Authors' pre-proof. Article published in *International Journal of Industrial Ergonomics* vol. 71, pp. 8-13. https://doi.org/10.1016/j.ergon.2019.01.011

Aviation deicing workers, global risk assessment of musculoskeletal injuries

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Abstract

Deicing technicians working from open baskets are exposed to ergonomic risks and fatigue. This study aims to assess the global risk of musculoskeletal injuries (MSIs) for this type of activity. An ergonomic study was conducted with the workers of a Canadian airport deicing operator during the winter of 2016–2017. Video recordings made it possible to observe the activities during the most intensive work shifts, as well as characterise and quantify (frequency and duration) the movements/postures of twelve human subjects. The resulting risk assessment identified the body structures submitted to exertion, analysed the efforts involved and globally assessed the forces exerted on the spine and upper limbs. This global risk assessment leads to the conclusion that the risks to the upper limbs are preoccupying and must be examined further.

Keywords: Deicing; Ergonomics; Musculoskeletal injury; Risk assessment

1 Introduction

Aircraft ground deicing is a seasonal activity spanning from mid-November to mid-March, with an increase in activity from mid-December to the beginning of January, in Montreal. Aviation de/anti-icing activities are under demanding time and work rate constraints, dictated by the departures scheduled by airports. Deicing trucks with open baskets make it possible for deicing technicians to get closer with their equipment to spray ethylene glycol onto the surfaces needing deicing, as well as get closer to planes to perform tactile and visual inspection of the quality of the deicing (except for propeller-driven planes, for which inspection is performed from the ground). Deicing technicians must carry the deicing nozzle (3 kg and 4 kg) in their hands while moving about and moving it to and fro. This type of work has its share of ergonomic risks deserving of study (Busch et al., 2016). Strenuous tasks (Landau et al., 2017) for women are perceived as fatiguing for everyone, in particular for workers aged less than 30 and less experienced (Torres et al., 2016). Thus, this paper focuses on evaluating the physical work load. More precisely, it will focus on the global risk assessment of musculoskeletal injury (back and upper limbs) that could stem from the work postures and movements of deicing technicians working in open baskets.

The work of the aircraft deicing technician is not well known and to the best of our knowledge, no documented literature exists that describes the ergonomic requirements of this type of work. In such cases, it is common practice to study the work methods and processes, the efforts and conditions related to the work as it is performed, the musculoskeletal system and joint structures involved and their modes of interplay. Several biomechanical (Kim and Zhang, 2017) and ergonomics models (for example: ~~2,5,6,7~~Chander and Cavartota, 2017; Landau et al.2017, Schaub et al., 2013; David, 2005) can then be used to assess the efforts and analyse the effort-resistance relationships of the previously named structures. At first, the authors supposed that a back injury could be caused by submitting the spine to a compressive force as has been supposed or shown by several authors in the literature (for example the model of the National Institute for Occupational Safety and Health (NIOSH); Arjmand et al., 2015; Demers et al., 2013, 2017; Marras, 2016~~8,9,10,11~~) and this, even though other risk factors related to the various types of pressure on

the spine being known (Kim and Zhang, 2017). The most dreaded injury in the workplace is disc herniation, which frequently occurs between L5/S1 (5th lumbar vertebra, 1st sacral vertebra), more precisely posterolaterally (Nadeau, 2001). The lesionnal mechanisms that cause a herniated disc are trunk rotation with lateral flexion (Demers et al., 2013, 2017; Nadeau, 2001; Nadeau et al., 2004).

As for the upper limbs, this study focuses on static efforts and postural changes. According to Kroemer (1970), static work that does not exceed approximately 15–20% of the maximal strength of a muscle group of a subject can be maintained. Nevertheless, beyond this limit, fatigue will occur locally after some time and even exhaustion if the static work capacity is exceeded. The physiological manifestations of local fatigue are a progressive lessening of the maximal strength, with a shortening of the length of time the effort can be maintained and the use of other muscle groups that are further and further away from the point of action. The worker's movements will consequently be less and less precise in terms of positioning, the line of movement will widen and the muscle response time will increase.

As for deicing technicians working in open baskets, the compression of the lumbar rachis complies with the limits established by international recommendations. Nevertheless, certain postures and movements of the upper limbs are preoccupying. Further study of the exertion required by the deicing hand-arm-nozzle system and spine is necessary, in particular regarding the grip of the nozzles.

2 Methodology

The postures and movements of 12 deicing technician test volunteers (on a population of forty) were recorded using remote cameras (fixed HD camera, 3h30/subject) and cameras placed in their open basket (Go Pro, HERO 3 + SILVER EDITION, 5 h/subject), during the deicing winter season of 2016–2017 (from end of December to mid-April). For each subject, the most intensive work shift was isolated and analysed (approximately 1 h–1h30 of footage) minute by minute (Landau et al., 2018a). Thus, it was possible to make a chronological description of the activities as well as identify the postures and quantify their frequency and duration. Details of the results of the time studies can be found in Landau et al., 2017) (Landau et al., 2017). and Landau et al., 2018b (Landau et al., 2018b). Our methods were duly approved by the ethics committee for research with human participants of École de technologie supérieure.

The risk assessment for musculoskeletal injuries was conducted in four stages:

1) First, a risk estimation based on the work of Winnemuller et al. (2004). This is a general and rough risk assessment whose development was based on the evaluation of affected workers, supervisors and ergonomists. For 2-h time periods of a work shift, the only thing that needed to be observed was whether a specific musculoskeletal risk was present or not ("Risk factors were defined by a 2-h time period during which the risk factor was present", Winnemuller et al. (2004)). These assessments are based on the Washington State Ergonomics Rule of 2002/03 (for an updated review of this, see Park, 2016 (Park, 2016)).

2) Then, a risk estimation using a biomechanical model and the 3D SSPP software 4.2 version (~~Landau et al., 2018b).~~ Chaffin et al., 2006). This model poses the hypothesis that the acceleration forces are negligible. For our analysis, the pressure at the nozzle was considered to be 195.7N (Winnemuller et al., 2004). Analyses was made for two male mannequins representative of the study's subject population (Torres et al., 2016) (and of the 5th and 95th percentile of the North American population) and holding the two types of deicing nozzles (3 kg and 4 kg). The main work posture was forward flexion along with axial rotation or lateral bending. However, workers were likely to be deviated from neutral with various angles in one or more directions. All possible postures and deviations were taken into account in order to make a confident prediction:

a) Case A - height: 165 cm, weight: 65 kg;

b) Case B - height: 193 cm, weight: 95 kg.

3) Then, a study was made on the efforts demanded of the muscles at the nape of the neck and shoulders and these observations were compared to the recommendations of Lehto and Buck (Task Force Tips, 2013), as well as to those of Chaffin (1973).

4) Finally, a study was made on the efforts when the arms are extended to perform a task beyond the reach zone, based on the work of Ditchen et al. (2014). We thought it necessary to add to, as well as to check, the evaluation with the 3D SSPP model using the calculations according to Ditchen et al. (2014) as unusual hand-arm-shoulder strains could occur within the thresholds of the reach zones while spraying deicing fluids.

3 Results

The population studied is composed of 12 subjects: 10 men and 2 women. The population's main characteristics are described in Table 1.

Table 1 Main characteristics of the population under study.

alt-text: Table 1

Gender	Number	Age (years)			Weight (kg)			Height (m)		
		Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Men	10	33	21	54	81.1	68.0	90.7	1.83	1.64	1.95
Women	2	24			56.5	52.0	61.0	1.64	1.57	1.70

Open basket deicing technicians work in postures that are not optimal from an ergonomic perspective, for example:

- Sagittal flexion sometimes up to 90°. The angle of flexion depends on the workers' height and their work methods;
- Lateral flexion sometimes up to 25°. Lateral flexion often occurs when workers are spraying de/anti-icing fluids;
- Trunk rotation sometimes up to 25°. Trunk rotation occurs frequently in a standing position, when the deicing technician is backing up the truck or occurs together with a sagittal flexion when the deicing technician is spraying de/anti-icing fluids;
- Arms completely extended forward. When spraying type IV deicing fluid, the worker's arms are extended (to the maximum limit of the reach zone) frontwards;
- Forearms flexion sometimes up to 60°;
- Head strongly bent either in the sagittal or lateral plane or in rotation.

The reader will find an analysis using the Ergonomic Activity Sampling (EAS) method (Landau et al., 2018b) along with an analysis of the physiological measurements (cardiac measurements) in Le Floch et al. (Le Floch et al., 2018).

3.1 Model of Winnemuller et al. (Winnemuller et al. (2004)

According to the work of Winnemuller et al. (2004), in open basket deicing activities, despite its non-ergonomic postures, major efforts and movements repeated at considerable frequency, do not meet the criteria that would deem it as posing an elevated or moderate risk. As a matter of fact, the majority of activities that are preoccupying occur within a timeframe of less than 2 h. As the following section (3.2) will show, the deicing activities are anything but risk-free. The 0/l assessment according to Winnemuller et al. (2004) (“present within a 2-h time period or not”) is therefore not suitable for our purposes.

3.2 Analysis of the exertion on the spinal column, model of Chaffin et al. (Chaffin, 1973)

Using 3D SSPP software, analysing 27 different postures with two different nozzles, the following was found:

- Case A (Fig. 1), the maximum spinal vertebrae compression at L5/S1 is of 1989 ± +/- 143 N, which is by and large lower than the maximum limit specified by the NIOSH (6400 N) and of its limit in compression of 3400 N.
- Case B (Fig. 2), the maximum spinal vertebrae compression at L5/S1 is of 2915 ± +/- 219 N, which is lower than the maximum recommended limit of the NIOSH (6400 N) and of its limit in compression of 3400 N.
- Spinal vertebrae compression at L5/S1 is maximum when the workers assume a posture of 60° forward flexion, 15° axial rotation, and 15° lateral bending simultaneously whether they use the 3 or 4 kg nozzles.

		nozzle's weight: 3 kg			nozzle's weight: 4 kg		
Axial rotation	Lateral bending	Flexion= 35°	Flexion= 60°	Flexion= 80°	Flexion= 35°	Flexion= 60°	Flexion= 80°
0°	0°	1059 N	1700 N	1100 N	1450 N	1631 N	1126 N
	15°	1470 N	1615 N	1057 N	1417 N	1625 N	1086 N
	25°	1400 N	1644 N	1110 N	1493 N	1505 N	1140 N
15°	0°	1477 N	1600 N	1543 N	1513 N	1600 N	1583 N
	15°	1495 N	1989 N	1696 N	1590 N	1952 N	1750 N
	25°	1515 N	1642 N	1524 N	1600 N	1775 N	1548 N
25°	0°	1463 N	1836 N	1500 N	1550 N	1761 N	1530 N
	15°	1600 N	1900 N	1365 N	1680 N	1880 N	1400 N
	25°	1423 N	1554 N	1374 N	1490 N	1644 N	1400 N

Fig. 1 Analysis of the exertion on L5/S1 using 3D SSPP, case A.

alt-text: Fig. 1

		nozzle's weight: 3 kg			nozzle's weight: 4 kg		
Axial rotation	Lateral bending	Flexion= 35°	Flexion= 60°	Flexion= 80°	Flexion= 35°	Flexion= 60°	Flexion= 80°
0°	0°	1820 N	2600 N	1988 N	2205 N	2519 N	2013 N
	15°	2196 N	2505 N	1960 N	2145 N	2515 N	1990 N
	25°	2091 N	2511 N	2025 N	2185 N	2364 N	2050 N
15°	0°	2238 N	2494 N	2484 N	2274 N	2489 N	2524 N
	15°	2235 N	2915 N	2678 N	2330 N	2870 N	2732 N
	25°	2222 N	2531 N	2430 N	2315 N	2664 N	2453 N
25°	0°	2208 N	2743 N	2400 N	2294 N	2662 N	2427 N
	15°	2342 N	2820 N	2300 N	2417 N	2790 N	2343 N
	25°	2118 N	2398 N	2270 N	2184 N	2485 N	2300 N

Fig. 2 Analysis of the exertion on L5/S1 using 3D SSPP, case B.

alt-text: Fig. 2

Fig. 3 shows the percentage of the population capable of sustaining the effort generated in case A, Fig. 4 for case B. For the majority of joints studied, more than 80% of the population of workers can maintain the effort required for both cases. Workers with shorter height seem more at ease with this task.

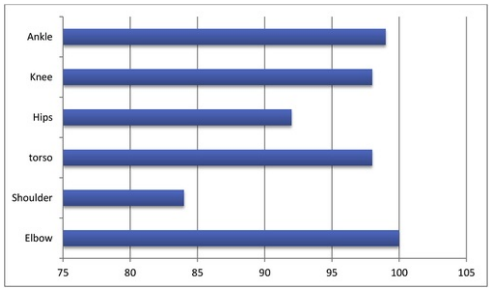

Fig. 3 Percentage of the population capable of maintaining the required effort, 3D SSPP study, case A.

alt-text: Fig. 3

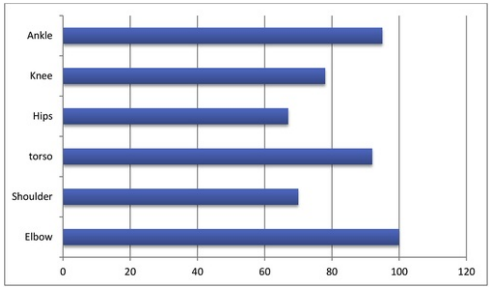

Fig. 4 Percentage of the population capable of maintaining the required effort, 3D SSPP study, case B.

alt-text: Fig. 4

3.3 Analysis of muscle exertion of the nape of the neck and shoulders

During deicing activities, the technicians must at times abduct the shoulder. These movements most frequently occur when:

- Activating the controls of the basket (to move the truck, and to raise or lower or laterally move the basket). Abduction is of approximately 60°;
- Spraying the deicing fluids. Abduction varies between 60° and 90°;
- Verbally communicating with other members of the deicing team. The technician must then raise his/her arms to reach his/her microphone. Abduction of approximately 60°.

These abductions are not preoccupying for the majority of the population of workers (~~Task Force Tips, 2013~~Lehto and Buck, 2008).

Chaffin (1973) proposed an average time curve to establish local muscle fatigue (accompanied with severe pain) for young men in relation to the angle of arm abduction. The deicing technicians must handle a deicing nozzle of 3–4 kg, which implies a static effort. In the majority of situations, the joint movements involved are short and the authors observed that the postures vary significantly. This has recuperative effects on the muscles.

3.4 Analysis of exertion when the arms are extended to do work beyond the reach zone

Deicing technicians whose height is less than 170 cm must at times bend forward deeply (>60°) while extending their arms to reach beyond their reach zone (Fig. 5). This occurs more often with deicing fluid type IV than with type I. The physical characteristics of the deicing nozzle used for type IV seems to bring about this posture for the worker and this, even though the pressure of the nozzle for the deicing fluid type IV is lower than that of type I.

Fig. 5 Posture showing pronounced sagittal bending while extending arms to do work beyond the reach zone.

alt-text: Fig. 5

On the basis of the works carried out by Ditchen et al. (2014), as a first approximation it is possible to calculate the spinal compression force exerted on the L5/S1 vertebrae using the following equation:

$$F = b + m \times L \quad (1)$$

whereby

F = force of compression on L5/S1 (N)

b = constant used to take into account the posture of the trunk

m = constant of weight

L = weight of the object (kg)

In a posture similar to that in Fig. 5, whereby there is a load transfer (the deicing nozzle is held to one side of the basket with trunk rotation, coupled with lateral and sagittal bending), F = 2080 N, which is lower than the limit recommended by the NIOSH of 3400 N for men and 2600 N for women.

Arm extension beyond the reach zones was also observed when the technicians are spraying deicing fluid on the underside of the airplane wings (see Fig. 6). This posture leads to momentary exceedance of the recommended limits stated by Diffrient et al. (1990) for the deltoid, supraspinatus and subscapularis muscles.

Fig. 6 Arm extension beyond the reach zone spraying deicing fluid on the underside of the airplane wings.

alt-text: Fig. 6

As first approximation, based on the work of Ditchen et al. (2014), the spinal compression force on the L5/S1 vertebrae, in a posture similar to that in Fig. 6, whereby an object is held in one hand or to one side of the body, is F = 1055 N, which is less than the limits recommended by the NIOSH.

4 Discussion

The sample of subjects is predominantly male as the population of deicing technicians is (Torres, 2014). The present study focussed on the physical aspects (postures and movements) of the aviation deicing technician's work. However, the issue of back pains is deemed to have multiple causes (Marras et al., 2016). We did not take into consideration biological or individual risk factors, nor psychosocial, mechanical-biological factors (Marras et al., 2016) or organisational factors (Marras, 2012).

In our risk assessment for musculoskeletal injuries to the spine, we formulated a hypothesis that the lesionnal mechanism was disc compression, which is greatly simplifying the circumstances. According to the models of Chaffin et al. (Diffrient et al., 1990) and Ditchen et al. (2014), the exertions on the spine comply with the maximum limits recommended by the NIOSH. In contrast, it turned out that the 0/l assessment for 2-h time periods according to Winnemuller et al. (2004) is too general for our purposes. The deicing technicians work in postures of pronounced sagittal flexion (>60°) for short and medium periods. Literature on the relationship between this type of posture and back pain has, up until recently (Lagersted-Olson et al., 2016), concluded that there is a causal relationship between these postures and back pain. Further research is needed to substantiate this evidence. Given the hypothesis presented in this study and those underlying the models used, a more accurate and realistic analysis of the forces exerted on the spine, for instance using more precise models (Marras, 2012) proves necessary.

When the output pressure of the deicing nozzle is not taken into consideration, our assessment of the risk of musculoskeletal injury to the upper limbs indicates that despite the static efforts, the movements requiring shoulder abductions are not preoccupying. However, the act of spraying deicing fluids under the airplane wings leads to arm extensions such that (beyond the reach zones) a more in-depth analysis of the deicing hand-arm-nozzle system is imperative.

Literature on the various types of industrial nozzles have determined risks to the wrist, hands and shoulders in the furniture upholstery sector (Mirka et al., 2002). Shoulder and elbow pain are mentioned in the painting sector (Björing and Hägg, 2000a). The dimensional characteristics of the nozzle (weight (Björing and Hägg, 2000b; Lee et al., 1997), dimensions (Björing and Hägg, 2000b), shape and point of center of gravity) are explanatory variables (Nadeau, 2001). The effect of surface characteristics (more precisely, the presence of contaminants on the nozzle surface), the quality of the nozzle coupling (type of grip, location of grip, dimensions of the grip (Björing and Hägg, 2000b), the surface properties of the grip (Björing and Hägg, 2000b), effort required to activate the controls (Lee et al., 1997)), as well as the nozzle's features (compatibility with the type, repetition and frequency of actions to be taken (Lee et al., 1997)) that should not be neglected (Nadeau, 2001). The spray gun hose has an impact that needs to be clarified (Björing and Hägg, 2000a, 2000b), as well as the use or not of protective gloves (Larivière et al., 2010). The latter can hamper efforts to grasp the tool's handle or to press its trigger (Radwin, 1996).

Deicing nozzles are fire hose nozzles that have or have not been modified depending on the type of fluid that is to be sprayed on the surface of the airplane. To the best of our knowledge, only the research of Kluth et al., 2000, 2004, 2007 deals with muscle requirements (7 muscles of the upper limbs) for the use of fire nozzles. Despite the fact that these are different from the nozzles used by the aircraft deicing operator participating in this study, they are considered here. Using electromyography and a qualitative assessment (observation of the shape and dimensions of the grip and nozzle activation system, ease with which efforts can be exerted, physical pains felt, etc.), they studied three types of fire nozzles in life-like work conditions with 11 volunteer subjects from a fire department. It is clear that the nozzles studied did not undergo a proper ergonomics study (physiological cost of static and dynamic efforts) and that certain physical characteristics of these nozzles (type and shape of grip, type of controls and activation mechanism) need improvement.

This study did not consider the influence of strategies used by the deicing technicians such as leaning their body on the basket's guardrail or grasping the top rail (Jones et al., 2013, 2015).

Finally, we come to the conclusion that a more in-depth biomechanical study of the hand-arm-nozzle deicing system, as well as the force exerted on the L5/S1 vertebrae is necessary. It would be of particular interest to conduct a study similar to those of Kluth et al., 2000, 2004, 2007 while adding to these a computer simulated analysis of the grip with which recommendations could be made to the manufacturers of deicing nozzles. The biomechanical models recently proposed in the literature (Desmoulins et al., 2014) could also prove useful.

To the best of our knowledge, no other research team has studied the issues of musculoskeletal injuries of aircraft open-basket deicing technicians, which means this study makes a unique contribution to the scientific literature on this little-known profession.

5 Conclusion

The aircraft open-basket deicing technician's work, based on this first global assessment, does not appear to pose any risk of musculoskeletal injury to the spine. As for a risk of musculoskeletal injury to the upper limbs, there is cause for concern. A more in-depth ergonomics study of the hand-arm-nozzle deicing system and of the forces exerted on the L5/S1 vertebrae is recommended.

Uncited references

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Acknowledgments

The authors wish to thank the Natural Sciences and Engineering Research Council of Canada École de technologie supérieure for their financial support. They would also like to acknowledge T. LeFloch (École de technologie supérieure) for the on-field work.

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Highlights

- Compression of the lumbar rachis complies with ~~the limits established by~~ international recommendations.
- Some postures and movements of the upper limbs are preoccupying.
- ~~More in-depth b~~Biomechanical study of the hand-arm-nozzle deicing system~~, as well as~~ and the force exerted on the L5/S1 vertebrae is necessary.

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