions of future productivity levels can be considered in the intervention process.

The objectives of this study were (1) to illustrate the effectiveness of standard learning curve analysis in the characterization of the changes in productivity that take place as an individual works with an ergonomic intervention and (2) to compare two different types of training protocols in terms of their effect on characteristics of the learning process.

2. Methods

2.1. Subjects

Eighteen subjects were recruited to participate in this study. The group had equal numbers of male and female subjects (average age 27 years (standard deviation 6 years) and average stature 173.9 cm (standard deviation 7.9 cm). All participants signed the university-approved Informed Consent Form prior to participation. Exclusion criteria included current or chronic back pain, experience using mechanical patient lifting assist devices, and nursing experience.

2.2. Apparatus

The task performed in the study involved moving a "patient" (a healthy 75 kg student volunteer) from a hospital bed to a wheelchair by using a mechanical lifting assist device. The experimental environment was set up to simulate a room within a hospital (standard sized hospital bed, standard wheelchair, limited maneuvering space (Fig. 1)). The height of the working surface of the hospital bed was 30 in. The mechanical lifting assist device used was the Arjo brand "Opera" model (Arjo, Inc, Roselle, IL) (Fig. 2).

Both objective and subjective data were collected in this experiment. The principal objective data were measures of productivity (i.e. time to complete the task) and these were collected using a stopwatch that recorded accurately to the 0.01 s.

Survey data were also collected. The subjects were asked to respond on a 1–5 scale to the following questions. An answer of 5 corresponded to "excellent" or "absolutely", and an answer of 1 corresponded to "poor" or "absolutely not".

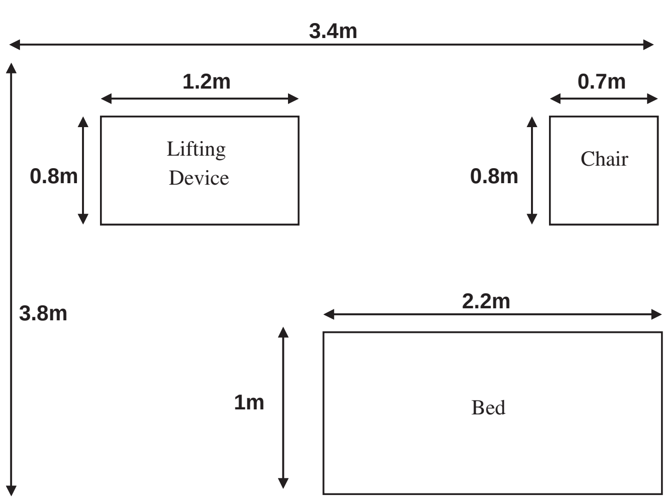

Fig. 1. Layout of experimental environment.

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

2.3. Experimental design

2.3.1. Independent variables

There were two different types of training that were administered to the subjects. The subject either was trained in Method A ("See-One-Do One") or Method B ("Interactive"). In Method A the experimenter completed the task while giving verbal explanations of each step of the task. The subject was allowed to watch while the experimenter completed the entire task. They then performed the patient transfer task by themselves. In Method B, the task was broken into steps, and the experimenter completed a step of the task with explanation, then allowed the subject to complete the step. The explanation given to the subjects in Method B was slightly more detailed, which coincided with the step-by-step training. Method B gave the subject a more hands-on, interactive experience with the equipment and task.

2.3.2. Dependent variables

Quantitative measures related to the learning process (objective) and survey response data (subjective) were the dependent variables in this study. There were five objective measures that were calculated from the time-to-complete data: (1) learning rate, (2) time 0, (3) $\Delta 1$, (4) $\Delta 2$, and (5) $\Delta 3$. Learning rate provided a standard way to describe the gradual decrease in completion time from data point 0 (first time completing the task) and data point 10 (11th time completing the task). "Trial 0" was the amount of time required to complete the first independent patient transfer task. The second measure calculated from this time-to-complete data were measures of the immediate change in time-to-complete called "$\Delta 1$", "$\Delta 2$", and "$\Delta 3$" and were measures of the rapid reduction in completion time in the first several trials. "$\Delta 1$" is defined as the difference in completion times between Trial 0 and Trial 1. "$\Delta 2$" is defined as the difference in completion times between Trial 0 and Trial 2. "$\Delta 3$" is defined as the difference in

Fig. 2. The patient lift-assist device.

completion times between Trial 0 and Trial 3. Finally, the responses to the survey questions were collected as integer values between 1 and 5 and were the subjective measures gathered in this study.

2.4. Experimental procedures

The study was completed in a single session that averaged 90 min per subject. After arriving to the laboratory, the subject was introduced to the researcher and the "patient", the procedures were explained and the participant was asked to read and sign the Informed Consent Form. Next the subject watched the experimenter complete the task of moving the patient from the bed to the wheelchair using the device. This was called the orientation because it allowed the subject to see the task being completed from start to finish. The experimenter completed the task in silence, allowing the subject to observe from a close distance. Next the participant was taken through the pre-determined training protocol (A or B) that was determined through randomization. The script used in this training is provided in the Appendix A, with the bold faced words used in Method B to better describe the stepwise/interactive training approach.

After the appropriate training protocol was completed, the subjects performed a "Trial 0", in which they were able to ask the experimenter questions while completing the task. During Trials 1–10, the subjects were not able to ask questions. In each trial the subject was encouraged to go at a fast pace, and was told that their time-to-complete at the end of each trial as motivation to improve. A short break between trials was provided as the experimenter returned the room to its original configuration and the "patient" returned to the bed. After all the trials were completed, the subjects were asked to complete the survey.

2.5. Data analysis

For each subject learning rate was calculated using Eqs. (1) and (2) with Time 0 as K and Time 10 as Y_X. The value for "Time 0" required no calculation and $\Delta 1$, $\Delta 2$, and $\Delta 3$ were simply the difference between the Trial 0 and Trials 1, 2, and 3, respectively.

Analysis of variance (ANOVA) was used to evaluate the effect of Training Method on the dependent variables using a between-subject statistical model with subject nested within group ($F = \mathrm{MS_{GROUP}}/\mathrm{MS_{SUBJ(GROUP)}}$). The assumptions of the ANOVA technique (homogeneity of variance, independence of observations, and normality of residuals) were tested using the graphical methods advocated by Montgomery (2001). The survey data were analyzed using the nonparametric Kruskal–Wallis test. Throughout the statistical analysis a p-value of less than 0.05 indicated a significant effect.

3. Results

3.1. Performance data

The change in task completion time as a function of trial number provides support for the utility of learning curve theory in the prediction of future productivity with an ergonomic intervention (Fig. 3) with an average absolute error (AAE) of the predicted relative to the actual of 8.1 s. Interestingly, the quality of the fit was better for the Method A training (AAE 5.2 s) than for the Method B training (AAE 10.9 s). The ANOVA results showed no significant effect of Training Method for Learning Rate ($F = 3.68$), $\Delta 1$ ($F = 4.34$), or $\Delta 2$ ($F = 0.25$). The learning rate was 85.2% for the interactive training and was 81.1% for the see-one-do-one training. Significant differences ($p < 0.05$) were found, however, between training groups for Trial 0 ($F = 8.14$) and $\Delta 3$ ($F = 10.29$) (Fig. 4).

The subjective responses of the participants were consistent with the objective data in that the only question that produced responses that were significantly affected by Training Method were the responses to Question 3 that asked the subjects to rate their comfort on their first independent trial ($X^2 = p = 0.021$)—Method B generating an average response of 3.6 (more favorable than neutral),

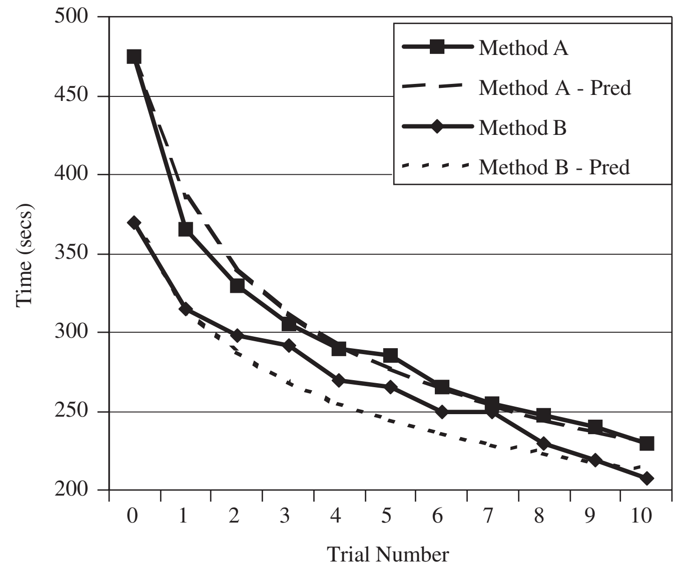

Fig. 3. Task completion time as a function of learning. Dashed/Dotted lines note the "predicted" values using Eq. (1).

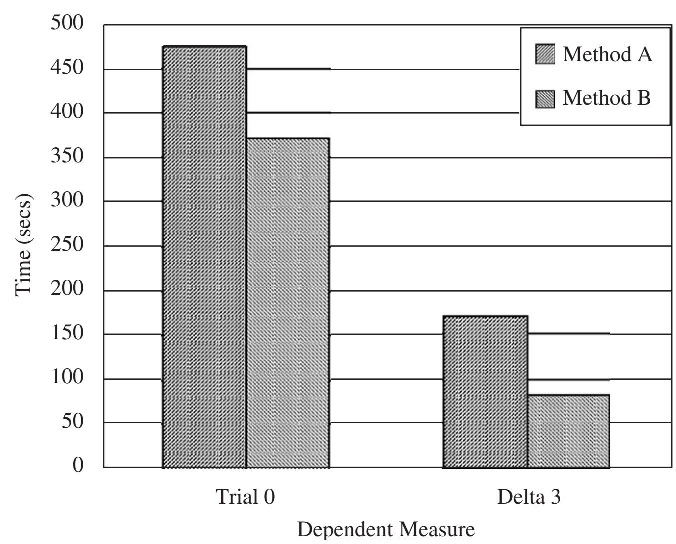

Fig. 4. Significant effect of Training Method on (1) time to complete the first patient transfer task and (2) the reduction in time to complete the task between the first and third attempt.

while Training Method B generated an average response of 2.6 (less favorable than neutral).

4. Discussion

The objectives of this study were to explore the application of learning curve theory in the process of introducing ergonomic interventions, and assess the impact of training technique on quantitative variables describing the learning process. The results of this study have shown that the change in task completion time does follow the expected trends in improvement with the average learning rate for the use of a patient lift-assist device being 83.2% (Method B 85.2%, Method A 81.1% (not a statistically significant difference)). This learning rate falls in the middle of the previously established range of learning rates (cognitive learning tasks usually have a learning rate percentage of 70% while purely physical learning tasks usually have a percentage of 90% (Konz and Johnson, 2000)). This would suggest that for this particular ergonomic intervention there is both a physical component (i.e. learning how to secure the sling, developing a technique to rotating the lift-assist device, etc.) as well as a cognitive component (i.e. remembering all to the required steps, performing them in the proper sequence, etc.)

The effects of Training Method on the dependent variables in this study shed light on both the short- and long-term effects of training style. First, it is important to note that most of the response measures that considered the overall response were not significant (learning rate, overall subjective responses). In fact, the productivity responses converge quite quickly, after only ten repetitions. The immediate response (i.e. time to complete the first patient transfer task, the immediate improvements in productivity, subjective assessment of comfort in doing the first patient transfer task) were significantly affected by the training style. This may have important implications for the immediate "accept" or "reject" response of the user of the intervention, and therefore, should not be overshadowed by the longer-term non-significant effects shown in this study.

The documentation of the learning rates is particularly useful in overcoming the resistance of management (and workers) to the changes in productivity that immediately result from the intervention. For example, if the standard time for a patient transfer task were say 120 s and the nurse were to use the lift-assist device for the first time and find that the time to complete the task was 475 s (as might reasonably be expected given that the Method A training in this experiment is often seen in health-care settings), this person might immediately reject the lift-assist device. However, if the ergonomist were able to point out that research has shown that after using this device just 10 times the time can be expected to be reduced to just 240 s (as was shown in this study) and further extrapolate (using the learning curve equation) that after 100 repetitions the time can be expected to drop to 115 s (i.e. less than the original time to complete manually) they might be willing to accept a short-term reduction in productivity.

While productivity when using patient lift-assist devices has been the focus of this study, it is important to remember the true purpose of the patient lift-assist intervention: preventing over-exertion musculoskeletal disorders in health-care workers. These interventions are meant to protect the workers, and although productivity numbers may decrease as a result of their use (even when the long-term learning effects are considered) other measures of effectiveness are substantially improved. To consider the overall cost–benefit relationship, the ergonomist must emphasize both the direct and indirect costs associated with a serious musculoskeletal injury.

There are several limitations of this study related to the direct applicability of these results to the health-care setting that should be noted. First, the research was done in a laboratory setting, which implies fewer distractions (relatively unobstructed work space, agreeable patient, etc.) that might influence the learning process. Second, the 11 trials were done in sequence. Learning remission is a well-documented phenomenon that shows how learned technique can be lost with the passage of time without using what has been learned. This phenomenon influences the overall learning process when there are longer breaks between successive patient transfer tasks. Since patient lifting can be done relatively infrequently throughout the workday, learning remission may have potential to alter the learning rates shown in this study. Third, the participants in this experiment were not nurses and our "patient" was not in any physical distress. Concerns related to patient safety and dignity that are learned through work experience might influence the learning rate under more realistic hospital care conditions. Finally, it is recognized that the actual task of transferring the patient is only one component of the overall process of using the lift-assist device. One of the most time-consuming parts of using the device is often tracking down the device and rolling it to the patient room where it is to be used, and then returning it to the area from which it was taken. When we consider this broader task, we see even greater potential for learning. As the user begins to more fully incorporate the use of the device into their work process, they can begin to develop strategies for its use. The first couple of times that the lift is used, the nurse may only think of getting the device at the moment it is needed. As they become a more regular user, they can plan for its use and collect the lift device as a part of their movement around the unit. This procedure would represent a more global integration of using the device into the overall work flow, a concept that was not explored in the current study.

5. Conclusions

Ergonomic intervention is often hampered by concerns related to detrimental effects on productivity. Learning curve modeling is an established process that allows one to predict future productivity based on an inverse logarithmic response as a function of time. In this study, this modeling approach was applied to the introduction of a mechanical patient handling device and considered the effects of training type. The results of the study showed that this modeling technique was appropriate for this application, generating a good fit between the actual and predicted productivity levels as a function of time. It was further found, through the application of these data, that an interactive training procedure had an immediate impact on the time to complete the task during the first trial (370 s during the interactive training vs. 475 s during the see-one-do-one training) but this training type effect was short-lived. Subjective responses confirmed the immediate impact of the interactive training, and also showed that this response was fleeting.

Appendix A. Training script (bold-faced words only used in the interactive training (Method B)

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

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

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

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

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

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

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

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