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An Overview of Various Tasks and Trades in the Construction Industry Offering Potential for Exoskeletons

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ABSTRACT

This paper reviewed a Canadian construction firm's health, safety, and environment database. A total of 13 Canadian offices were represented in the database, spanning January 2019 through June 2022. All 4395 entries were categorized based on damage type, injury nature, accident type, and causal agent. A thorough analysis of each event description was conducted to determine whether wearable technologies if they had been available and used, could likely have prevented the accident. This paper identifies the various tasks and trades in the construction industry which offer the potential for using wearable technologies, more specifically exoskeletons. It discusses the types of accidents that could possibly be prevented by using innovative exoskeletons. Based on the findings, this study also lists criteria that exoskeletons should meet to be beneficial to construction workers' health.

Keywords: Wearable technologies, Exoskeletons, Construction industry, Musculoskeletal disorder, Accident analysis

INTRODUCTION

Wearable technologies, more precisely exoskeletons, are progressively gaining more attention in industries where physical work is omnipresent. These technologies assist employees who perform repetitive or physically demanding tasks. The use of exoskeletons aims at enhancing physical capacity in various manual handling tasks. The term exoskeleton refers to a kinematic chain in close contact with the human body that provides support, rigidity, protection, or augmentation of strength and/or sensitivity (Karvouniari et al., 2018). These technologies are expected to reduce the physical workload and fatigue workers experience, thus decreasing the risks of musculoskeletal injuries and improving their health (de Looze et al., 2018). Exoskeletons also aim at increasing worker productivity by enabling them to work faster and more efficiently.

The subject of exoskeletons appears to be of particular interest among scholars in the context of the construction industry where manual labor is widespread (Linner et al., 2018; Kim et al., 2019; Zhu et al., 2021). Many trades require workers to perform physically demanding tasks over most of the workday, increasing the risk for musculoskeletal injuries. Tasks often include manual handling, awkward postures, repetitive movements, exposure to vibration, and high-force application when using different types of power tools.

Every year, work-related accidents are numerous in the construction industry. In Canada, worker compensation boards report 28 452 accidents with loss time in 2018, 28 111 in 2019, and 23 718 in 2020 (AWCBC, 2021). More specifically, among the compensated work-related musculoskeletal disorders (WRMSD) in the province of Québec, the construction industry accounted for 5.9 % in 2017, 6.2% in 2018, 7.2% in 2019, and 8% in 2020 (CNESST, 2021). Compensated WRMSD in the construction industry increases every year. Working conditions in this industry make exoskeletons an appealing proposition to improve worker safety. Nonetheless, such technologies are yet uncommon in the construction sector (Linner et al., 2018). As the construction industry encompasses several trades and many tasks, it is difficult to identify which ones could benefit from such technologies.

This research can be used by safety professionals in the construction industry as a starting point to identify areas where the implementation of exoskeletons could be beneficial. It can also help manufacturers of exoskeletons to develop innovative products that better help and protect workers. On a larger scale, this paper intends to motivate the industry and improve the working conditions of laborers.

METHODOLOGY

Database

Data on construction accidents at a large Canadian construction firm were used for this study. More specifically, an analysis of the company's Health, Safety, and Environment (HSE) database helped identify the tasks that were being performed when an accident occurred, which caused a musculoskeletal injury. As part of the dataset provided by the firm, the following information was provided: the date and location of the accident, the trade, and title of the worker injured, the event type, the primary cause, the nature and the body area of the injury, and the number of lost days. It is important to note that there was also a fairly detailed description of each accident that provided insights into the context and nature of the accident. A total of 13 Canadian offices across two provinces were represented in this database, spanning January 2019 through June 2022. The database included 4395 entries about human and environmental incidents, accidents, and near misses. Among these entries, 822 were removed from the dataset because they lacked information regarding the type of event and injury. Other injuries were removed, as they were deemed irrelevant to the objective of the study (e.g., cuts, pinches, and motor vehicle accidents). A total of 3573 entries were thus analyzed.

Data Classification

As a starting point, three researchers analyzed 499 selected entries. Injuries to the musculoskeletal system, including internal damage, strain, pain, and faintness, were selected using a filter based on injury type. Researchers also reviewed accidents that had previously been classified as musculoskeletal by the construction firm. In this study, the term musculoskeletal refers to accidents involving one or a combination of the following: force exertion, awkward postures, repetitive motions, or manual handling of heavy or over-dimensioned objects. From the descriptions found in the database, these accidents typically result in sprains, pain, internal damage, or faintness.

The researchers classified accidents in the database using the accident classification scheme provided by the CNESST (Commission des normes de l'équité de la santé et de la sécurité du travail), the province of Québec's worker compensation board (CNESST, 2023). Table 1 shows the CNESST's accident classification scheme.

Table 1. CNESST accident classification scheme.

Accident Type	Accident Type Specified
Fall to a lower level	Fall to a lower level, unspecified. Falling down stairs or steps. Fall from the edge of a roof. Fall from a stationary vehicle. Fall from a ladder, a stepladder. Fall from a platform, scaffolding, etc. Fall through an opening in a floor. Fall from the top of the beams of a building or other steel structure. Fall through a floor surface.
Fall at the same level	Fall at the same level, unspecified. Fall onto a floor, walkway or other surface. Fall on or against objects.
Stuck or crushed by equipment or objects	Stuck or crushed by equipment or objects. Stuck by moving equipment or machinery. Crushed or stuck by rolling, sliding or moving objects.
Contact with extreme temperatures	Contact with extreme temperatures.
Contact with electric current	Contact with electric current, unspecified.
Overexertion	Overexertion while lifting an object. Overexertion while holding, carrying, turning or brandishing objects. Overexertion when pulling or pushing objects. Overexertion while throwing objects. Overexertion, unspecified.
Exposure to caustic, harmful or allergenic substances Contact with extreme temperatures	Contact with skin or other exposed tissue. Exposure to caustic, noxious or allergenic substances, unspecified.
Fall to a lower level	Falling down stairs or steps.

Continued

Table 1. Continued

Accident Type	Accident Type Specified
Struck by an object	Struck by a falling object. Struck by an object, unspecified. Struck by a door or portable barrier. Struck by a swinging or sliding object, unspecified. Struck by an object that slips from the hands. Struck by a flying object, unspecified. Struck by an ejected substance or object. Struck by a flying object or a loose particle (material breaking loose from a tool, machine or other equipment).
Friction or abrasion by friction or pressure	Friction or abrasion by handled objects on a surface. Friction or abrasion by friction or pressure, unspecified. Rubbing or abrasion by a foreign body in the eye. Friction or abrasion while kneeling.
Hit an object	Hitting a stationary object. Hitting an unspecified object. Hitting a moving object.
Repetitive motion	Repetitive motion, unspecified. Repetitively placing, grabbing, or moving objects, except tools. Repetitive use of tools.
Body reaction	Body reaction, unspecified. Bending, climbing, crawling, stretching, turning. Slipping, tripping, losing balance -- not falling, unspecified. Slip on an object -- without falling. Tripping over an object -- without falling. Step into a hole -- without falling. Body reaction to exertion.

To better reflect the database content, categories were added. As many accidents were found to occur when workers were working with their hands above their shoulders or in kneeling positions, the awkward posture category was added to the scheme. A category for excessive strain when using vibrating or rotary portable power tools was also added because of the high number of accidents in the database where the tool jammed unexpectedly causing different types of upper limb strains.

All entries were categorized according to damage type (bodily injury, material breakage, near miss, environmental, unknown), injury nature (musculoskeletal or other), accident type, and causal agent. Additionally, a content analysis of each entry was performed, and it was determined whether wearable (or assistive) technologies, if available and used at the time of the accident, could likely have prevented it. As a result, 198 entries were deemed relevant or relevant under certain conditions. This categorization revealed injuries associated with activities for which no exoskeleton device currently seems available on the market, but could be considering the state of current technologies. We categorized these entries as relevant under conditions. We determined specific conditions that must be met by innovative exoskeletons to assist a manufacturer in developing wearable equipment that could help avoid the overexertions associated with these accidents.

Data Analysis

JMP 17 Pro Statistical Discovery (from SAS) software package and Excel were used to generate results. To describe the frequencies of categories, descriptive analyses were performed. The analysis was limited to the 198 entries that were considered relevant or relevant under conditions.

RESULTS AND DISCUSSION

Trades

Anwer et al., (2021) suggest that musculoskeletal injuries are influenced by trade and task-specific risk factors. Findings from one trade may not necessarily apply to others (e. g., painters versus rebar workers) (Anwer et al., 2021). To determine which trades are most likely to suffer from WRMSD and hence benefit from exoskeletons, this study examined accidents by trade. Laborers were involved in 53 accidents, or 27% of the total number, as shown in Figure 1. With 42 accidents, carpenters made up 21% of all accidents. The number of accidents among rod busters (rebar workers), electricians, and ironworkers was 17 (9%), 15 (8%), and 10 (5%), respectively. All 22 other trades had accident rates below 4% among the 198 entries analyzed.

Figure 1: Trades by accident.

ACCIDENT TYPE AND INJURY LOCATION

According to Figure 2, 41 % of all accidents analyzed resulted in back injuries. Among the accidents analyzed, injuries to the arm, hand, shoulder, leg/knee, and elbow accounted for 20%, 12%, 7%, and 5%, respectively. A study by Pan et al., (2022) showed that the back is the body part most susceptible to injuries in construction. In terms of injury type, strains account for most cases (40%), followed by pain (24%), faintness (10%), bruises (10%), internal damage (5%), and others (13%).

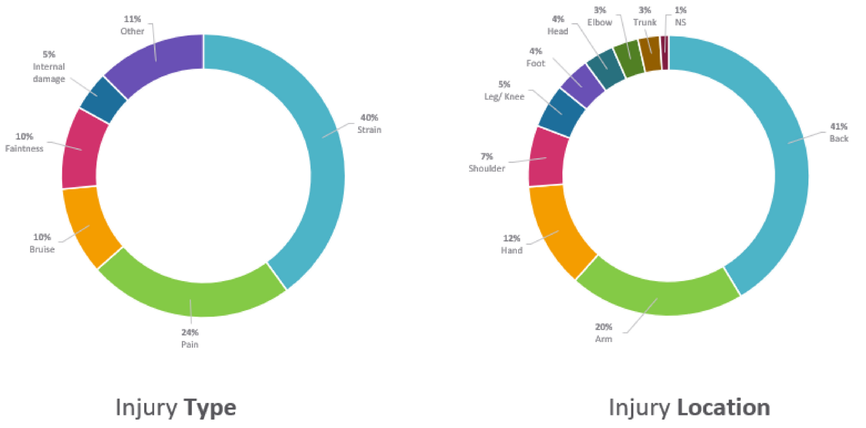

Figure 2: Injury location and type.

Table 2 illustrates the relationship between the injury type and body location. Accordingly, when an accident involving the back or the arms occurs, workers will probably suffer from strain and pain.

Types of Construction Accidents

According to the Occupational Safety and Health Administration, root causes are underlying factors responsible for the occurrence of an accident (OSHA, 2015). The direct cause occurred immediately before the accident and directly caused it (Argonne National Laboratory, 2017). As root causes are not always immediately evident, and direct causes sometimes differ, both were determined. An example within the database would be a worker that felt a sharp pain in his back after forcing a ventilation duct into place. He was performing his task in the ceiling. An excessive strain would be the direct cause, while an awkward posture would be the root cause since he was working with his hands above shoulder level. Another example is a worker who fell as he was going up a staircase while carrying several 2x4s on his shoulder. The root cause would be an excessive strain and the direct cause would be a fall. Finally, a worker and his colleague were transporting a pipe weighing approximately 105 lbs. One of the workers fell and dropped the pipe, causing his co-workers' shoulder to be injured. As a direct cause, the injured worker was struck by an object, while as a root cause, the colleague fell and dropped the pipe. Of the 198 accidents, 39 had a different root and direct cause.

According to Figure 3, nearly 80% of the accidents analyzed had a root cause associated with overexertion, body reactions, and awkward posture. Among the 198 accidents analyzed, there were 126 cases of overexertion (64%), 16 cases of body reactions (8%), and 14 cases of awkward postures (7%). Similar results were found for the direct cause of the accidents. Overexertion (59%), body reactions (10%), and awkward postures (10%) were also responsible for about 80% of the accidents. To prevent future accidents,

Table 2. Relationship between injury type and body location.

Injury Type	Injury Location	# of acc.	Total # of acc.
Strain	Back	44	80
	Arm	15	
	Shoulder	9	
	Hand	7	
	Elbow	2	
	Leg	2	
	Trunk	1	
Pain	Back	18	48
	Arm	10	
	Shoulder	4	
	Head/Neck	2	
	Leg/Knee	5	
	Hand	3	
	Trunk	3	
	Foot	2	
	Elbow	1	
Faintness	Back	14	20
	Head/Neck	2	
	Arm	1	
	Elbow	1	
	Leg/Knee	1	
	Trunk	1	
Bruise	Back	5	20
	Arm	5	
	Foot	5	
	Hand	2	
	Head/Neck	1	
	Elbow	1	
	Trunk	1	
Internal Damage	Arm	6	9
	Hand	1	
	Leg/Knee	1	
	Foot	1	
Other (Irritation, crushing, cut)	Hand	10	21
	Head/Neck	3	
	Arm	2	
	Not specified	2	
	Leg/Knee	1	
	Elbow	1	
	Back	1	
	Shoulder	1	

organizations should focus on the root cause rather than the direct cause (Argonne National Laboratory, 2017).

Overexertion was primarily associated with holding, carrying, turning, or brandishing objects, lifting, pulling, or pushing objects, and using rotating power-vibrating hand tools. Body reactions manifested when bending,

Figure 3: Accident types.

climbing, crawling, stretching, and turning. Twisting was included here as well. Finally, awkward postures were associated with kneeling, squatting, and working with the hands above shoulder level. Table 3 provides more details. Direct causes also yielded similar results.

Regarding injuries associated with exertions for which no exoskeletons are currently available, exoskeletons should meet the following conditions:

- Allow handling loads with widely varying characteristics (e.g., weight, dimensions);
- Provide a good grip on the load being handled;
- Provide good equipment to better support the use of power hand tools;
- Help pull on loads;
- Help with squatting and kneeling-related tasks to maintain stability and comfort;
- Possible usage in a narrow and difficult environment;
- Assistive equipment for the forearms and hands;

Only 22 of the 198 accidents analyzed resulted in lost days, totaling 189 days. Manual handling was the most common cause of these accidents. Workers in the construction industry handle a variety of materials, such as formwork panels, benches, insulating canvas, lumber, reinforcing steel rods, steel beams, cable rolls, concrete buckets, and bricks. Figure 4 shows that exoskeletons that allow handling loads with widely varying characteristics could possibly have prevented 15% of the analyzed accidents. The database showed workers hurting their backs while lifting large fans from concrete blocks, carrying reinforcing steel bars to a lower lever, lifting 300 lbs of acoustic panels, and much more. Exoskeletons that would provide a better grip on objects could have prevented 11 % of accidents. There were several accidents where workers were injured while handling large plywood sheets, canvas, and metal heddles because they slipped from their hands. In 17 of the 198 accidents, workers handled materials as a team since the loads were too heavy for a single individual. Several examples of heavy materials included a 200-pound pipe, a 1000-pound material lift, a 200-pound heating unit, metal walkway parts, and electrical panels. Several accidents occurred when a teammate dropped his side of the load. Manual handling accidents could

Table 3. Root cause accident types specified.

Accident Type	Accident Type Specified	# of acc.	Total # of acc.
Overexertion	Overexertion while holding, carrying, turning or brandishing objects.	42	126
	Overexertion while lifting an object.	41	
	Overexertion when pulling or pushing objects.	22	
	Excessive strain when using a rotating or vibrating hand tool.	16	
	Overexertion.	5	
Body reaction	Bending, climbing, crawling, stretching, turning.	10	16
	Tripping over an object -- without falling.	3	
	Body reaction to exertion.	2	
	Slipping, tripping, losing balance -- not falling, unspecified.	1	
Awkward posture	Kneeling or squatting.	7	14
	Work above the shoulders.	6	
	Work far from the center of gravity.	1	
Struck by an object	Struck by an object that slips from the hands.	7	11
	Struck by a falling object.	2	
	Struck by an object used or handled.	2	
Stuck or crushed by equipment or objects	Stuck or crushed by equipment or objects.	6	7
	Stuck by moving equipment or machinery,	1	
Repetitive motion	Repetitive use of tools.	4	5
	Repetitive motion.	1	
Fall at the same level	Fall onto a floor, walkway or other surface.	4	5
	Fall on or against objects.	1	
Cut by an object	Cut by an object with sharp edges.	3	3
Hit an object	Hitting a stationary object.	2	2
Contact with extreme temperatures	Contact with extreme temperatures;	1	1
Fall to a lower level	Falling down stairs or steps.	1	1

possibly be reduced by exoskeletons that could provide a good grip on objects and that would allow workers to handle loads with varying characteristics.

An exoskeleton capable of supporting rotating hand tools could potentially have prevented 10% of analyzed accidents. Many accidents occurred due to drilling bits getting stuck suddenly and straining workers' hands and arms by the tool's counter-reaction. 6% of accidents could have been prevented by exoskeletons that could help workers pull on loads. Workers injured their backs, torsos, and hands while pulling on power cables, geosynthetic materials, and concrete out of a 15-foot well. Exoskeletons that could

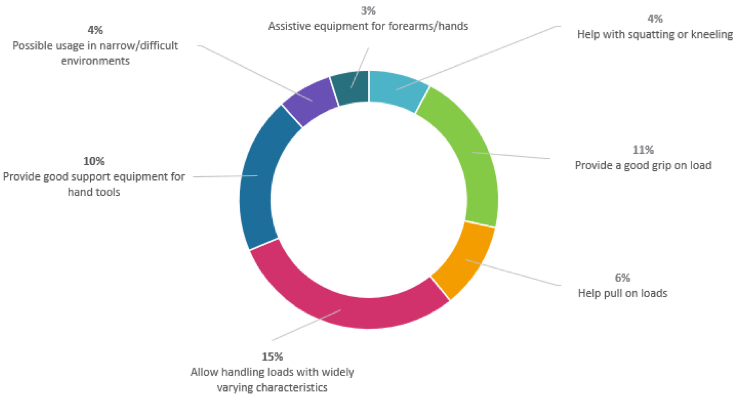

Figure 4: Exoskeleton desirable characteristics.

help with squatting and kneeling could have prevented 4% of accidents. A worker experienced back pain after installing framing on scaffolding in a kneeling position. Other workers experienced back and shoulder pain while sanding concrete floors and beams on their knees. Bulky exoskeletons would be unsuitable for tasks in restricted places, like the plenum space in ceilings, which accounted for 4% of the accidents. Finally, assistive equipment for the forearms and hands to better hold a tool could have prevented 3% of analyzed accidents. A worker injured his wrist while exerting force on a tool to loosen an object, while another injured his forearm during intensive scraping.

CONCLUSION

By analyzing accident databases, employers gain insight into accident causes and injuries, allowing them to determine which tasks and trades could potentially benefit from existing or new exoskeletons. It also informs manufacturers on the requirements that their exoskeletons should meet to better help and protect workers. According to the data analysis, exoskeletons could greatly benefit laborers and carpenters. Manually handling objects of various sizes and weights, or rotating hand tools jamming unexpectedly, were the most common causes of accidents in the database analyzed. These were associated with overexertion that most often resulted in back and arm strain, among other injuries. Many accidents analyzed in this database could not be prevented with the exoskeletons currently available. Future exoskeletons should therefore be capable of helping with handling loads with varying characteristics, providing a good grip on objects, assisting in pulling loads, and providing good hand tool support equipment.

The second phase of this study will focus on using exoskeletons in construction sites to collect data and assess their effectiveness with trades and tasks established in this first phase.

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