An Ergonomic Analysis of Muscle Activation and Posture When Terra Firma Products are Utilised During Pit Lid Lifting and Replacing Operations

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ABSTRACT

When considering the potential risk of injury for workers conducting manual handling activities some clear links can be seen.

As the weight of an object being moved increases the risk of injury to the worker also increases. The risk of injury is highest at the point when the most strain is put on the muscles while moving an object. This point is called peak muscle activation. Bending the body (trunk flexion) beyond 30° also increases risk of injury.

Reduction in peak muscle activation and trunk flexion directly decreases the risk of injury in workers who lift and replace lids as part of their daily work tasks.[1]

Terra Firma Industries retail composite pit lids and lifting handles. These lids are substantially lighter than conventional concrete or ductile iron lids. The difference in weight could potentially have a great effect in reducing manual handling stress and associated risk of injury for workers who inspect drains or perform routine maintenance tasks. Terra Firma Industries have manufactured a specific tool to lift these lids; however, the impacts of the weight and design of the lids and lifting tool on worker stress have not been measured. Thus the aim of this study was to assess the differences in muscle activation and posture when a range of pit lids were lifted and replaced. The effect on muscle activation and posture of different lifting handles was also assessed.

Peak muscle activation stresses were measured using wireless electromyography to quantify muscle activation levels from the back (erector spinae) and the shoulder (trapezius) muscles. Trunk flexion was observed in the field via video and in the laboratory using a 12-camera motion analysis system.

Peak Muscle activation reductions of over 200% were seen when comparing Terra Firma products to traditional products. It can be estimated in this case that injury risk is most probably dropping by up to 200 fold when using Terra Firma products.

BACKGROUND

Peak muscle activation is a measure taken at the point when the most force is being generated by a muscle during any particular activity. The link between peak muscle activation and propensity for injury has been clearly established. The higher the peak of the muscle activation, the more the muscle is utilized which results in a higher propensity for injury. High peak muscle activation equates to higher injury risk.[1]

There is also a link between body position and injury risk, where bending past 30 degrees equates to reduced spine stability and higher injury risk.[1]

When risk is identified in a workplace, occupational health and safety (OH&S) practices recommend a Hierarchy of Controls for removing or reducing the risk.[2]

The options identified earliest in the Hierarchy of Controls are most effective, as they address the hazard (the thing that could cause harm), rather than just reduce the risk (the harm that the hazard could cause).

The Hierarchy of Controls is as follows:

1. Eliminate the hazard altogether. For example – get rid of the dangerous machine.
2. Substitute the hazard with a safer alternative. For example – replace the machine with a safer one.
3. Isolate the hazard from anyone who could be harmed. For example – keep the machine in a closed room and operate it remotely.
4. Use engineering controls to reduce the risk. For example – attach guards to the machine to protect users.
5. Use administrative controls to reduce the risk. For example – train workers how to use the machine safely.
6. Use personal protective equipment (PPE). For example – wear gloves and goggles when using the machine

Broken concrete pit lids have long been identified as a hazard. Almost all major Australian Councils have a maintenance program targeted at removing and replacing broken concrete pit lids. A casual search on almost any city street will reveal cracked and damaged concrete drainage covers, and there have been a number of successful lawsuits brought by individuals suffering harm from falling into pits as a result of damaged or missing lids.

Less commonly recognised however, is the impact of working with these heavy lids on council maintenance staff. The injury statistics for council maintenance workers are high and highlight these risks. Council maintenance workers are in the highest-risk category for Australian workers:

They're labourers – the group with the highest rate of serious worker compensation claims

They work in construction – an industry with claim rates substantially above the national average

They work with concrete – manual handling claims for concreting service employees are double the industry rate

Lifting and replacing pit lids is an everyday task for councils. Things can easily go wrong due to the heavy weights involved and many concrete lids will crack or break when lifted. The main injuries sustained by workers are muscular-skeletal, with the damage being done to backs, fingers, hands and shoulders.

Terra Firma Industries have developed lightweight, composite pit lids and lifting tools with the intention of eliminating the hazard and OH&S risks found with traditional concrete and heavy ductile iron pit lids. Although pit lids cannot be eliminated entirely (step 1.), Terra Firma products address the OH&S Hierarchy of Controls at two levels; step 2. Substitution controls and step 4. Engineering controls. Terra firma have replaced traditional hazard pit lids with stronger, lighter options. In

combination with this substitution strategy Terra Firma have implemented a range of engineering strategies in the design of their lids and lifters.

The aim of our study was to compare impacts on muscle activation and posture between the Terra Firma range of products and traditional concrete and ductile iron products with consideration for these OH&S strategies for risk (and injury) reduction.

The Strategies:

The Substitution Strategy implemented by Terra Firma replaced relatively weak, brittle concrete lids prone to breakage and collapse (catastrophic failure) with significantly stronger composite products that maintain integrity and as a result eliminate the hazard of collapsed pit lids. As this strategy had been studied elsewhere in some detail, the focus of our study was primarily on assessing the OH&S Engineering Strategies Terra Firma had implemented.

There were three significant engineering components to consider when assessing the Terra Firma products against traditional products.

1. The impact of the weight reduction achieved with Terra Firma pit lids.

   Reduced weight is generally associated with reduced muscle activation and is relatively straightforward to measure. However, there are two other factors associated with weight that needed to be considered, firstly the impact of repeat lifts of varying weights as these involve effects on muscle fatigue (associated with increased propensity to injury). Secondly, the impact of weight on body position where lifting increased weights is associated with more awkward body postures and greater flexion and torsion of the spine along with greater propensity to back injury in particular.

2. The impact of the lift and drag technique used for opening Terra Firma pit lids.

   The lift and drag technique potentially replaces a force strategy (a sharp, sudden increase where peak muscle activations tend to be higher and are associated with higher propensity to injury), with a momentum strategy, where peak activations and propensity to injury tend to be lower.

3. The impact of the ergonomic lifter Terra Firma has developed for use with their pit lids.

   A more upright posture is associated with increased spine stability and reduced injury risk. Variations in use of lifters could be examining by assessing the variations in body position while lifting and replacing lids.

METHODOLOGY

The Terra Firma products were tested against a range of common, comparative pit lids and lifters.

Two male participants performed a series of repeat lifts and replacements of each product with defined rest intervals between lifts. In all cases a standardised product was used. No instruction was given to either participant regarding the technique used to lift the pit ids.

Testing was conducted in the field for maximum environmental validity wherever feasible, in order to capture real-life manual handling stresses. Laboratory testing was also carried out to capture controlled data. Peak muscle activation stresses were measured using wireless electromyography to quantify muscle activation levels from the back (erector spinae) and the shoulder (trapezius) muscles.

Trunk flexion was observed in the field via video and in the laboratory using a 12-camera motion analysis system.

All data were analysed to quantify the differences in trunk posture and muscle activation between products during a pit lid lifting phase and a pit lid replacement phase.

FINDINGS

REPORT 1. Terra Firma B80 SEP TF5130 Fibreglass Composite vs VicRoads SEP

METHODS

The Terra Firma B80 Fibreglass Composite cover weighing 24kg was tested against a comparable VicRoads Concrete cover weighting 65kg. Two male participants performed six repeat and replacements of each cover with defined rest intervals between lifts. In all cases a standardised lifter was used. No instruction was given to either participant regarding the technique used to lift the lids. Testing was conducted in the field to capture real-life manual handling stresses. Stresses were measured using wireless electromyography to quantify muscle activation levels from the back (erector spinae) and the shoulder (trapezius) muscles. Trunk flexion was observed passively via video quantified separately in laboratory testing (see report 7).

RESULTS

The Terra Firma B80 Fibreglass Composite cover elicited up to a 253% reduction in peak muscle activation of the back and shoulder compared to the VicRoads concrete cover (figure 1a&b).

Trunk flexion was visibly reduced when lifting the Terra Firma B80 Fibreglass Composite cover.

FIGURE 1A.

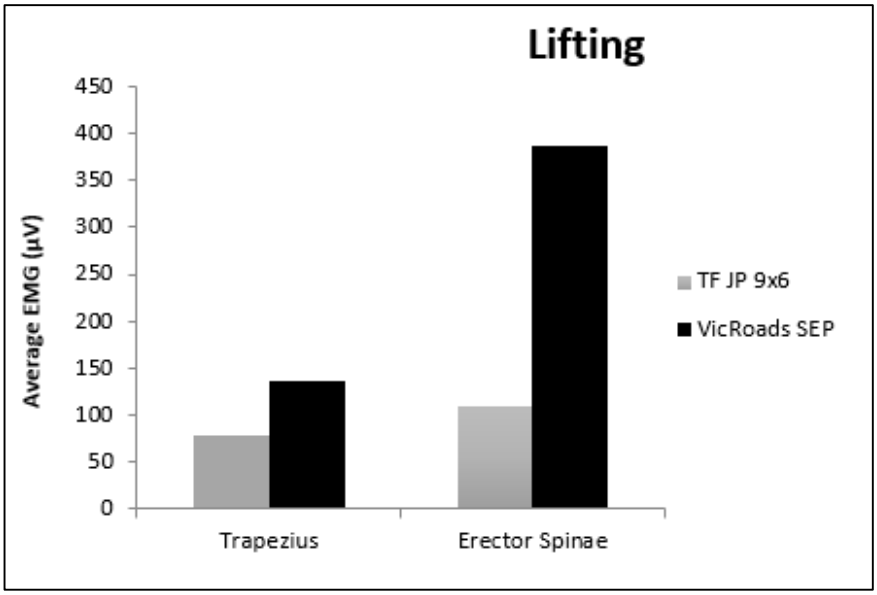
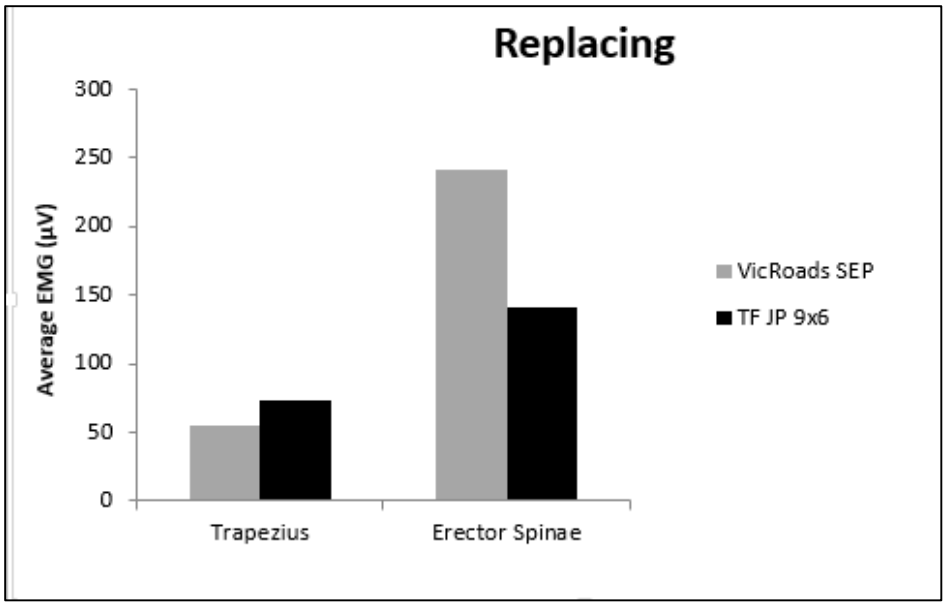


FIGURE 1B.



CONCLUSIONS

The Terra Firma B80 Fibreglass Composite cover produced safer posture and muscle activation levels compared to its standard VicRoads counterpart. These findings support the conclusion that the Terra Firma B80 lid stresses the body significantly less during lifting and replacement. Reduction in peak muscle activation directly decreases the risk of injury in workers who lift and replace lids as part of their daily work tasks.[3]

REPORT 2. Terra Firma E400 Fibreglass Composite vs D-Class Ductile Iron with Concrete Infill

METHODS

The Terra Firma E400 Fibreglass Composite in-road cover weighing 28kg was tested against a comparable ductile Iron with concrete Infill cover weighing 70kg. Two male participants performed five repeat lifts and replacements of each pit lid with defined rest intervals between lifts. In all cases a standardised lifter was used. No instruction was given to either participant regarding the technique used to lift the lids. Testing was conducted in the field to capture real-life manual handling stresses. Stresses were measured using wireless electromyography to quantify muscle activation levels from the back (erector spinae) and the shoulder (trapezius) muscles. Trunk flexion was observed passively via video quantified separately in laboratory testing (see report 7).

RESULTS

The Terra Firma E400 Fibreglass Composite in-road cover elicited up to a 53.44% reduction in peak muscle activation of the back and shoulder compared to the ductile iron concrete infill cover (figure 2a&b).

Trunk flexion was visibly reduced when lifting the Terra Firma E400 (see report 7).

FIGURE 2A.

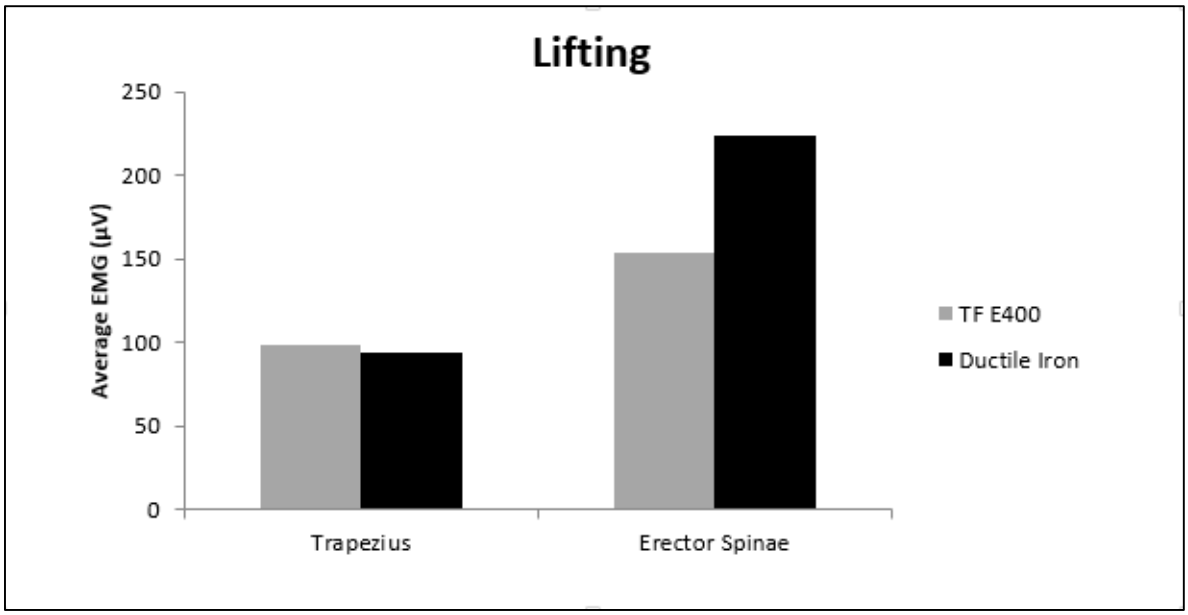
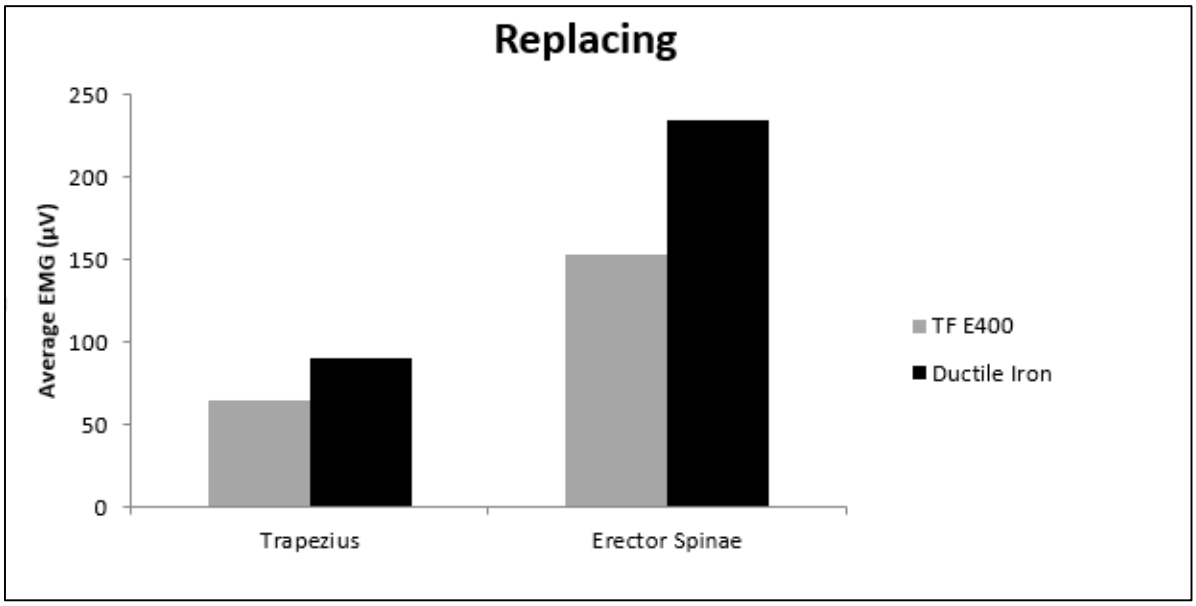


FIGURE 2B.



CONCLUSIONS

The Terra Firma E400 Fibreglass Composite in-road cover produced safer posture and muscle activation levels compared to its standard ductile iron infill counterpart. These findings support the conclusion that the Terra Firma E400 Fibreglass Composite in-road cover stresses the body significantly less during lifting and replacement. Reduction in peak muscle activation directly decreases the risk of injury in workers who lift and replace lids as part of their daily work tasks.[3]

REPORT 3. Terra Firma E400 Fibreglass Composite vs Cast Iron with Concrete Infill

METHODS

The Terra Firma E400 Fibreglass Composite cover weighing 28kg was tested against a comparable cast iron with concrete Infill cover weighting 95kg. Two male participants performed three repeat lifts and replacements of each pit lid with defined rest intervals between lifts. In all cases a standardised lifter was used. No instruction was given to either participant regarding the technique used to lift the lids. Testing was conducted in the field to capture real-life manual handling stresses. Stresses were measured using wireless electromyography to quantify muscle activation levels from the back (erector spinae) and the shoulder (trapezius) muscles. Trunk flexion was observed passively via video quantified separately in laboratory testing (see report 7).

RESULTS

The Terra Firma E400 Fibreglass Composite cover elicited up to a 130.65% reduction in peak muscle activation of the back and shoulder compared to the cast iron concrete infill lid (figure 3a&b).

Trunk flexion was visibly reduced when lifting the Terra Firma E400 Fibreglass Composite cover (see report 7).

FIGURE 3A.

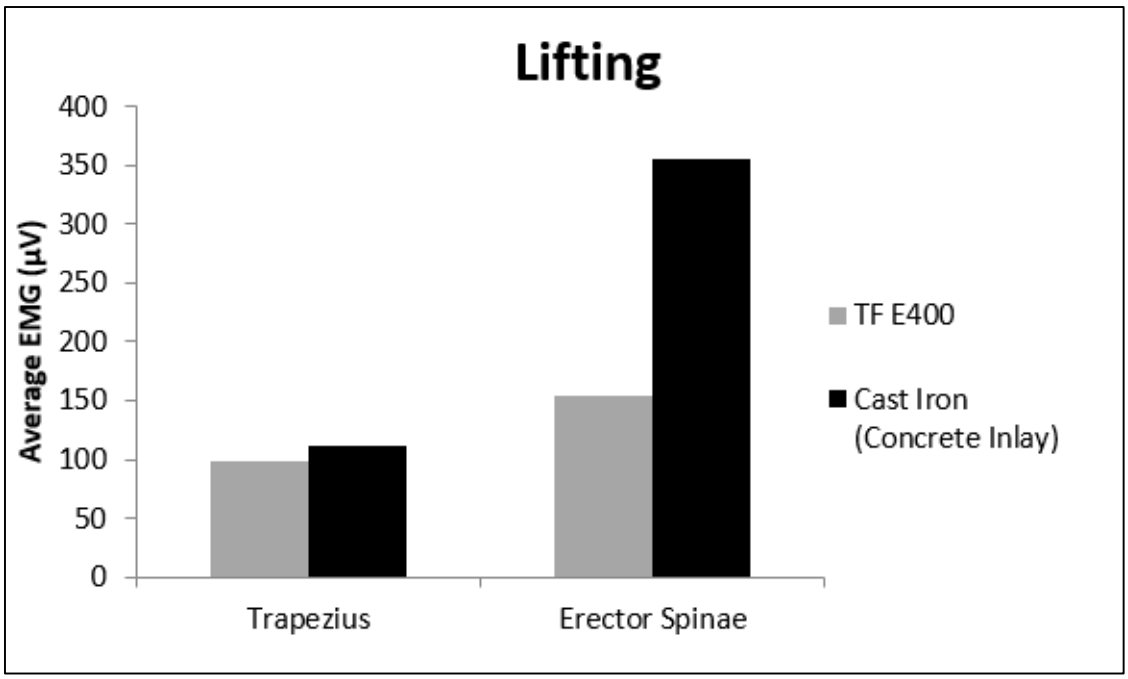
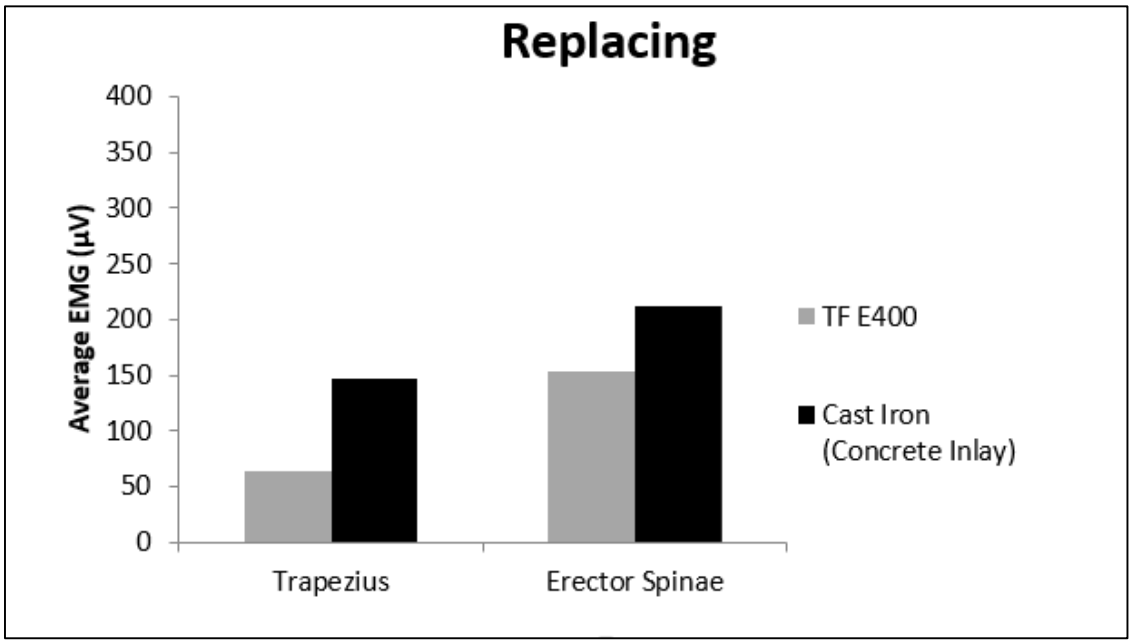


FIGURE 3B.



CONCLUSIONS

The Terra Firma E400 Fibreglass Composite cover produced safer posture and muscle activation levels compared to its cast iron concrete infill counterparts. These findings support the conclusion that the Terra Firma E400 Fibreglass Composite cover stresses the body significantly less during lifting and replacement. Reduction in peak muscle activation directly decreases the risk of injury in workers who lift and replace lids as part of their daily work tasks.[3]

REPORT 4. Terra Firma B80 SEP TF5130 Fibreglass Composite vs Slab Concrete

METHODS

The Terra Firma B80 Fibreglass Composite cover weighing 24kg was tested against a comparable sized slab concrete cover weighing 120kg. Two male participants attempted to perform three repeat lifts and replacements of each pit lid with defined rest intervals between lifts. In all cases a standardised lifter was used. No instruction was given to either participant regarding the technique used to lift the lids. Testing was conducted in the field to capture real-life manual handling stresses. Stresses were measured using wireless electromyography to quantify muscle activation levels from the back (erector spinae) and the shoulder (trapezius) muscles. Trunk flexion was observed via video and quantified separately in laboratory testing.

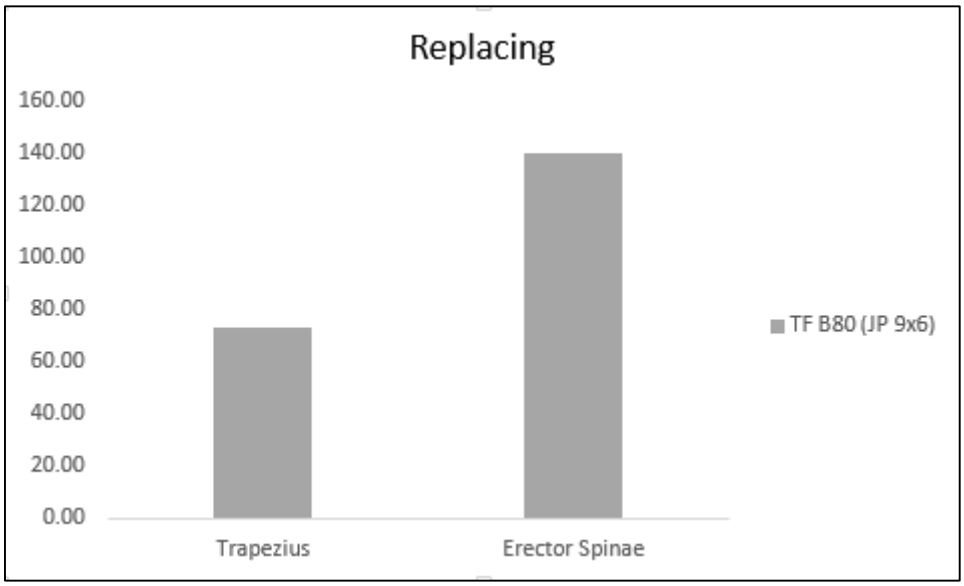
RESULTS

Although some lift of slab concrete cover was achieved, it was neither possible nor safe to achieve the full opening of the pit required for comparative muscle activation testing. The Terra Firma B80 Fibreglass Composite cover completed testing without incident (figure 4a&b).

Trunk flexion was visibly reduced when lifting the Terra Firma B80 Fibreglass Composite cover.

FIGURE 4A.

FIGURE 4B.



CONCLUSIONS

The Terra Firma B80 Fibreglass Composite cover produced safer posture compared to its standard slab concrete counterpart. Slab concrete could not safely be considered a comparable product for testing purposes. These findings support the conclusion that the Terra Firma B80 Fibreglass Composite cover stresses the body significantly less during lifting and replacement. Reduction in peak muscle activation directly decreases the risk of injury in workers who lift and replace lids as part of their daily work tasks.[3]

REPORT 5. Terra Firma B80 SEP TF5130 Fibreglass Composite vs Hinged Composite

METHODS

The Terra Firma B80 Fibreglass Composite cover weighing 24kg was tested against a comparable sized hinged composite cover weighing 25kg. Testing was conducted both in the lab and field to capture controlled and real-life manual handling stresses. Two male participants performed six lifts and replacements of each pit lid in each environment with defined rest intervals between lifts. In all cases a standardised lifter was used. No instruction was given to either participant regarding the technique used to lift the lids. Stresses were measured using wireless electromyography to quantify muscle activation levels from the back (erector spinae) and the shoulder (trapezius) muscles. Trunk flexion was observed passively via video and quantified separately in laboratory testing (see report 7).

RESULTS

The hinged composite cover elicited up to a 245.32% increase in peak muscle activation of the back and shoulder compared to the Terra Firma B80 Fibreglass Composite cover (figure 5a&b). The stresses of manipulating the hinged composite cover were the most dramatic activation of the back (erector spinae) muscles seen in any testing including opening and closing the much heavier 95kg cast iron and concrete cover (see report 3).

Trunk flexion was visibly reduced when lifting the Terra Firma B80 Fibreglass Composite cover.

FIGURE 5A.

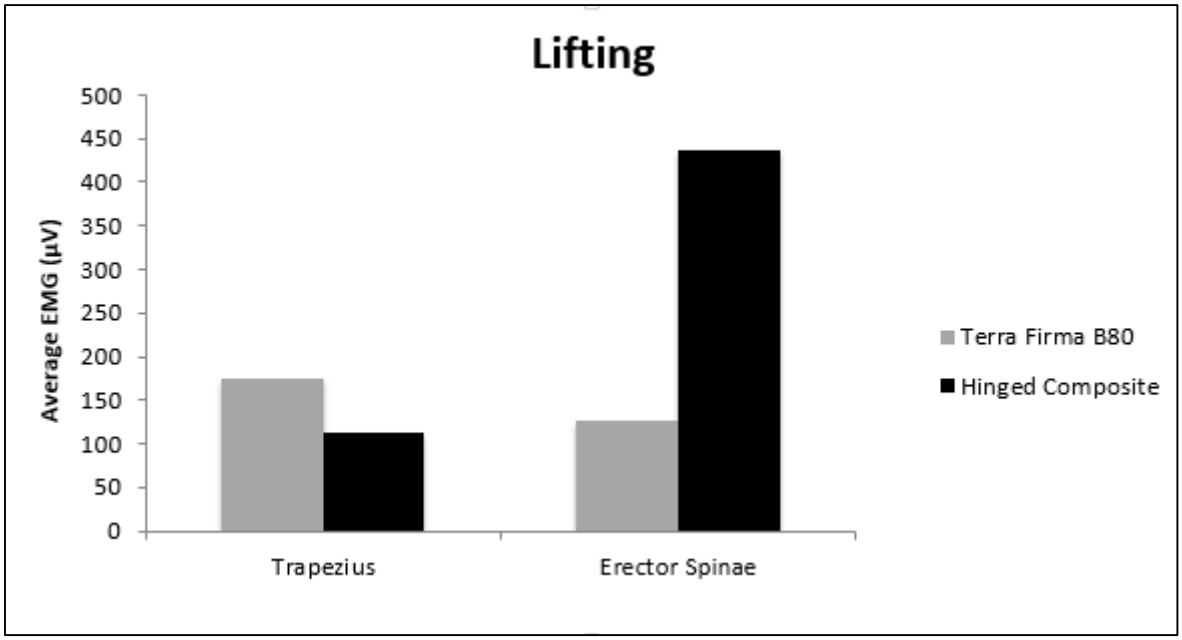
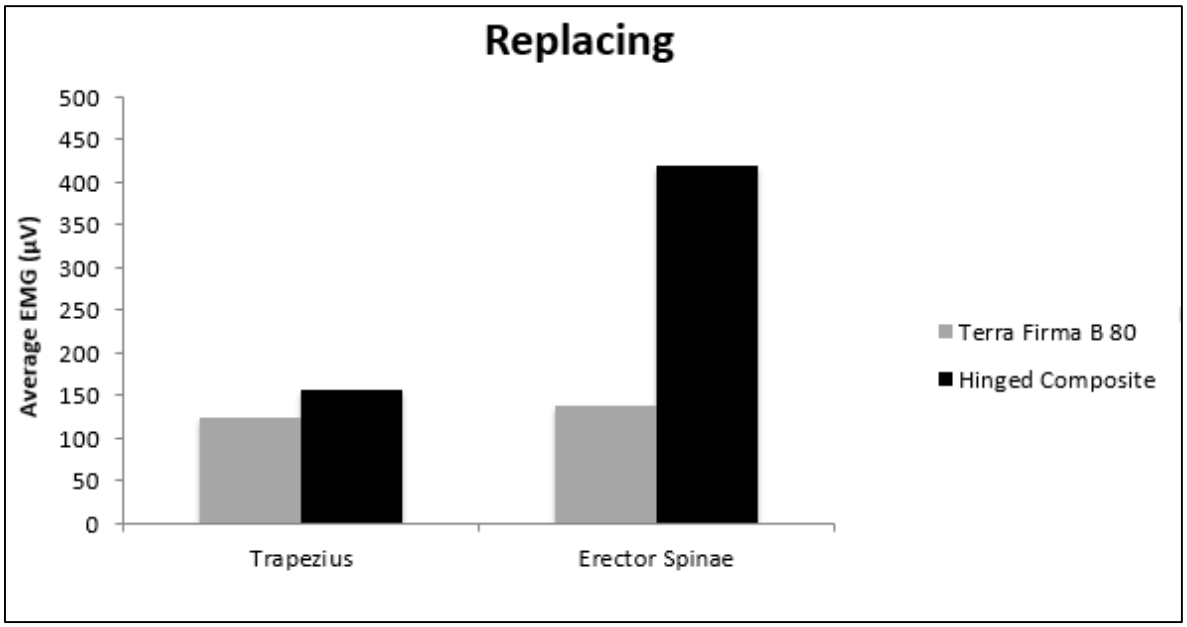


FIGURE 5B.



CONCLUSIONS

The Terra Firma B80 Fibreglass Composite cover produced safer posture and muscle activation levels compared to its hinged composite counterpart. These findings support the conclusion that the Terra Firma B80 Fibreglass Composite cover stresses the body significantly less during lifting and replacement. Reduction in peak muscle activation directly decreases the risk of injury in workers who lift and replace lids as part of their daily work tasks.[3]

REPORT 6. Terra Firma Ergonomic lifter vs Standard Lifter

METHODS

One male participants performed three repeat lifts and replacements of each pit lid with defined rest intervals between lifts. A standard (short) and Ergonomic (long) lifter was used for comparisons. Composite lids lifted included the Terra Firma B80 and Terra Firma C150 Fibreglass Composite models. No instruction was given to either participant regarding the technique used to lift the pit lids. Participant lifting mechanics were quantified in a laboratory setting by using a 12-camera motion analysis system. Muscular stresses were also measured using wireless electromyography to quantify muscle activation levels from the back (erector spinae) and the shoulder (trapezius) muscles. All data were analysed to quantify the differences in trunk posture and muscle activation between tools during a lid lifting phase and a lid replacement phase.

RESULTS

Analysis of the data collected suggests that using the Ergonomic lifter significantly reduced the level of bending required. The Ergonomic lifter required on average 28° less trunk flexion to lift the lid and 35° less trunk flexion to replace the lid than the standard lifter counterpart (figure 6a&b).

No difference was identified between lifters in muscle activation from the back or shoulders. This can be attributed more to the similarity in size and weight of the covers than to the lifter itself.

This finding is consistent across both models of covers.

FIGURE 6A.

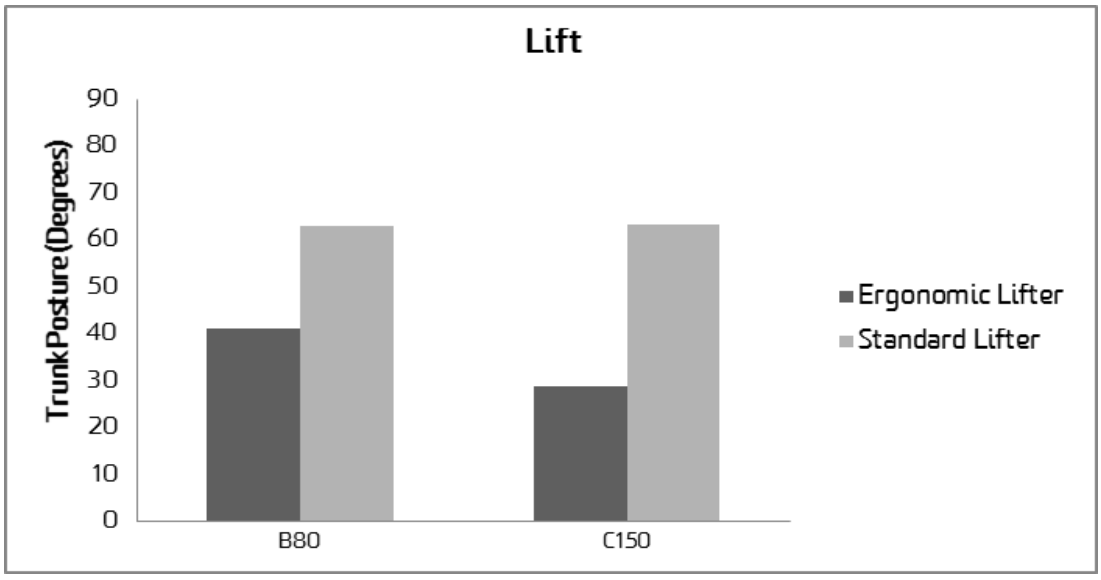
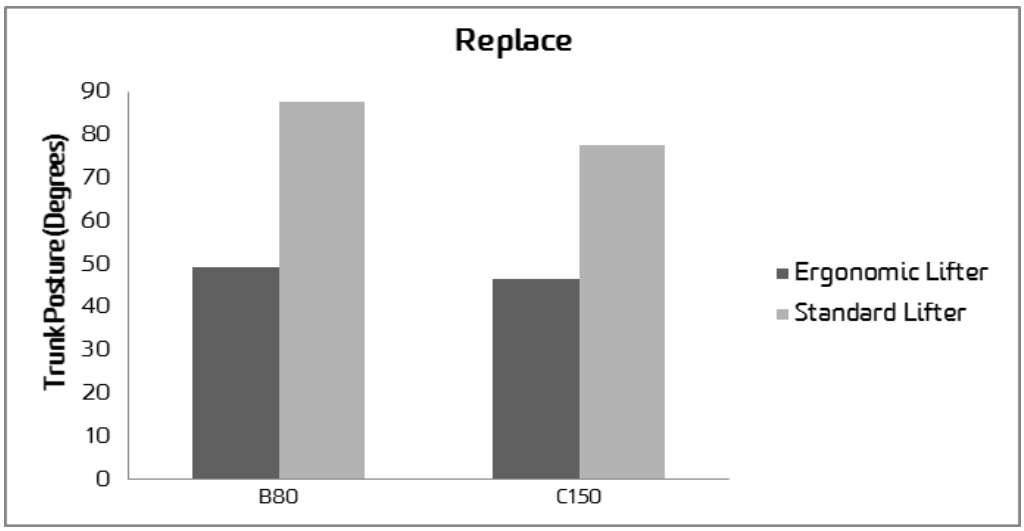


FIGURE 6B.



CONCLUSIONS

These findings support the conclusion that the Terra Firma Ergonomic lifter stresses the body significantly less during lifting and replacement. This confirms that the Ergonomic lifter is the tool of choice to decrease manual handling stress on the worker directly decreasing the risk of injury in workers who lift and replace lids as part of their daily work tasks.[3]

REPORT 7. Terra Firma E400 Seal Breaker vs Standard Ductile Iron Concrete Infill Lifter

METHODS

One male participants performed three repeat lifts and replacements of each pit lid with defined rest intervals between lifts. A Terra Firma Seal Breaker and a ductile iron concrete infill lifter were used for comparisons. A Terra Firma E400 Fibreglass Composite in-road cover and comparable ductile iron concrete infill lid were lifted. No instruction was given to either participant regarding the technique used to lift the lids. Participant lifting mechanics were quantified in the laboratory setting by using a 12-camera motion analysis system. Lifting mechanics were quantified in the field using single camera video. Muscular stresses were also measured using wireless electromyography to quantify muscle activation levels from the back (erector spinae) and the shoulder (trapezius) muscles. All data were analysed to quantify the differences in trunk posture and muscle activation between tools during a lid lifting phase and a lid replacement phase.

RESULTS

The Terra Firma E400 Seal Breaker elicited up to a 53.44% reduction in peak muscle activation of the back and shoulder compared to the ductile iron concrete infill lifter (figure 7a&b).

Detailed analysis of trunk flexion data was limited by the extreme range of motion required to initiate the lifting process for the ductile iron cover. This included actions such as jumping and twisting with trunk flexion well beyond measurable tolerances. The Terra Firma E400 Seal Breaker maintained a stable upright posture, required minimal trunk flexion, and significantly reduced lumbar spine muscle activation than all other lifters tested.

FIGURE 7A

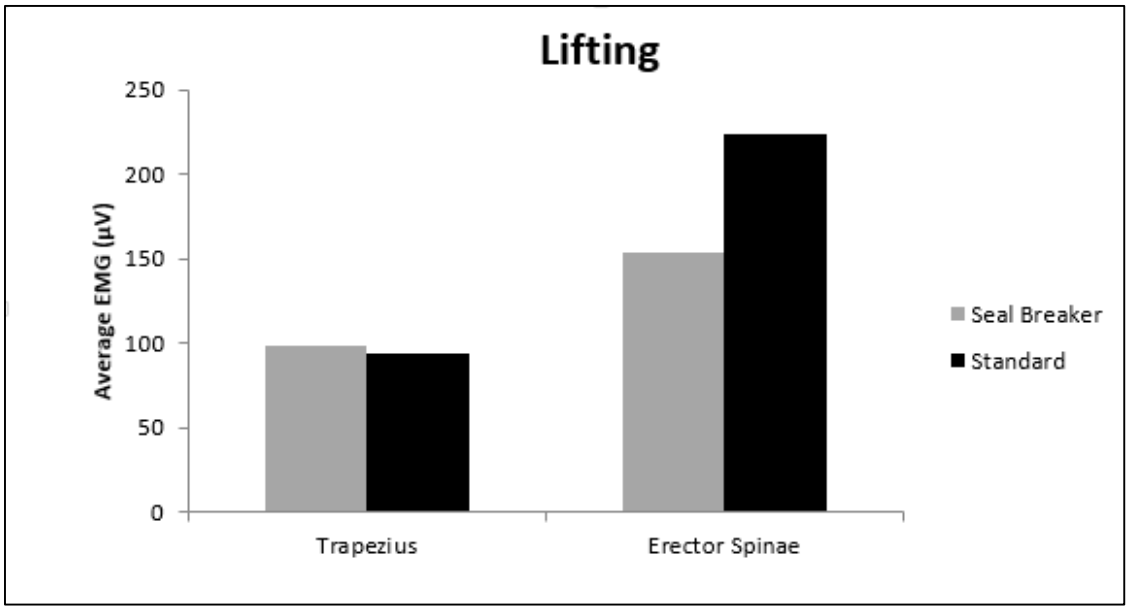
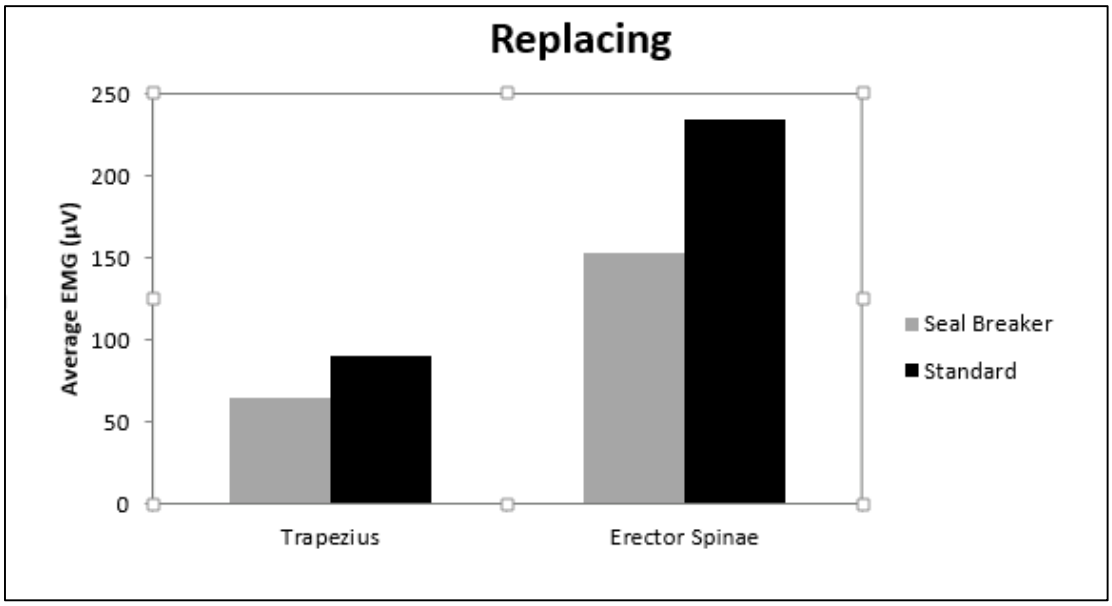


FIGURE 7B



CONCLUSIONS

These findings support the conclusion that the Terra Firma E400 Seal Breaker stresses the body significantly less during lifting and replacement but most dramatically during lift initiation. This confirms that the Terra Firma E400 Seal Breaker is the tool of choice to decrease manual handling stress on the worker directly decreasing the risk of injury in workers who lift and replace lids as part of their daily work tasks.[3]

DATA

For detailed data please contact Dr Kevin Netto, Senior Lecturer - Biomechanics, School of Exercise and Nutrition Sciences, Deakin University or Mr Ashley Reid, Terra Firma Industries on 03 9464 6169.

DISCUSSION

1. The impact of the weight reduction achieved by the Terra Firma pit lids.

This study identified that the lower weight of the terra firma products was clearly and consistently associated with reduced muscle activation. However surprisingly, while expecting a 10, 20 or 30 percent reduction in muscle activation the study consistently identified muscle activation reductions of up to 200 percent. This is a significant finding as it indicates a shift from using muscles at almost peak intensity (for traditional products) to using muscles at very much optimal ranges (for Terra Firma products).

The impact on muscle fatigue, and associated propensity to injury, as a result of reduced peak activations was equally dramatic. Terra Firma products consistently achieved significant weight reductions over all traditional products and were 96kg lighter (5 times lighter) than slab concrete lids. Fatigue acts with a cumulative effect, although it might not be on the first lift that injury occurs it is common for workers to lift multiple times a day over weeks and years. Risk increases over each lift. The weight reduction seen in the terra Firma Products directly impacts rates of fatigue.

The impact of weight on body position was also examined. In some instances testing of traditional products elicited results where movements were quite extreme with bending clearly beyond the recommended 30 degrees seen along with significant twisting motions. As a consequence results in these tests were not accurately quantifiable (see Report 2). One traditional product was so heavy it was not considered safe to complete testing (see Report 4). Terra Firma products also consistently achieved a more upright (safer) body posture when compared to traditional products.

2. The impact of the lift and drag technique used for opening Terra Firma pit lids.

Testing confirmed that the Terra firma products utilised a momentum strategy with the lift and drag technique, where peak activations and propensity to injury tend to be lower. The traditional products tested all elicited a more risky force strategy (a sharp, sudden increase where peak muscle activations tend to be higher and which is associated with higher propensity to injury).

Of particular note was the hinged lid. Three issues with this lid became apparent on analysis of the data and video. Firstly, the impact of the weight of the lid as already discussed above. Secondly, the mechanism of lifting. The lifter has to be 100% sure to get the lid past 90 degrees while at the same time managing the increased risk of falling into the open pit. Finally, the risk of the lid falling back onto the lifter (and subsequent risk of injury). All three of these risks were engineered out by the Terra Firma lift and drag technique.

3. The impact of the ergonomic lifter Terra Firma had developed for use with these pit lids.

This was examined by assessing the impacts on body position while lifting and replacing lids, where a more upright posture is associated with increased spine stability and reduced injury risk.

We found, without much surprise, the ergonomic lifter maintained a more upright posture compared to other lifting mechanisms. In a more upright posture the spine is more stable and consequently stronger. When bending forward, the spine is weaker. When bending forward past 30 degrees, the spine is very weak. Bending past 30 degrees puts the spine into what is described as the elastic zone. If the spine is continually put into the elastic zone what is generally seen is that over time the deformation in the disc becomes permanent. 30 degrees is a breaking point at which the disc does not come back to its normal size. This deformity can become acute. A significant number of work compensation claims arise from this sort of injury. It is arguably one of the most expensive non-fatal or non-totally debilitating or bed-ridden injuries to be seen in Australia.

In summary:

The muscle activation patterns seen while testing traditional pit lid products can be compared to studies done on air fighter pilots. The fighter pilot studies elicited big activation patterns in postural muscles, muscles of the back and of the neck. When flying straight and level, fighter pilots have activation levels of 10% to 20%. But when dog fighting with high G-forces, this can go up to 90%, 95%, even over 100% of their potential maximum activation. Significantly 90% of fighter pilots have neck injuries. Some of them have career-ending neck injuries.[1]

With the discrepancy of activation of over 200% seen between Terra Firma products and traditional products the potential risk of injury is extremely high with traditional products. By engineering risk out of their products it can be estimated that injury risk is not dropping by tenfold but more probably dropping by 200 fold when using Terra Firma products.

CONCLUSION

The terra Firma products tested produced safer postures and muscle activation levels compared to their respective counterparts

These findings suggest Terra Firma products stress the body's musculoskeletal system less during pit lid lifting and replacing than their respective counterparts.

This reduction in stress will decrease the risk of injury as well as fatigue in works who commonly lift and replace pit lids as part of their daily work tasks.

Terra Firma products are ergonomically safer compared to their market counterparts.

These products substantially lower muscle activation in the back and shoulders and allow workers to adopt safer postures during pit lid lifting and replacing operations.

These changes in the workers ergonomics will substantially decrease the risk of musculoskeletal injury.

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