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SHEET METAL MANUAL HANDLING AIDS: EFFECTS OF DESIGN DIFFERENCES ON MUSCLE ACTIVITY AND SUBJECTIVE ASSESSMENT

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ABSTRACT: Manual material handling is a common task in various industries and has been linked to work-related musculoskeletal injuries. Handling heavy and bulky sheet metal manually can cause awkward postures and forceful exertion, leading to intense biomechanical load on the workers. A trolley lifter was designed and fabricated to address this issue and improve work postures during sheet metal transfer tasks. This study aimed to investigate the potential ergonomic benefits of the trolley lifter design compared to the traditional hydraulic table cart. The study aims to determine the effect of the design differences between the two devices on muscle activities during sheet metal handling operations and to compare subjective perceptions of the subjects on these devices. The independent variable in this study was the type of device used for sheet metal handling (i.e., trolley lifter vs. traditional hydraulic table cart) and types of sheet metals (vary by thickness). The dependent variables were muscle activities in four different muscles (biceps brachii, triceps brachii, erector spinae, and trapezius) and subjective perceptions of the devices. A randomized repeated-measure experimental design was employed, surface electromyography was used to measure muscle activities, and a subjective questionnaire was administered to gather data on the participant's perceptions of the devices. Participants were asked to perform separate sheet metal handling operations using both devices. The relationship between the dependent and independent variables was examined. The non-parametric test indicated that there were significant decreases in muscle activation levels in the biceps brachii, triceps brachii, erector spinae, and trapezius muscles when using the trolley lifter compared to the traditional hydraulic table cart. Moreover, participants rated the trolley lifter as more usable, useful, and desirable than the traditional hydraulic table cart. In conclusion, the trolley lifter was a more effective and ergonomically beneficial tool for handling large sheet metals than the traditional hydraulic table cart. This study highlights the importance of ergonomic interventions in manual material handling tasks, advocating for adopting tools and equipment that can enhance worker safety, reduce physical strain, and improve overall job satisfaction.

ABSTRAK: Pengendalian bahan secara manual adalah tugas biasa dalam pelbagai industri dan telah dikaitkan dengan kecederaan muskuloskeletal yang berkaitan dengan kerja. Mengendalikan kepingan logam yang berat dan besar secara manual boleh menyebabkan postur yang janggal dan tenaga yang kuat yang membawa kepada beban biomekanikal yang kuat pada pekerja. Untuk menangani isu ini, pengangkat troli telah direka untuk memperbaiki postur kerja semasa tugas pemindahan kepingan logam. Kajian ini bertujuan untuk menyiasat lebih lanjut potensi faedah ergonomik reka bentuk pengangkat troli berbanding troli meja hidraulik tradisional. Objektif kajian ini adalah untuk menentukan kesan perbezaan reka bentuk antara kedua-dua peranti pada aktiviti otot semasa operasi pengendalian kepingan logam dan untuk membandingkan persepsi subjektif subjek kepada peranti ini. Pembolehubah bebas dalam kajian ini ialah jenis peranti yang digunakan untuk pengendalian kepingan logam (iaitu, pengangkat troli berbanding troli meja hidraulik tradisional) dan jenis kepingan logam (berbeza mengikut ketebalan). Pembolehubah bersandar ialah aktiviti otot dalam empat otot yang berbeza (biceps brachii, triceps brachii, erector spinae, dan trapezius) dan persepsi subjektif pada peranti. Reka bentuk eksperimen ukuran berulang secara rawak telah digunakan dan elektromiografi permukaan digunakan untuk mengukur aktiviti otot, serta soal selidik subjektif telah diberikan untuk mengumpul data mengenai persepsi peserta kepada peranti. Peserta diminta melakukan operasi pengendalian kepingan logam menggunakan kedua-dua peranti pada masa yang berasingan. Hubungan antara pembolehubah bersandar dan tidak bersandar telah dikaji. Ujian bukan parametrik menunjukkan bahawa terdapat penurunan ketara dalam tahap pengaktifan otot dalam bisep brachii, triceps brachii, erector spinae, dan otot trapezius apabila menggunakan pengangkat troli berbanding dengan troli meja hidraulik tradisional. Selain itu, peserta menilai pengangkat troli sebagai lebih boleh digunakan, berguna dan diingini daripada troli meja hidraulik tradisional. Kesimpulannya, pengangkat troli telah terbukti sebagai alat yang lebih berkesan dan ergonomik untuk mengendalikan kepingan logam yang besar berbanding dengan kereta meja hidraulik tradisional. Kajian ini menyerlahkan kepentingan campur tangan ergonomik dalam tugas pengendalian bahan manual, menyokong penggunaan alatan dan peralatan yang boleh meningkatkan keselamatan pekerja, mengurangkan ketegangan fizikal, dan meningkatkan kepuasan kerja secara keseluruhan.

KEYWORDS: *Ergonomics, manual material handling, trolleys, sheet metal, electromyography.*

1. INTRODUCTION

Manual material handling (MMH) is prevalent in industries and associated with work-related injuries such as musculoskeletal disorders. The International Labor Organization and the World Health Organization have raised concerns about the rise in work-related musculoskeletal disorders, which significantly impact productivity and have serious health implications. Injuries like overexertion may occur when workers perform MMH tasks that exceed their physical capabilities [1]. Workers' compensation claims associated with injuries due to MMH were found to represent a significant number of claims in Malaysia, with over 8000 cases reported in 2022 [2]. To mitigate these risks, several guidelines on MMH have been published by various agencies and regulatory bodies to guide proper handling techniques [3-5]. Improper handling techniques, especially for heavy and large items, can lead to low work efficiency and safety and health issues, such as back pain, sprains, strains, cuts, and bruises. These items can be challenging for human workers to handle due to their large dimensions and weight. As a result, mechanical aids are often used to facilitate safer and more efficient handling operations. Controlling hazards in material handling activities within the industry presents significant challenges, particularly in eliminating or substituting these hazards. Consequently, engineering controls are often the preferred approach. The design of material handling aids represents a form of engineering control aimed at minimizing ergonomic risks in material handling tasks.

There are two main types of mechanical aids available for handling large and heavy items: motorized and non-motorized. Motorized aids, including forklifts, vacuum lifting devices, and crane systems, enhance worker ergonomics and efficiency during heavy lifting tasks [6]. However, these devices can be expensive and bulky, require specific operational skills, and necessitate more space, making them less practical for small workshops. Non-motorized devices, such as industrial trolleys, hand trucks, hydraulic table carts, and tilt-top trolleys, offer a more cost-effective and compact alternative for handling large items. In Malaysia's labor-intensive economy, with many foreign workers providing cheaper labor, non-motorized devices are still widely used, especially in small and medium-sized enterprises. However, these devices may be less efficient, and handling operations can still expose workers to health and safety risks, particularly when dealing with large or sharp-edged items like sheet metals, necessitating careful examination of more ergonomically designed devices.

When designing material handling equipment, it's essential to consider various ergonomic factors to ensure the well-being of workers. This includes minimizing the force required to operate equipment, avoiding awkward postures, reducing repetitive motions, considering the weight of objects being handled, optimizing workstation dimensions, and enhancing overall productivity. Considering these criteria, we can minimize the physical strain on workers' body mechanics and create a more efficient and healthy workplace design. Incorporating proper measures to control musculoskeletal hazards plays a crucial role in achieving Sustainable Development Goal (SDG) 3, which focuses on promoting good health and well-being. Furthermore, SDG 8, centered on promoting decent work and economic growth, emphasizes the importance of integrating occupational health and safety practices within the framework of decent work. Lastly, SDG 9 highlights the significance of industry, innovation, and infrastructure, emphasizing how effective ergonomic design can enhance efficiency and safety within operations.

Numerous ergonomic studies have explored manual handling aids to reduce work-related musculoskeletal disorders (WMSDs) [7-8]. For instance, Koppelaar et al. [9] examined the impact of ergonomic devices on the biomechanical load of nursing staff when handling patients. Greco et al. [10] proposed a method to analyze the design parameters of an industrial cart to assess ergonomic risks during pushing or pulling tasks. Kundu et al. [11] designed a trolley for mud transfer in brick-molding activities to reduce physical strain on workers by improving working postures. Additionally, using MMH aids for lifting has been shown to significantly lower the incidence rates of low-back injuries, physical work demands, and WMSD symptoms [12-14]. However, many studies have focused on the effects of various factors on human biomechanical load when using specific MMH aids [15-21]. Few studies have examined the efficiency of multiple non-motorized manual handling aids for large objects and compared their ergonomic impacts on users. These studies assessed changes in biomechanical workloads, such as when using modified table carts in production and warehouse lifting activities [22-23], hand trucks for agricultural products [24], assistive mechanisms for patient lateral transfers [25], auxiliary handling devices for construction work [26], and devices for carrying large water bottles [27].

For the manual handling of large sheet metals, the research team previously designed, developed and fabricated a trolley lifter to improve work postures [28]. The trolley lifter has shown early promise in improving work efficiency, occupational safety, and health conditions. In addition to reducing cycle time and manpower utilization, the device was found to enhance work postures and reduce exposure to physical contact with sharp edges, compared to traditional handling methods used by technicians. This study aims to further quantify the potential benefits of the trolley lifter design compared to traditional manual handling methods. Specifically, the study aims to investigate the impact of design differences between the trolley lifter and the traditional hydraulic table cart on muscle activity and subjective perceptions of subjects during sheet metal handling operations.

2. METHODOLOGY

A randomized, two-way, repeated-measures experiment was conducted to determine the effect of material handling device design on muscle activities and subjects' subjective perceptions of using the devices during the sheet metal handling task. The experiment took place at a fabrication workshop involving a cutting machine for sheet metals.

2.1. Subjects

Twenty-five healthy, non-smoking male subjects, young adults, participated in the experiment. Only subjects free of any musculoskeletal disorders or injury history that might affect how they performed the experimental tasks were recruited. The subjects were fully informed and understood the study before beginning the experimental procedures, which included detailed information about the study's purpose, procedures, potential risks, and their right to withdraw at any time without consequence. Additionally, all data collected were anonymized and handled strictly to protect participants' privacy. Our study was designed following recognized ethical principles, including those outlined in the Declaration of Helsinki. Written informed consent was obtained from all participants aged between 20 and 25 years old, with a mean body weight of 75 kg (SD = 15) and a mean height of 175 cm (SD = 10).

2.2. Experimental Design

The experiment involved two independent variables: types of trolleys and types of sheet metals. Figure 1 shows the trolleys used in this experiment. The hydraulic lift table cart in Figure 1 (left) is the trolley commonly used in the operations of the fabrication workshop as a material handling tool. The authors designed the tilt-top trolley lifter in Figure 1 (right) to improve the handling of large sheet metals. Table 1 describes its basic structural elements. The details of the new trolley lifter have been described in a previous study [28].

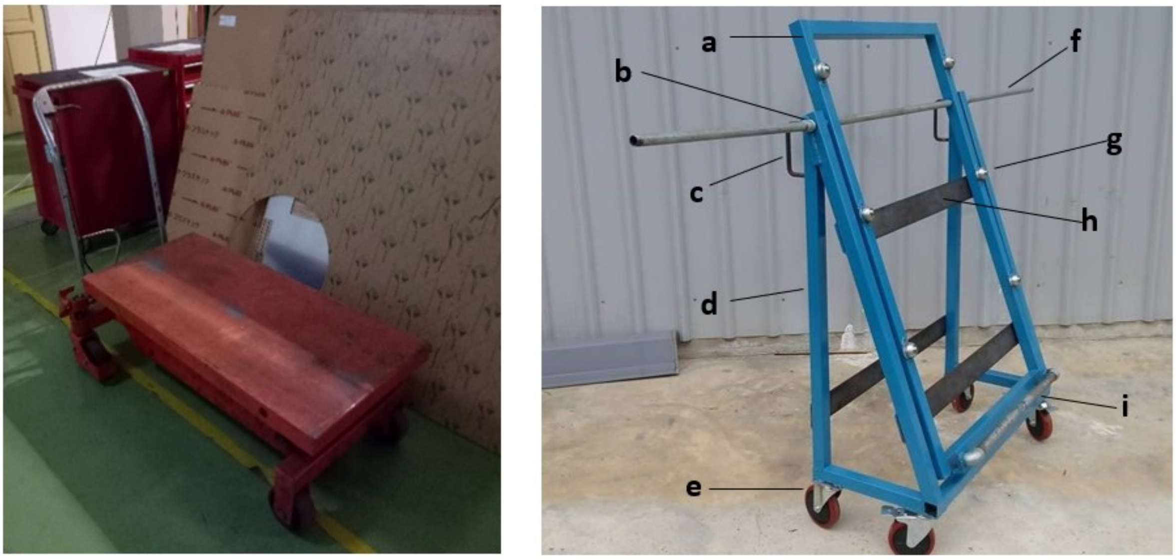

Figure 1. A hydraulic lift table cart (left) and tilt-top trolley lifter (right) were used in this study.

Three types of same-size sheet metals that differ by thickness were used in this study, representing various metal weights commonly handled by technicians in a local fabrication workshop. The sheet metals studied were 1mm galvanized iron sheet metal, 3 mm aluminum sheet metal, and 6mm aluminum sheet metal. The dependent variables were the subjects' normalized muscle activities (percent maximum voluntary contraction, %MVC) of four different muscles and subjective perceptions of the material handling devices' usability, usefulness, and desirability. The muscles involved in this study are the right side biceps brachii (BB), triceps brachii (TB), erector spinae (ES), and upper trapezius (TP), which were measured using surface electromyography (EMG). Additionally, subjective assessments were also conducted using a questionnaire specifically designed to gather the participants' perceptions of the two devices, focusing on the usability, usefulness, and desirability of the studied devices. A small pilot run was conducted with a few participants to ensure the questions were clear, understandable, and appropriate for the study context. Any feedback from the pilot was carefully incorporated into the final version of the questionnaire to enhance its relevance and clarity.

Table 1. Overview of trolley lifter components (as per Figure 1)

Label	Part Element	Material
a	Rectangular frame	Hollow metal tube
b	Rotation socket	Galvanized iron
c	Handle for pushing/pulling	Iron rod
d	Triangular side frame	Hollow metal tube
e	Swivel caster wheel	Rubber wheel with galvanized steel
f	Support rod	Galvanized iron
g	Rollerball	Stainless steel
h	Plate support	Steel
i	Handle for tilting	Steel with rubber grip

A randomized repeated measure experimental design was conducted such that each subject performed all the sheet metal and device combinations in a randomized order to prevent an order effect bias. Each combination was replicated twice for each subject. In each experimental task, the subject, with the help of an assigned helper, loaded a sheet metal onto the trolley from the storage rack and then transferred the metal to the specified location before unloading the metal onto a laser cutting machine (see Figure 2).

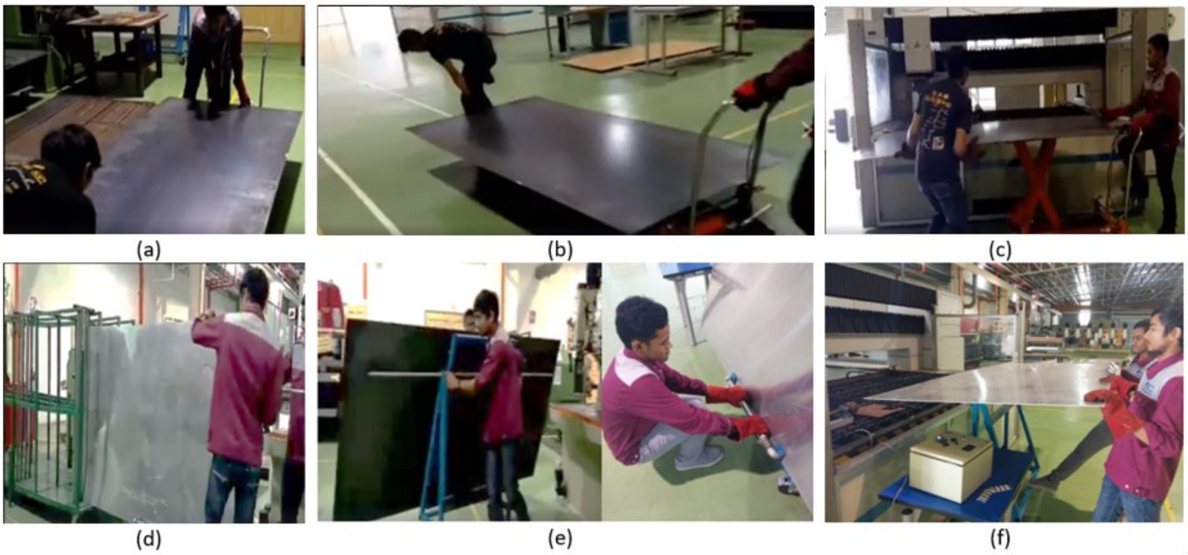

Figure 2. (a)-(c): The process of sheet metal handling with a table cart,
(d)-(f): The process of sheet metal handling with a trolley lifter.

Before the subject performed the experimental tasks, skin preparation at the electrode sites was done as in [29] according to the sensor locations recommended by the standardization

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guideline “Surface electromyography (sEMG) for non-invasive assessments of muscles” (SENIAM) [30]. Figure 3 depicts the location of the sensors for the four muscles. A reference electrode was placed at the right lateral epicondyle of the humerus, approximately 1 inch from the olecranon elbow [31]. Maximum voluntary muscle contraction (MVC) value was recorded for each muscle three times. Each contraction lasted 3 seconds, and 30 seconds of rest was given between each successive MVC recording, as in [32].

In the experimental task, the subject was asked to perform sheet metal handling operations involving loading, transferring, and unloading from the storage location to the laser cutting machine. The subject must first load the sheet metal from the storage area onto the handling device and then transfer the metal to the cutting machine in the fabrication workshop. The metal was then unloaded from the trolley onto the cutting machine. Each subject performed the operations with the help of a helper, as the sheet metal needed to be handled by two people. The EMG amplitude data was recorded during the loading of the sheet metal onto the handling device and the unloading of the metal onto the cutting machine from the handling device. The subject will repeat the experiment for a different device and sheet metal weight. Each subject rested for two minutes between successive experiments as in [31].

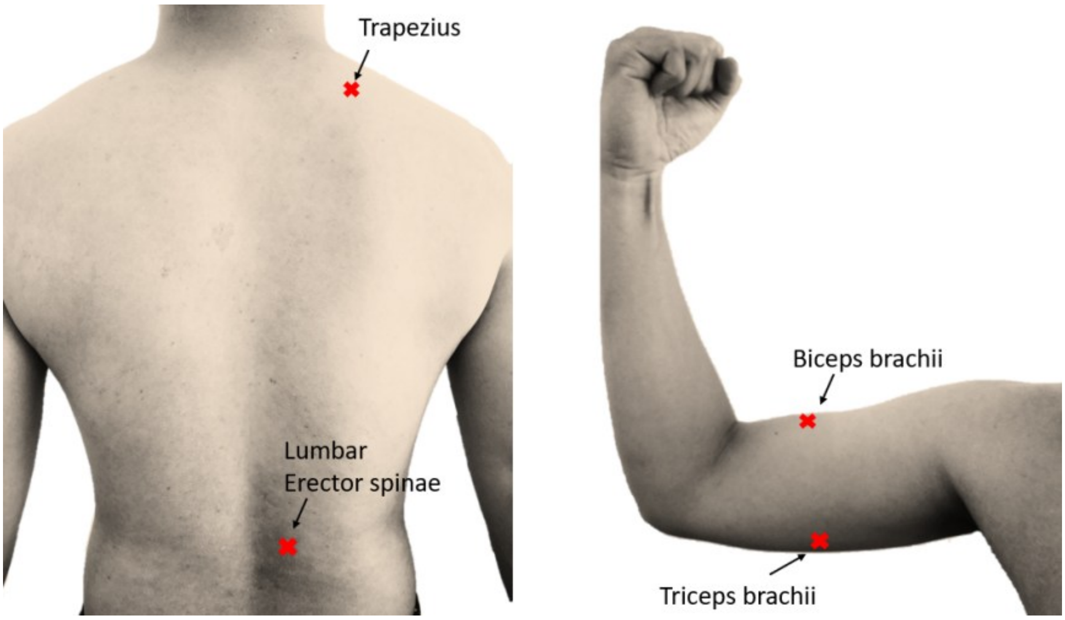

Figure 3. The placement of electrodes at lumbar erector spinae, upper trapezius, biceps brachii, and triceps brachii.

The EMG data was collected using sEMG TeleMyo 2400T G2 (Noraxon Inc., USA) device with Ag/AgCl electrodes. MyoResearch Master Edition software (Noraxon Inc., USA) was used to record and process the EMG signal data from each muscle studied. Each subject's resulting mean EMG amplitude data were normalized to the maximum voluntary contraction (MVC), a reference value for contraction.

After the subject completed all experimental task units, a questionnaire was given to obtain the subject's perception of the material handling devices concerning their usability, usefulness, and desirability. The subject was asked to indicate their level of agreement with the questions asked according to the 5-point Likert scale (1=strongly disagree, 2=disagree, 3=neutral, 4=agree, 5=strongly agree). Likert scale is a widely used questionnaire instrument to measure the degree of agreement with a set of questions in research [33].

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2.3. Statistical Analysis

Muscle activities in the biceps brachii, triceps brachii, erector spinae, and trapezius muscles were measured for both device types (trolley lifter and traditional hydraulic table cart) during loading and unloading tasks across three types of sheet metals (1mm, 3mm, and 6mm). Following data collection, comparisons of muscle activities were conducted between the two handling devices across the three sheet metal conditions for both tasks. The study analyzed differences in peak muscle activities using mean normalized EMG data (%MVC) at the 90th percentile [34].

We initially assessed the normality of the EMG data using the Shapiro-Wilk test. While most data sets yielded p-values above 0.05, indicating normality, some showed p-values below 0.05, suggesting deviations from normality. Given the sample size of 25 and mixed normality results, we applied non-parametric tests uniformly to ensure consistency and avoid selective bias in the analysis. Consequently, the Friedman test was employed to examine the effect of device types on peak muscle activities across the three types of sheet metal for both loading and unloading tasks. The significance level was set at $p < 0.05$, with effect sizes calculated using Kendall's W. Post hoc pairwise comparisons were performed using the Wilcoxon signed-rank test with Bonferroni correction to control for multiple comparisons. All statistical analyses were conducted using the SPSS statistics package [35]. Additionally, subjective perceptions were compared using descriptive statistics, with the median and interquartile range (IQR) reported as measures of central tendency to provide insights into participants' responses. The Wilcoxon signed-rank test was then utilized to examine the significant differences in participant response between the two devices.

3. RESULTS

3.1. Muscle Activities

Table 2 shows the means and standard deviations of normalized EMG (%MVC) data for each muscle from the loading and unloading tasks. The Friedman Test results, as shown in Table 3 on both loading and unloading tasks for each muscle, showed that there were significant differences in mean normalized EMG values between the related groups. Multiple pairwise Post Hoc comparisons were conducted to analyze the differences in peak muscle activity among the devices and the metal types using a Wilcoxon signed-rank test with a Bonferroni-corrected significance level of $p<0.0056$. Table 4 shows the results of the pairwise comparisons over nine combinations of levels. The Wilcoxon signed-rank test pairwise comparison revealed that the handling device significantly affected the peak muscle activity when compared over each type of sheet metal ($p<0.001$) for both loading and unloading tasks. The trolley lifter appeared to result in lower muscle activities, whereby the level of differences depended on the type of sheet metal. The types of sheet metals also affected the peak muscle activity for both devices in both tasks, such that higher muscle activities tend to correspond to heavier metal sheets. However, comparing the devices during the loading task with 6mm sheet metal, the differences in peak muscle activity were marginal for erector spinae and trapezius muscles. In addition, the results were also marginal for the trapezius muscle when comparing the handling devices over 3mm sheet metal in the unloading task. In the unloading task, an exception showed that handling the 3mm and 6mm sheet metals with a trolley lifter did not significantly affect the difference in the erector spinae peak muscle activity. These patterns can be observed in Figure 4-5. In short, the trolley lifter gives some advantages over the table cart in reducing biceps brachii, triceps brachii, lumbar, and trapezius muscles' activities depending on the types of sheet metal handled.

3.2. Subjective Perception

Table 5 displays the results of the subjective assessment of the studied devices. The assessment showed more favorable results for the trolley lifter, including the subjects' perception of fatigue and muscle pain when operating the devices. Small IQR values indicate a relatively small spread in the central portion of your data, suggesting more consistent responses or agreement among participants regarding both devices. The Wilcoxon signed-rank test also showed that the differences in subjective perception between table cart and trolley lifter were significant for all questions with p<.001 and *W*=0 except for question 9 (*W*=210). In addition, through direct comparison, 60 percent of the subjects agreed to use the trolley lifter, while the rest remained neutral. In contrast, none of the subjects agreed that they preferred to use the lift table cart, but 64 percent remained neutral. Besides, 80 percent agreed that the trolley lifter was easy to use, while only 8 percent agreed that the lift table cart was easy. In short, the trolley lifter was more usable, practical, and desirable for handling large sheet metal manually than the lift table cart.

Table 2. Mean normalized EMG data (%MVC) and standard deviation at 90th percentile (n=25).

Loading Task									
		Biceps		***Triceps***		***Erector Spinae***		***Trapezius***	
Device	**Metal**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Table	1mm	2.416	0.348	9.152	1.270	6.578	2.635	4.705	0.449
	3mm	6.050	1.049	14.191	2.497	15.518	3.493	6.801	0.978
	6mm	29.305	10.437	24.222	4.190	27.802	5.942	16.059	3.333
Trolley	1mm	1.726	0.205	5.267	0.749	3.403	0.647	2.733	0.612
	3mm	4.436	0.751	11.975	1.789	10.500	2.282	5.292	1.007
	6mm	12.627	2.092	19.713	3.105	24.963	5.921	13.567	2.682
Unloading Task									
		Biceps		***Triceps***		***Erector Spinae***		***Trapezius***	
Device	**Metal**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Table	1mm	3.403	0.656	12.970	1.646	10.445	2.552	6.569	1.792
	3mm	8.730	1.314	18.296	3.055	21.404	4.683	7.120	1.674
	6mm	16.254	3.087	27.650	5.223	24.060	5.507	16.686	2.481
Trolley	1mm	2.048	0.297	7.834	1.216	6.619	1.229	3.477	0.744
	3mm	6.041	0.825	12.064	1.992	17.943	4.099	6.646	1.282
	6mm	13.930	1.958	16.845	2.287	17.926	3.451	10.611	1.368

Table 3. Friedman Test results

Task	**Muscle**	**Chi-Squared**	**df**	**p**	**Kendall's W**
Loading	Biceps	124.451	5	< .001	0.996
	Triceps	121.069	5	< .001	0.969
	Erector Spinae	118.463	5	< .001	0.948
	Trapezius	120.017	5	< .001	0.960
Unloading	Biceps	123.080	5	< .001	0.985
	Triceps	114.371	5	< .001	0.915
	Erector Spinae	115.400	5	< .001	0.923
	Trapezius	112.794	5	< .001	0.902

4. DISCUSSIONS

This study revealed that the peak muscle activation levels were statistically significantly lower in the trolley lifter than in the lift table cart for both loading and unloading tasks (refer to Table 4 and Figures 4 to 5). This difference may be influenced by the types of sheet metal used. When using the table cart, the highest mean EMG value was recorded in the biceps brachii during the loading of a 6mm metal sheet (29.31). In contrast, when using the trolley lifter, the highest average load was observed in the erector spinae when loading a 6mm metal sheet (24.96). Further analysis of the data for both loading and unloading tasks indicated that the use of a trolley lifter had shown a reduction in muscular efforts, with an average maximum reduction of 57 percent in the biceps brachii, an average maximum reduction of 42 percent in the triceps brachii, an average maximum reduction of 48 percent in the erector spinae, and an average maximum reduction of 47 percent in the trapezius. For these muscles, the trolley lifter provided more advantages during the unloading task than the loading task. This conclusion outcome suggests that the trolley lifter can significantly decrease the muscular load when handling large sheet metals compared to the lift table cart. This is supported by the subjective perception assessment, which indicated more favorable results for the trolley lifter.

Table 4. Wilcoxon signed-rank test results on loading and unloading tasks

Muscles / Group pair	Biceps		Triceps		Erector Spinae		Trapezius	
	Z	Asymp. Sig. (2-tailed)	Z	Asymp. Sig. (2-tailed)	Z	Asymp. Sig. (2-tailed)	Z	Asymp. Sig. (2-tailed)
Loading Task								
Tab,1mm - Tab,3mm	-4.372[b]	<.001	-4.372[b]	<.001	-4.372[b]	<.001	-4.372[b]	<.001
Tab,1mm - Tab,6mm	-4.372[b]	<.001	-4.372[b]	<.001	-4.372[b]	<.001	-4.372[b]	<.001
Tab,3mm - Tab,6mm	-4.372[b]	<.001	-4.372[b]	<.001	-4.345[b]	<.001	-4.372[b]	<.001
Tro,1mm - Tro,3mm	-4.372[b]	<.001	-4.372[b]	<.001	-4.372[b]	<.001	-4.372[b]	<.001
Tro,1mm - Tro,6mm	-4.372[b]	<.001	-4.372[b]	<.001	-4.372[b]	<.001	-4.372[b]	<.001
Tro,3mm - Tro,6mm	-4.372[b]	<.001	-4.372[b]	<.001	-4.372[b]	<.001	-4.372[b]	<.001
Tab,1mm - Tro,1mm	-4.372[c]	<.001	-4.372[c]	<.001	-4.372[c]	<.001	-4.372[c]	<.001
Tab,3mm - Tro,3mm	-4.345[c]	<.001	-4.345[c]	<.001	-4.049[c]	<.001	-4.130[c]	<.001
Tab,6mm - Tro,6mm	-4.372[c]	<.001	-3.484[c]	<.001	-2.731[c]	0.006	-2.973[c]	0.003
Unloading Task								
Tab,1mm - Tab,3mm	-4.372[b]	<.001	-4.292[b]	<.001	-4.372[b]	<.001	-1.601[b]	<.001
Tab,1mm - Tab,6mm	-4.372[b]	<.001	-4.372[b]	<.001	-4.372[b]	<.001	-4.372[b]	<.001
Tab,3mm - Tab,6mm	-4.372[b]	<.001	-4.345[b]	<.001	-4.023[b]	<.001	-4.372[b]	<.001
Tro,1mm - Tro,3mm	-4.372[b]	<.001	-4.372[b]	<.001	-4.372[b]	<.001	-4.372[b]	<.001
Tro,1mm- Tro,6mm	-4.372[b]	<.001	-4.372[b]	<.001	-4.372[b]	<.001	-4.372[b]	<.001
Tro,3mm - Tro,6mm	-4.372[b]	<.001	-4.372[b]	<.001	-.040[c]	0.968*	-4.372[b]	<.001
Tab,1mm - Tro,1mm	-4.372[c]	<.001	-4.372[c]	<.001	-4.372[c]	<.001	-4.372[c]	<.001
Tab,3mm - Tro,3mm	-4.372[c]	<.001	-4.372[c]	<.001	-4.345[c]	<.001	-2.812[c]	0.005
Tab,6mm - Tro,6mm	-3.646[c]	<.001	-4.372[c]	<.001	-4.372[c]	<.001	-4.372[c]	<.001

a. Wilcoxon Signed ranks Test.
b. Based on positive ranks.
c. Based on negative ranks.
* non-significant result.

This study identified that the two devices—the table cart and trolley lifter—exhibited distinct muscle activation patterns as they handled heavier loads. Specifically, when comparing loading versus unloading tasks, the peak muscle loads on the biceps brachii, triceps brachii, erector spinae, and trapezius muscles were generally lower during loading tasks for both devices. However, exceptions emerged when handling 6mm metal sheets. With the table cart, the biceps, brachii, and erector spinae muscles showed higher activation levels during loading than unloading. Notably, the biceps brachii experienced a substantial increase in muscle load—nearly double—during the 6mm metal sheet loading. In contrast, when using the trolley lifter, higher muscle activation was observed in the triceps brachii, erector spinae, and trapezius during the loading task compared to unloading. These differences suggest that each device relies on distinct muscle recruitment strategies to manage the increased demands of heavier loads.

Additionally, during the loading tasks, the triceps brachii generally experienced higher peak loads than the biceps brachii across conditions. However, a notable exception was observed when using the table cart for loading the 6mm metal sheet, where the biceps brachii showed higher activation than the triceps brachii. This pattern indicates that the table cart may require more arm stabilization, possibly due to the positioning or grip required when handling heavier materials.

When comparing the two devices, all muscles showed an upward trend in activation levels as the metal sheet thickness increased, which aligns with previous findings [36]. However, the erector spinae muscle displayed a slight decrease in activation during the unloading of the 6mm sheet using the trolley lifter. This suggests that the trolley lifter might engage other muscle groups—such as the hips or legs—to assist in managing the load during unloading, thereby reducing the demand on the erector spinae.

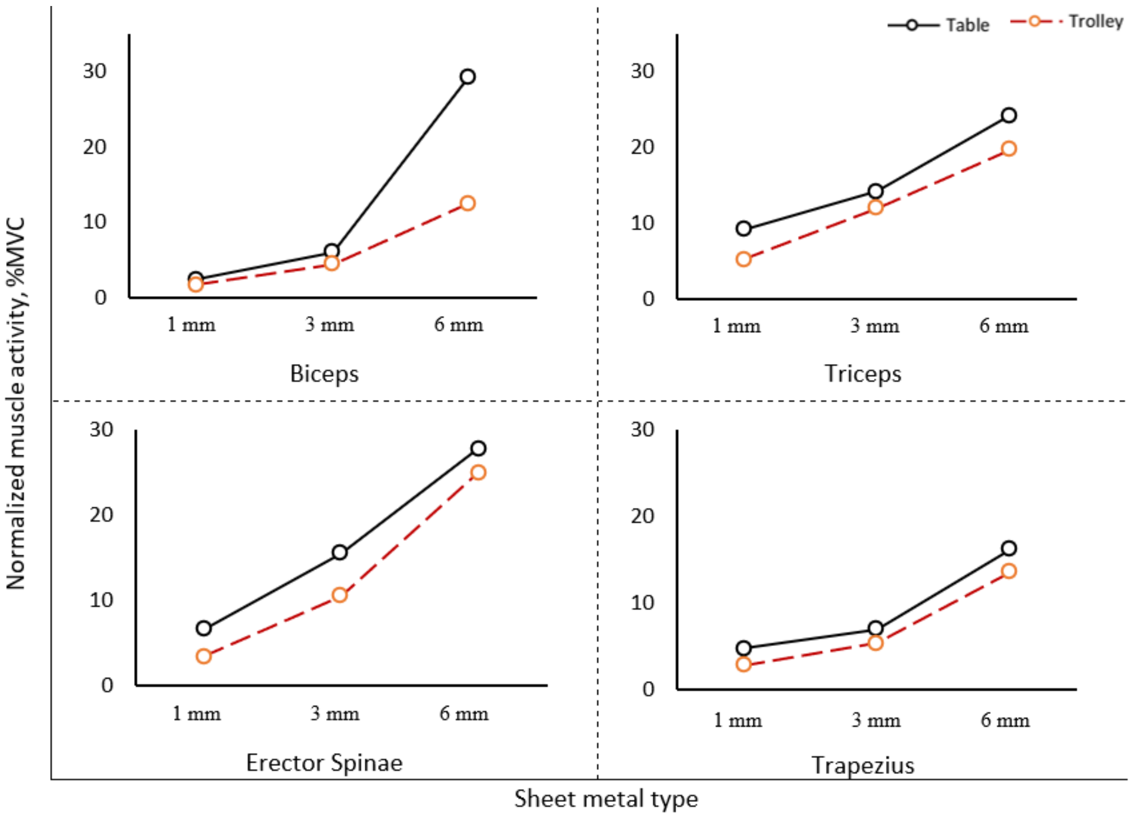

Figure 4. Mean normalized EMG values comparisons during the loading task against three different sheet metals for the four muscles.

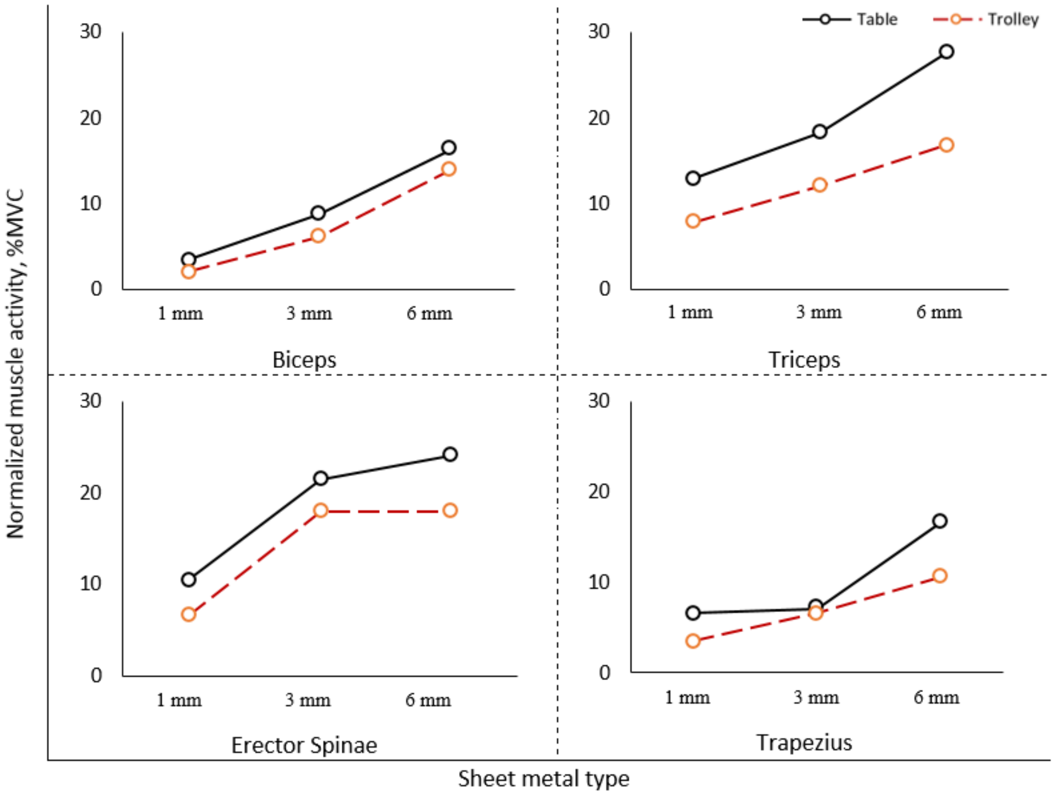

Figure 5. Mean normalized EMG values comparisons during the unloading task against three different sheet metals for the four muscles.

Table 5. Subjective assessment of the two devices.

Questions	Median (IQR) Score	
	Table cart	*Trolley lifter*
1. I can perform the task easier by using this device.	3(1)	4(0)
2. I was able to complete the tasks quickly when using the device.	2(1)	4(0)
3. I think that I would need the support of a person to be able to use the device.	4(0)	3(0)
4. I found the device meets my needs.	2(1)	4(0)
5. I am satisfied with the device.	2(1)	41)
6. I felt the device was useful.	3(1)	4(1)
7. I would like to use the device for the sheet metal transfer task.	3(1)	4(1)
8. I think using the device can reduce fatigue at the end of the work day.	3(1)	4(1)
9. I think I have muscle pain when performing the task using the device.	4(1)	2(1)

Likert scale: 1=strongly disagree, 2=disagree, 3=neutral, 4=agree, 5=strongly agree.

As previously highlighted, the activation levels across the muscles generally followed a consistent trend across the devices and tasks, except when handling the heavier 6mm sheet metal. This exception likely reflects adaptive muscle recruitment strategies the body employs to maintain stability under increased mechanical demand [37]. Achieving this stability involves a coordinated activation pattern across multiple muscles, resulting in continuous adjustments depending on the task requirements [38]. For example, the biceps brachii exhibited higher EMG values when loading the 6mm sheet metal using the table cart, likely due to the need to hold the sheet horizontally in a bent posture before placing it on the cart. The weight of the sheet metal required greater activation from the biceps brachii to stabilize the arm and prevent extension while supporting the load.

The relationship between physical demand and spinal stability has been well-documented in previous studies, with stability quantified through lumbar spine compression force [39-40]. Higher physical demands trigger the co-activation of agonistic and antagonistic trunk muscles, enhancing lumbar stability and preventing injury. Research also emphasizes that mechanical stability requires co-activation across multiple antagonistic muscle groups [41-43]. In line with this, Lavender et al. [44] demonstrated that the co-activation of additional muscles can reduce the activation level of the erector spinae during physically demanding tasks.

In this study, the unloading task with the 6mm sheet metal using the trolley lifter potentially induced co-activation of other muscle groups, alleviating the load on the erector spinae. Interestingly, EMG data showed a slight reduction in erector spinae activation during this task (see Figure 5). This pattern may be attributed to the postural adjustments required for unloading, where the subject had to lift a tilted panel from a lower position and slide the metal using the trolley's roller wheels. In such scenarios, the subject likely relied more on hip and leg muscles to assist in the lifting motion, reducing the demand for the trunk muscles. Previous studies suggest that kinematic trade-offs between hip and trunk motion during lifting tasks influence muscle recruitment patterns [45-46]. Specifically, bending at the hips allows for a more upright trunk posture, reducing the load on the trunk muscles while lifting from lower positions [47]. Noe et al. [48] also reported that engaging the leg muscles is a common strategy to minimize the burden on the erector spinae during heavy lifting. However, the complex interactions between the trunk and other muscle groups remain insufficiently understood, especially in tasks with high mechanical demand [49].

This study was limited to the activation levels of a few muscles measured unilaterally and did not capture the full extent of co-activation among multiple muscles during the task. Future research should investigate neuromuscular control strategies across a broader range of muscles, particularly trunk and leg muscles, to enhance our understanding of how different muscle groups coordinate during material handling. Additionally, this study provides insights into how different non-motorized material-handling devices influence muscle recruitment strategies, which subsequently impact the load on specific muscles. Understanding these recruitment patterns can guide ergonomic design improvements, making handling devices more effective in reducing muscular strain and improving worker performance.

Our findings align with previous research, demonstrating the effectiveness of ergonomically designed handling in reducing work-related musculoskeletal disorders (WMSDs) and physical work demands. However, unlike many studies that focus on specific MMH aids in isolation, this research offers a comparative analysis between two different non-motorized devices—the trolley lifter and the table cart—providing valuable insights into their distinct impacts on worker health and safety. This comparative approach highlights the importance of evaluating device performance and how these devices influence muscle recruitment patterns under varying task demands.

5. CONCLUSION

The study investigated the effect of design differences between the trolley lifter and traditional hydraulic table carts on muscle activities with subjective assessment during the manual sheet metal handling task. The study showed that the trolley lifter reduces muscle activation levels in the biceps brachii, triceps brachii, erector spinae, and upper trapezius muscles. Additionally, participants rated the trolley lifter as more usable, useful, and desirable than the traditional hydraulic table cart. The findings of this study have important implications for the design and use of manual handling devices in various industries. The trolley lifter may offer a significant advantage over the traditional hydraulic table cart in reducing biomechanical load and improving worker safety and comfort. However, the finding of this study is limited to the loading and unloading task of handling large sheet metals. Future research could investigate the effectiveness of the trolley lifter in other manual handling tasks and settings. It would also be valuable to explore the underlying mechanisms driving muscle activation changes and extend the analysis to additional muscles on both sides of the body for a more comprehensive understanding. In conclusion, this study contributes to the growing knowledge of the benefits of ergonomically designed manual handling devices. The trolley lifter can potentially improve work postures, reduce muscle activities, and enhance subjective experiences compared to the traditional hydraulic table cart. Further research and implementation of this device may help reduce the incidence of work-related musculoskeletal disorders associated with manual material handling tasks, promoting both worker well-being and operational efficiency.

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