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# Quantitative and Qualitative Evaluation of the Lift-assist Device during Jackhammering Task

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**Abstract**

**Background:** Jackhammers are commonly used on construction sites, and their general use comes with several injury risks, especially focused on lifting the jackhammer. A Lift-assist (LA) device is available that is aimed at eliminating the risk to the user from lifting. However, to date no scientific study has been conducted to determine if the LA provides any benefits to the user. The goal of this study was to make quantitative comparisons and qualitative assessments of operating a jackhammer with and without a LA.

**Methods and findings:** Eight experienced jackhammer operators broke a 0.9 × 0.9 m section of concrete with two different weights of jackhammers with and without a lift-assist. Muscle activity of the upper body was reduced (approx. 40%) during the lifting portion of the task when using the LA. The reduction of the muscle activity required to lift the jackhammer also enabled the subjects to retain a better posture throughout the lift. Additionally, grip pressure was reduced in the lifting portion of the task. While the LA reduced the time required to lift the jackhammer, no change in overall task completion time was observed due to large variations in the time effect of the lift-assist among subjects and the relatively minor contribution of lifting time to the total task time. A longer study that allowed subjects to better adapt to the LA might be required to assess potential effects on task efficiency. Overall the subjects perceived the LA to provide a benefit to the user during the jackhammer task, and reduced the physiological stress experienced by the operator during the lifting portion of the task.

**Conclusions:** These results indicate that use of the LA can potentially translate to a reduction in lifting related injury risks to the operator.

**Keywords:** Ergonomics; Lift-assist (LA); Injury prevention; Jackhammering; Occupational biomechanics

## Abbreviations:

BB: Biceps Brachii; CJH: Conventional Jackhammer; CJHLA: Conventional jackhammer with lift-assist; DEL: Deltoid; ES: Erector Spinae; LA: Lift-Assist; LWJH: Light Weight jackhammer; LWJHLA: Lightweight Jackhammer with lift-assist; nLA: No Lift Assist; RMS: Root Mean Square

## Introduction

Construction is commonly recognized as a sector of industry with high workplace incidental injury rates. In 2007, construction had the 2nd highest nonfatal injury rate [1] and this continued into 2011 and 2012 as construction remained ranked in the top three for nonfatal injury rate across all private industries in the United States [2,3]. The high injury rate is a result of the dynamic work environment which exposes its workers to various injury risk factors and may vary from one task to another.

Researchers have identified that material handling and lifting are among the most frequent tasks performed in the construction industry [4-6], and the frequency of exposure is associated with low back injuries [7,8]. Repetitive handling of moderate to heavy loads has also been shown to have strong association with low back pain [9,10]. Other risk factors associated with overexertion injuries are high force, repetitive motions, contact stress, and segmental vibration [11,12]. Jobs in other industries that involve repetitive lifting, such as automotive and health care, also have high rates of musculoskeletal disorders similar to construction [13,14]. Over the years, researchers have proposed various lift-assist devices to aid lifting of heavy materials, patients, etc., and these have been effective at limiting the physiological cost of the task [15,16]. In tasks that require lifting on the worksite, the construction industry could potentially benefit from such a device.

A commonly used device on the construction worksite is the jackhammer. A typical jackhammering operation involves many risk factors, including vibration exposure, noise, and repetitive lifting, as the operator is constantly breaking concrete and lifting the jackhammer back onto the unbroken surface to complete the task. If we take the lifting portion of the jackhammering task and perform an ergonomic assessment using the NIOSH lifting equation [17], the lifting index for a conventional 41 kg jackhammer exceeds the allowable limit of 25 kg, and therefore even a single lift could put the operator at risk of injury. The weight of the jackhammer could cause an overexertion injury during a single lift and overexertion while lifting was the most frequent event leading to back pain across all industries [18]. Although research and personal perceptions indicate that operating a jackhammer remains on the list of top hazardous tasks for one's health, little has been done to rectify this issue [19-22]. Previous research has identified that reducing the weight of the jackhammer from 41 to 30 kg can be beneficial to the operator, but the

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task still poses a risk for injury due to exposure to various hazards, especially due to lifting [23].

In order to reduce the low back injury risk from lifting a jackhammer during operation, an ergonomic intervention has been recently designed to aid with the lifting portion of the task. The jackhammering-specific Lift-assist (LA) is a device that is attached to an existing jackhammer. It uses a pneumatic power source to forcefully push a metal rod out of its housing and down on the pavement and propels the jackhammer out of the broken pavement instead of the user manually lifting the jackhammer onto the unbroken surface.

To date, the potential benefits of using the lift-assist during a jackhammering task have not been assessed. Therefore, the goal of this study is to perform objective and subjective assessment of the LA device during a standard jackhammering task. It was hypothesized that utilizing the LA device will reduce muscle activity and grip pressure of the operator, while not affecting the overall task time. Subjective qualitative measurements of user perception will also be assessed through a structured interview.


**Figure 1**: Operator (a) at the beginning of the trial and (b) just prior to completion of the trial.

## Methods

### Subjects

Eight volunteers (seven males and one female; 39 ± 6 years, weight 87 ± 22 kg, height 168 ± 10 cm) who were experienced jackhammer operators (3 to 20 years of experience) were recruited to participate in this study. Prior to the testing, each subject reviewed and signed an informed consent form that was approved by the University of Wisconsin-Milwaukee Institutional Review Board (IRB Protocol #13.119).

### Experimental protocol

The operators were asked to break a 0.9 × 0.9 m square area of a 15 cm thick concrete along marked lines (Figure 1) in four separate randomized trials, as if they were on the job. The trials consisted of the following conditions while using: A Conventional Jackhammer without a Lift-assist (CJH); a Conventional Jackhammer with a Lift-assist (CJHLA), a Lightweight Jackhammer without a Lift-assist (LWJH); and a Lightweight Jackhammer with a Lift-assist (LWJHLA). The conventional jackhammer has a slightly taller dimension (109.3 cm) and is much heavier (41 kg) than the lightweight jackhammer (101 cm, 30 kg). There were no differences between jackhammers in handle width (10.2 cm) and handle diameter (3.7 cm). The addition of the lift-assist added 4.54 kg and an extra trigger to the handle for operation. Not all operators had equal experience with using the lift-assist, and thus all subjects were allowed to practice operating a jackhammer with a lift-assist device prior to testing. In order to prevent fatigue operators were allowed to take as much time as they desired in between trials with minimum rest duration of 15 min.

### Instrumentation

Each trial was videotaped from two different angles using digital camcorders. Video footage was used to aid in synchronization of the collected data, track task duration, and distinguish between jackhammering styles.

A wireless surface electromyography system (Delsys Trigno, MA) was used to collect muscle activity (EMG). Sensors were placed on the right and left Bicep Brachii (BB), Tricep Brachii (TRI), Deltoid (DT), and Erector Spine (ES). The SENIAM recommendations were followed for EMG sensor placement. Additionally, all sensors were secured with athletic hypoallergenic tape-wrap to minimize the chance of falling off during the experiment. The sampling rate was set at 2 kHz.

Grip pressure was measured by using a pressure mapping glove with 24 individual pressure sensors (Vista Medical, CA) that was placed on the dominant hand of the operator. The individual sensors were placed evenly across the fingers and palms, and kept consistent for all subjects. The grip pressure data was collected at a rate of 5 Hz.

### Analysis

The EMG signals were filtered with a 4th order bandpass Butterworth filter from 20-450 Hz for the lifting analysis and 30-450 Hz for the overall EMG analysis. The reasoning for the separate filtering techniques was to eliminate the noise due to the dominant operating frequency that was measured to be 20 ± 5 Hz for both weights of jackhammer. The filtered EMG signal was Root Mean Squared (RMS) with a window size of 0.125 s and an overlap of 0.0625 s. A custom MATLAB program was used to separate the lifting muscle activity from the overall trial. The data that was sampled in the lifting portion of the task was the peak muscle activity in each lift. The peak lifting EMG values were then averaged across the whole trial to determine the representative lifting EMG value for that subject in a particular condition. The overall muscle activity was determined by averaging all of the data points sampled within a particular trial. A ratio between conditions were used to compare the difference in muscle activity between operating conventional and light weight jackhammer with lift-assist (LA) and without lift-assist (nLA) conditions respectively (Equation 1).

$$Ratio_{EMG}=RMS\ EMG_{LA}/RMS\ EMG_{nLA} \quad (1)$$

The values from each pressure sensor on the hand were recorded. Grip pressure at each time point was defined as the sum of all 24 sensors. Similar to the EMG analysis, a custom MATLAB program was used to separate out the lifting portion of the task for further analysis. Overall grip pressure was calculated by taking the average grip pressure across the whole trial. Lifting grip pressure was calculated by extracting the peak grip pressure measured during each lift and then the peak grip pressures from each lift were averaged.

Total task time was measured from the digital recording and was defined as the amount of time it took an operator to complete the task. Isolating the lifting portion of the trial was done manually through further video analysis. The numbers of lifts throughout the trial then were determined. The average lifting time was defined as time lifting the jackhammer divided by the number of lifts completed. The video recordings were also used for a subjective postural analysis of the operators across all experimental conditions.

At the end of the experiment, user perception was assessed via structured interview using the following predetermined statements by rating them from 1 (strongly disagree) to 5 (strongly agree):

- The lift-assist is easy to use.
- The lift-assist improved my performance.
- The lift-assist improves task completion time.
- The lift-assist relieves muscular effort from removing the jackhammer tip from the concrete.
- The added weight of lift-assist was not noticeable.
- The lift-assist is easy to control.

### Statistical analysis

This study utilized a within subject experimental design, and thus a paired t-test was used to statistically compare the lift-assist and no lift-assist conditions for each jackhammer weight individually. The significance level was set at 0.05.

## Results

Overall the lift-assist had the greatest impact on the lifting phase of the task. Utilizing the lift-assist reduced the average lifting time by 24% for the CJHLA and 17% for the LWJHLA trials ($t=2.01$, $p=0.045$ and $t=2.06$, $p=0.043$). Since the lift-assist does not affect the breaking of the concrete, and the time spent lifting the jackhammer was 7% of the whole task, the lift-assist did not affect the overall task time. The number of lifts an operator had to perform during any given trial varied greatly between subjects and ranged from 23 and 81 times per trial regardless of use of the LA.

### Muscle activity

The summary of results for muscle activity for all trial conditions are presented in Table 1 in separate sections for the lifting portion of the task and the task overall. Ratios less than 1 indicate a reduction in muscle activity while using a lift-assist device during the trial, while ratios equal to 1 or greater to 1 indicate no difference or an increase in muscle activity respectively.

Overall, using a lift-assist device resulted in a significant reduction of the muscle activity bilaterally during the lifting phase of the jackhammering task for both jackhammer weight conditions. The left and right bicep muscles experienced the largest impact due to lift-assist during the lifting phase of CJHLA trials with 57% ($t=5.23$, $p=0.003$) and 53% ($t=3.87$, $p=0.006$) reduction in average RMS values. The effect was slightly smaller in the case of the LWJHLA trials, with 30% ($p=0.021$) and 37% ($p=0.008$) reductions respectively.

Significant reductions in bilateral deltoid muscle activity of 38% ($p<0.05$) were observed due to lift-assist usage with the heavier hammer, and 12-21% ($p<0.05$) in the case of the lighter jackhammer. Despite a large variation detected in triceps muscle activity during both CJHLA and LWJHLA trials, on average there was a reduction of 19-36% (CJHLA) and 11-22% (LWJHLA) observed. The right and left erector spinae muscle RMS values were also reduced respectively by 34-36% ($t=3.14$, $p=0.013$ and $t=2.77$, $p=0.016$) in case of CJHLA and 12-19% ($t=1.44$, $p=0.097$ and $t=4.39$, $p=0.002$) in the LWJHLA case.

Analysis of the impact of the lift-assist device on the task overall (lifting and operation) revealed 7-17% reduction in muscle activity of the upper arm muscles (biceps, triceps and deltoid), but didn't have much impact on the erector spinae muscles for both CJHLA and LWJHLA trials. None of the results were found to be statistically significant ($p>0.05$) due to the large variation of data.

### Grip pressure

Figure 2 contains a comparison of average grip pressure results during the lifting phase of trials with and without the lift assist. Using the lift assist resulted in a 14% reduction in grip pressure for the lifting portion of the task for both LWJHLA ($t=2.45$, $p=0.025$) and CJHLA ($t=1.88$, $p=0.051$). It was observed that grip pressure was not consistently reduced until later in the trial (Figure 3), with some early lifts showing higher grip pressures using the LA. This effect was more pronounced for the CJHLA condition.

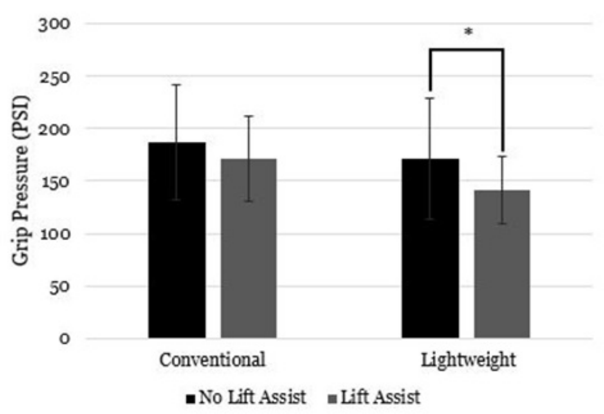


**Figure 2:** Average lifting grip pressure for the conventional and lightweight jackhammer conditions. *Represents a statistically significant reduction using the lift-assist condition.

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| Muscle Activity Ratio (Lift-assist/No Lift-assist) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Conventional Jackhammer (CJH) | | | | | | Lightweight Jackhammer (LWJH) | | | | | |
| Phase | Muscle | Avg | SD | t-value | p-value | Phase | Muscle | Avg | SD | t-value | p-value |
| Lifting | Lt BB | 0.43 | 0.11 | 5.23 | 0.003 | Lifting | Lt BB | 0.7 | 0.19 | 2.71 | 0.021 |
| | Rt BB | 0.47 | 0.15 | 3.87 | 0.006 | | Rt BB | 0.63 | 0.19 | 3.31 | 0.008 |
| | Lt Tri | 0.81 | 0.41 | 1.82 | 0.071 | | Lt Tri | 0.89 | 0.47 | 1.33 | 0.113 |
| | Rt Tri | 0.64 | 0.41 | 2.41 | 0.03 | | Rt Tri | 0.78 | 0.39 | 1.8 | 0.061 |
| | Lt Delt | 0.62 | 0.26 | 3.14 | 0.01 | | Lt Delt | 0.79 | 0.22 | 2.95 | 0.011 |
| | Rt Delt | 0.62 | 0.25 | 2.94 | 0.013 | | Rt Delt | 0.88 | 0.34 | 1.9 | 0.049 |
| | Lt ES | 0.64 | 0.19 | 3.14 | 0.013 | | Lt ES | 0.88 | 0.26 | 1.44 | 0.097 |
| | Rt ES | 0.66 | 0.12 | 2.77 | 0.016 | | Rt ES | 0.81 | 0.1 | 4.39 | 0.002 |
| Overall | Lt BB | 0.85 | 0.22 | 1.48 | 0.106 | Overall | Lt BB | 0.9 | 0.25 | 0.56 | 0.297 |
| | Rt BB | 0.82 | 0.16 | 1.82 | 0.064 | | Rt BB | 0.84 | 0.2 | 1.13 | 0.148 |
| | Lt Tri | 0.85 | 0.21 | 1.62 | 0.09 | | Lt Tri | 0.85 | 0.2 | 2.02 | 0.042 |
| | Rt Tri | 0.84 | 0.21 | 1.88 | 0.059 | | Rt Tri | 0.83 | 0.21 | -0.93 | 0.809 |
| | Lt Delt | 0.93 | 0.23 | 1.08 | 0.162 | | Lt Delt | 0.85 | 0.2 | 1.74 | 0.063 |
| | Rt Delt | 0.93 | 0.29 | 1.11 | 0.156 | | Rt Delt | 0.82 | 0.17 | 1.88 | 0.051 |
| | Lt ES | 1.05 | 0.34 | -0.61 | 0.715 | | Lt ES | 1.08 | 0.31 | -0.77 | 0.766 |
| | Rt ES | 0.97 | 0.17 | 0.23 | 0.414 | | Rt ES | 1.03 | 0.16 | 0.19 | 0.427 |

**Table 1**: EMG ratios during the lifting phase and the overall trial for the conventional and light-weight jackhammers. Values less than 1 indicate a reduction in muscle activity. Statistical significance ($p \leq 0.05$) is marked in bold.

The lift assist had less of an impact on grip pressure during operation and therefore the overall trial reductions were not significant for either of the jackhammers (t=1.47, p=0.108 and t=1.33, p=0.116).

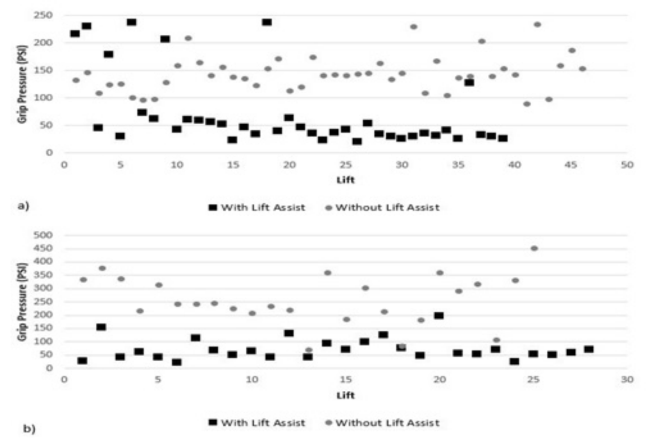


**Figure 3:** Comparison of lifting grip pressure with and without LA for a representative subject using (a) conventional and (b) lightweight jackhammer.

## User perception

The results from the questionnaire revealed that the operators liked using the lift-assist (Figure 4). When asked if the lift-assist was easy to use, all but one subject, who was neutral, agreed with this statement. Only one subject disagreed with the statement that the lift-assist was easy to control. Half of the subjects believed that the lift-assist improved task completion time, while three subjects were neutral and one subject strongly disagreed. One subject disagreed that the lift-assist improved their performance, while one was neutral and the others agreed or strongly agreed. All subjects did believe that the added weight of the lift-assist was noticeable.

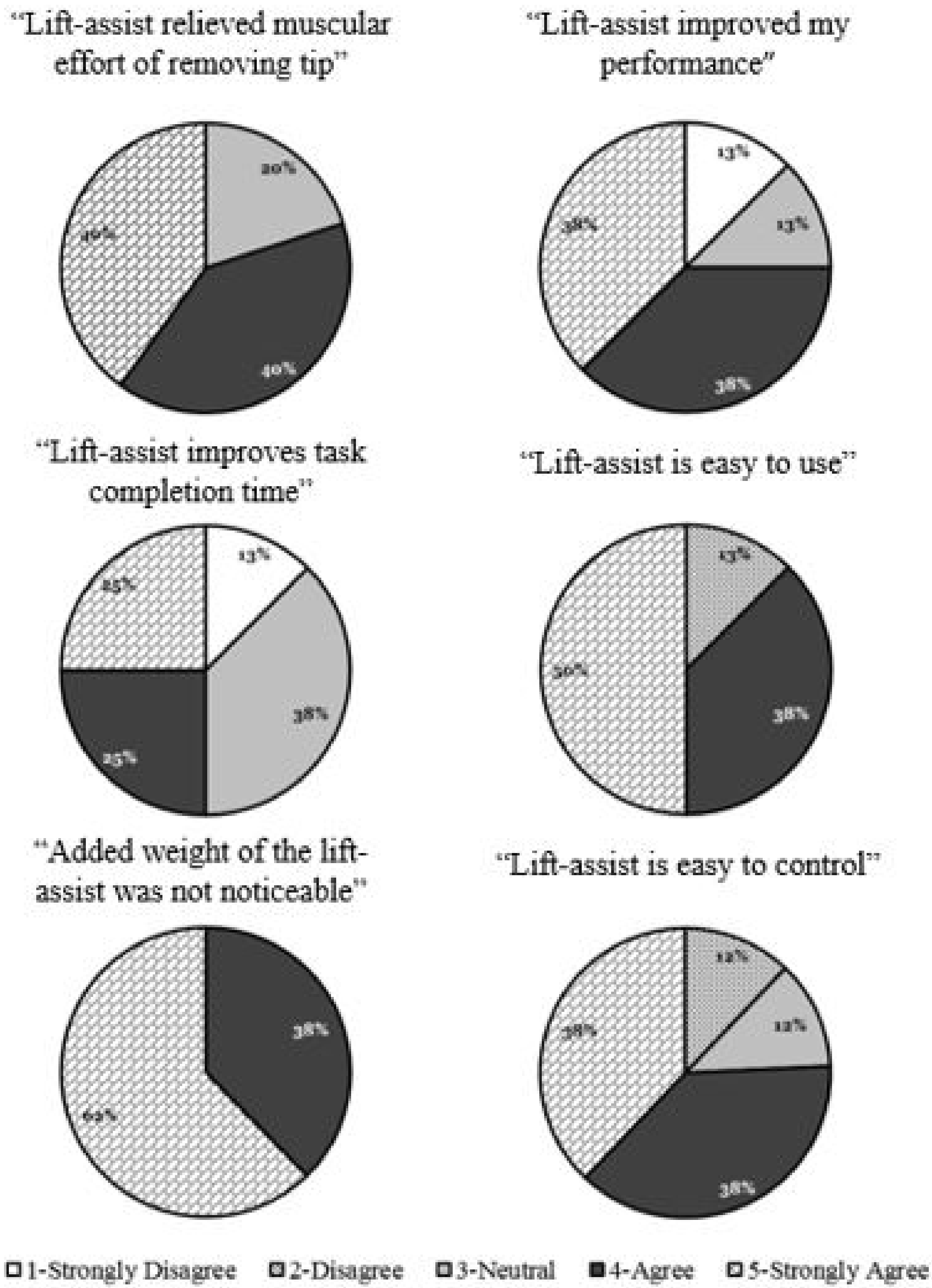


**Figure 4**: Distribution of responses to the interview questions with the four statements concerning the lift-assist.

## Discussion

The goal of this study was to perform objective and subjective evaluation of a specially designed jackhammer lift-assist device and determine whether there are any benefits to the operator during lifting and overall task performance. The LA reduced the muscle activity required to lift the conventional jackhammer for all muscles on average by 40% for the CJHLA trials. A previous study Johnson et al. [23] found a similar reduction in muscle activity during lifting when switching from a convention to lightweight jackhammer, indicating that, for the conventional jackhammer, the lift assist provides the same benefit with regards to muscle activity as does reducing the jackhammer weight by 35%. The average muscle activity for the LWJHLA trials was reduced by 22%, a smaller reduction than for the CJHLA condition which was expected due to the lighter weight of the tool.

The effect of the LA on triceps muscle activity varied the most between subjects, primarily due to some subjects trying to control the height that the lift-assist propelled the jackhammer into the air. It is possible that this action helped some subjects keep control of the jackhammer since a few operators commented that they thought the lift-assist pushed the jackhammer a little too high into the air. It should be noted that no operators ever lost control of the jackhammer due to use of the lift-assist.

Overall, a reduction in lifting muscle activity demonstrates that the LA is objectively aiding the operator during the lifting portion of the task. Less muscle activity means less effort is required. Reduction in erector spinae muscle activity is especially important as previous research has demonstrated that decreased erector spinae muscle activity is associated with lower compressive loads on the spine [24-26]. The reduction of compressive loads on the spine is beneficial as it has already been demonstrated that construction workers are at a high risk of a low back injury due to the frequency of manual lifting [6].

Another benefit resulting from utilizing the LA is that most operators improved their posture during the lifting phase and were bending less. This observation was made subjectively from the video recordings of the experimental trials and comparing the LA and nLA condition within the operator for both jackhammer conditions. Figure 5 provides a graphical representation of typical postural differences observed during various phases of the jackhammering task with and without LA. When operators used the LA their back would remain in an upright position during lifting the jackhammer from the pavement because the LA propelled the jackhammer upwards from the ground. The adjustment to remaining in a neutral posture is beneficial as frequently deviating from this posture has been found to be associated with more reports of back pain [27].

In addition to reducing injury risk, the LA could potentially reduce the fatigue of the operators over longer work periods due to lower muscular effort during lifting. O'Sullivan et al. found that reducing muscular activity can increase endurance, which suggests that the reduced muscle activity found in the current study would allow subjects to not be as physically exhausted after performing the jackhammering task [28].

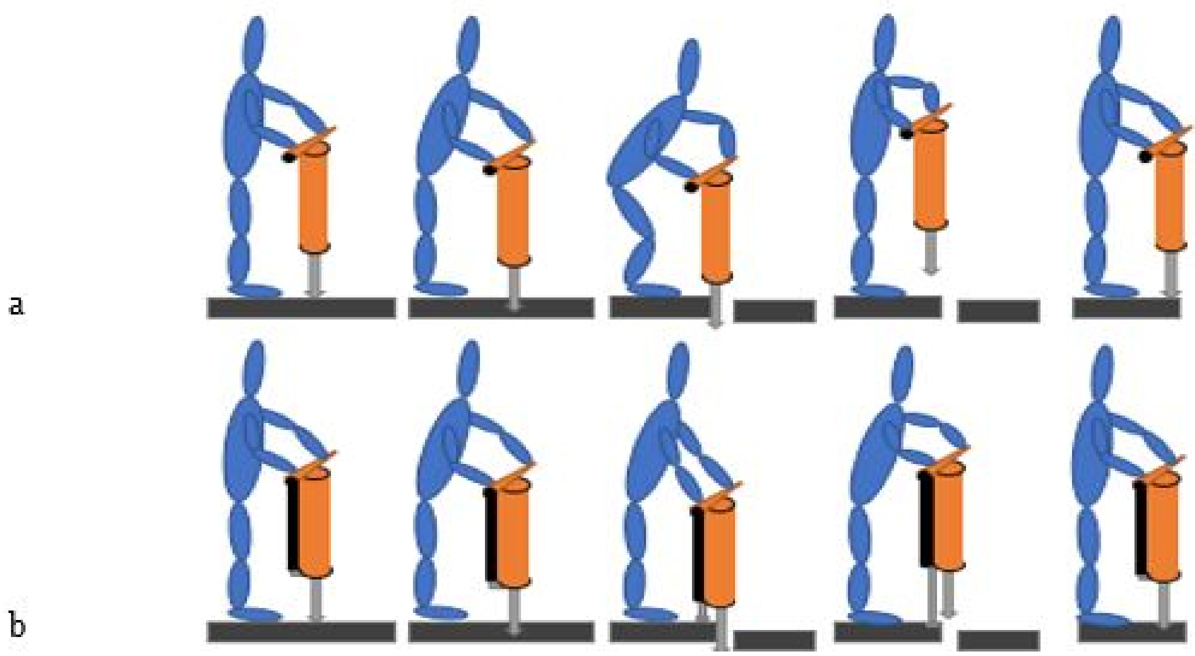


**Figure 5:** Graphical representation of subject posture during the 5 phases of the jackhammering task: (a) Without lift-assist and (b) With lift-assist.

It is worth noting that there was large variability between subjects in muscle activity when considering the overall trial within the same condition. It was observed that some subjects were more aggressive without the LA and pushed down more on the jackhammer during the operation phase. As lifting accounts for only 7% of the total task time, these variations in operating style had a greater effect on overall trial muscle activity than did the LA. The large variations in operating style may be due to anthropometry, gender, or training, etc., which should perhaps be explored in future studies.

Furthermore, the analysis of lifting grip pressure suggests that using the LA could benefit the operators through improving their ability to control the hammer during the lift. While the reductions were evident for both weights of jackhammers, some differences between the two weights were due to the operators having a harder time adjusting to using the conventional jackhammer with a lift assist. Generally, it was observed that the operators typically had higher grip pressures using the LA at the beginning of the trial that gradually dropped throughout the trial. The reduction in lifting grip pressure means that the operators required less hand grip force to maintain control of the jackhammer. Analysis of the grip pressure further supports that proper training and practice is necessary to get the full benefit of using the LA.

Although not statistically significant, most of the operators saw reductions in overall grip pressure (16% on average). The LA added a trigger to the handle which operates the device, and many subjects adjusted their grip so the fingers were not firmly around the handle but were left open to be able to pull the trigger immediately after operation. This open grip style, in addition to reductions in lifting grip pressure, could have resulted in the observed reduction of overall grip pressure.

Using the LA did reduce the average and total lifting time for both jackhammer weights, but this increase in lifting efficiency did not translate to an overall reduction in task time. As noted before, lifting accounts for only 7% of the total task time, making a reduction in lifting time unlikely to have a large impact on the total time. Another possible reason for this is that the LA was new to the operators and even though, prior to testing, subjects were given an opportunity to practice using the LA, to fully adapt to the new device might take longer than a day.

Overall, the operators perceived that the LA provided a benefit for them. All the users agreed that the lift-assist was beneficial during the lifting portion of the task. The only negative views were found in the perception of task time improvement and whether the LA was easy to control. For the task time results, all the subjects who disagreed that the LA improved their task time were also the same subjects that were observed to have an increase in task time when using the lift-assist. The only subject who didn't think the lift-assist was easy to control was the smallest subject included in the study, and it was visually evident that operating the LA was difficult for this subject. After each lift, the subject had to readjust the jackhammer to prepare to operate again. Even with the difficulty in controlling the jackhammer with the LA, the subject still preferred using the LA, along with half of the operators. The other half of the operators who did not prefer this device commented on how the lift-assist was not natural for them. Subjects explained that they have a natural rhythm of operating a jackhammer and having to remember to use the LA disrupted their normal flow. This mind set could be changed if the operators had more experience with the LA and received formal training on how to use it.

## Conclusion

This paper demonstrated that the addition of the lift-assist provided benefits to the operator. These benefits are highlighted by reductions in muscular stress during the lifting portion of the task. Less physiological stress experienced by the operator can reduce the risk of injury. Incorporating the lift-assist into normal jackhammering activities, just like any new device, should come with proper training to mitigate any negative effects due to lack of experienced. Overall this intervention could provide a positive impact on improving the safety for jackhammer operators.

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## Conflicting Interests

The Authors declare that they have no competing or conflicting interests.

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