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Title: Determination of an Ergonomically Sound Glovebox Gloveport Center Line

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NNSA NA-50 NSR&D Proposal Request

Title: Determination of an Ergonomically Sound Glovebox Gloveport Center Line

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Abstract

Technical Objective

- Determine an ergonomic glovebox gloveport center line location which will be used for standardization in new designs, thus allowing for predictable human work performance, reduced worker exposure to radiation and musculoskeletal injury risks, and improved worker comfort, efficiency, health, and safety.

- Continue development of glovebox ergonomic best practices and add to American Glovebox Society ergonomic knowledge base/recommendations.

Approach

Test a series of anthropometrically-determined glovebox gloveport center line locations via motion capture of glovebox workers' upper extremity kinematics. A randomized set of reaching protocols which simulate common reaching tasks through a gloveport mock-up will function as the test conditions; this will provide kinematic data which can be analyzed for optimal range of motion configurations and identify high risk postures. This will provide the foundation for development of the most ergonomic gloveport center line location possible over the course of 18 months.

Project Description, Drivers, Assumptions, and Limitations

Description

The goal of this project is to determine the most ergonomic location for glovebox gloveport center lines in order to improve new design and re-fabrication processes. Currently, the existing center line positions do not take into account the biomechanical dimensions of the human workers who must use them, leading to stressful and unsafe working postures and injury risk. If the gloveport location was designed to account for worker anthropometrics as they relate to standard tasks and reaching requirements within the glovebox, 3 significant benefits would result: 1) increased upper extremity range of motion and reduced contact stress leading to more ergonomic and pain-free biomechanics; 2) improved task efficiency, thus reducing worker exposure to radiation and musculoskeletal injury hazards; 3) an optimized design standard for the primary interface between glovebox interior and human worker. In order to determine the best gloveport set up, this study will involve a two part Human Subjects method: 1) current glovebox workers will be tested for shoulder range of motion kinematics in a variety of gloveport center line positions using motion capture equipment during simulated reaching tasks through a mock gloveport frame; center line positions will be tested in linear increments corresponding to the known upper extremity anthropometric ranges of 5^{th} percentile females to 95^{th} percentile males; 2) workers will be surveyed on the perceived comfort and work capability of gloveport positions in each condition. Motion capture data will quantify kinematic differences and potential restrictions in each gloveport condition and allow analysis to determine the optimal center line location for worker ergonomics. In turn this could allow for significant cost savings in terms of glovebox design prototyping/testing and reducing human injury costs related to glovebox work. The impact of this can be noted in the fact that gloveboxes are essential containment systems for hazardous materials across many applications and therefore affect a wide range of workers in the nuclear, pharmaceutical, semi-conductor, and biochemical industries. Mitigating these ergonomic impacts is therefore a very important mission.

Drivers

Ergonomic injuries are one of the three major risks which result from glovebox operations at LANL, which is the only National Laboratory or other institution known to study this in depth. [1] Current gloveport designs and center line locations pose numerous risks to workers as they frequently reduce range of motion at the shoulder and impose prolonged contact stress on the upper arms. This in turn can result in pinched nerves, reduced circulation, and rotator cuff injuries. Poor postures and worker discomfort can reduce task efficiency and increase worker fatigue, which may lead to increased work duration, radiation exposure, and added costs to treat injuries. The longer the glovebox operation, the higher the rate of reported symptoms. For example, workers reporting symptoms after 1-2 hours of glovebox work are 22%; this grows to over 50% if glovebox work exceeds 3 hours a day. [2]

The specific DOE directives and technical standards for appropriate ergonomics is defined in the laboratories compliance with 10 Code of Federal Regulations (CFR) 851, Worker Safety and Health Program, specifically 10 CFR 851.21, Hazard Identification and Assessment, 10 CFR 851.22, Hazard Prevention and Abatement, and 10 CFR 851, Appendix A, Section 6, Industrial Hygiene and Section 8, Occupational Medicine.

Assumptions/Expectations

Assumptions include extrapolating ergonomic-related injury data collected from LANL glovebox workers to be similar to that affecting other DOE-site glovebox workers. This assumption is made due to the lack of existing data. The project results are intended to ultimately be transitioned as part of American Glovebox Society ergonomics best practices. We anticipate the results can contribute directly to improved glovebox design through standardizing a key design parameter integral to human systems integration, which may in turn reduce design and manufacturing costs. We also would expect to see a reduction in millions of dollars spent on treatment of ergonomic injuries in workers as well as improvements for ALARA. Multiple defense and non-defense programs throughout the DOE utilize gloveboxes and thus all would benefit from ergonomically-based gloveport center line locations.

Limitations

The proposed research will cover how changes in upper extremity kinematics in varying gloveport center line positions relate to known ergonomic risks for the musculoskeletal system, as well as how workers perceive each position affects their work capability, physical function, and comfort during tasks. The research will not cover metabolic considerations, estimation of radiation exposure changes, or center line positions outside of the anthropometric measurements which accommodate 5^{th} percentile females to 95^{th}

percentile males. Sampling methods would be limited to on-site workers available and willing to participate. Additional limitations may include a limited sample size; this is due to the substantial accumulation of data which results with normal motion capture systems and the resulting large data sets which can be generated from even a few human subjects. Processing, analysis, and interpretation of this type of data would require the scope of the project remain relatively focused. Other limitations include the ability to adequately create simulated work tasks which provide meaningful data that comprehensively predict glovebox ergonomics in a wide spectrum of individuals.

Background

Currently, the existing gloveport center lines are often positioned 18-19" apart horizontally and 48-52" vertically. This design does not take into account anthropometric considerations of workers; as an example, a 95th percentile male at 6'1" in height would require a gloveport center line to be 17.2" apart horizontally. Smaller people would require even less distance. Because glovebox design has historically been undertaken without integrating anthropometric data, many glovebox work tasks require individuals to adopt biomechanical postures which are stressful and unsafe, primarily in the upper extremities and neck. [3]

Very little research has been done in the area of glovebox ergonomics; what does exist focuses mostly on glovebox gloves as they relate to fit and performance with regard to changes in hand dexterity, strength, and avoidance of glove breaches. [4,5] <u>No research of any kind has been established on optimal gloveport center line location(s) or gloveport shape(s).</u>

Business Case

<u>MECHANISM OF INJURY</u>: The gloveport center line is not standardized on any glovebox in the DOE complex and is a direct contributor to the majority of glovebox-related injuries in workers since it significantly alters normal biomechanics performed on a work station surface. To consider the impact of injuries stemming from glovebox work, LANL has seen 59 recordable glovebox-related injuries in PF-4 from June 2006 to December 2015, 54 of which were attributed to repetitive motion/cumulative trauma. 38% of these injuries were to the arm and elbow, 26% were to the shoulder and neck, and 21% were to the hand, wrist, and fingers; these composed the three largest groups of injuries and total 85% of all recordable injuries. Rotator cuff injury treatment costs alone are estimated to range from $50K-250K per incident, so it is possible to state that the mean cost to treat every 10 rotator cuff injuries is as high as $1.5 million.

<u>SYSTEM SAFETY</u>: Probabilistic risk analysis methods provide a way to determine and rank hazards present in a system; these methods can be applied to personnel hazards in nuclear glovebox work. Implementing risk analysis methods allows an organization to allocate time, money, and effort toward development of the most necessary and effective controls of hazards. An article published in 2011 in the Journal of Chemical Health and Safety ("Investigation of injury/illness data at a nuclear facility") used a Failure Mode and Effects Analysis (FMEA, see following table[1]) to analyze recordable injuries and illnesses at LANL's TA55 over a 4 year period and determine a risk priority number for each category. Identified hazards are dubbed "failure modes" and are ranked through criteria scales to indicate their severity, occurrence rates, and detection rates, all of which create a responding "risk priority number" (RPN). FMEA analyses allow potential failure modes to then be ranked together using risk priority numbers in order to assess likelihood of occurrence and impact to system operations. In this case, injury/illness

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categories were assessed for probable impact to nuclear glovebox work operations. Ergonomic injuries had the highest risk priority number in the article's FMEA results—ahead of abrasions, strains/sprains, chemical exposures, contusions, and lacerations—primarily due to the fact that their occurrence is relatively frequent, their severity is high, and their detection rate is difficult, sometimes taking months or years. The FMEA provides a framework for targeting the most critical failure modes and creating appropriate risk management plans. The following table makes it clear that ergonomic injuries are currently the highest personnel injury hazard resulting from glovebox work. [6]

TA-55 Injury Failure Modes and Effects Analysis (FMEA).

Potential Failure Modes	Potential Failure Effects	Severity	Occurrence	Detection	RPN
TA-55 operations	Abrasions	9	3	1	27
	Strains/sprains	9	6	1	54
	Chemical exposures	9	3	2	54
	Contusions	9	4	2	72
	Lacerations	10	4	6	240
	Ergonomic injuries	9	6	8	432

Currently, several DOE sites have plans to install large numbers of new gloveboxes; for example, there are 86 planned installations at LANL TA55, 300 at LANL CMRR, and approximately 150 for UPF at Y-12. At a cost of $1 million per glovebox installation, perfecting new designs prior to prototyping and manufacturing is essential. Additionally, each glovebox prototype can cost from $20K-50K, depending on complexity. Glovebox prototypes have no rule of thumb in terms of numbers per planned enclosure, but recent figures for LANL show a ratio averaging 2 prototypes for every 75 installations. Unique glovebox designs are more likely to require higher ratios of prototypes, but if a key design parameter could be standardized for run-of-the-mill designs, prototype ratios could potentially be minimized, saving hundreds of thousands of dollars. A standardized parameter like gloveport location would further contribute to reducing upper extremity injuries, saving additional millions, and could create reliability in predicting the location of other design parameters inside the glovebox, particularly those based on a worker's ability to reach equipment and perform routine tasks. For example, if prototype numbers for "simple" designs could be reduced on average from 2:75 to 1:100 through improved ergonomic design parameters known to predict human work performance, the lower limit cost savings would be $340,000 (see below table).

Ratio of prototypes per number of planned installations	**Cost per prototype per 1,000 installations (Base cost: $20K/prototype)**
Actual 2 : 75 = 27 : 1,000	$540,000
Potential 1 : 100 = 10 : 1,000	$200,000

Project Tasks and Deliverables

Tasks

1. Test participants in a series of standard and novel gloveport center line locations as determined by accepted anthropometrics and typical task demands.

2. Record participants' upper extremity kinematics and postures in each condition with a randomized set of reaching protocols which simulate common reaching tasks in gloveboxes using motion capture equipment.
3. Survey participants regarding each design's perceived comfort and work capability.
4. Import participants' kinematic data and assess high risk postures using DELMIA software for processing.
5. Produce clean, raw data formats for quantitative and qualitative statistical analysis.
6. Collate findings to create recommendations for optimal gloveport designs for safe worker performance based on anthropometrics and exposure considerations.

Anticipated Schedule

Project Task	Deliverable
1. Create experimental design and assemble prototypes (LANL, Y-12)	2 months after funding/IRB approval
2. Pilot testing and prototype revision as needed (LANL, Y-12); hire student for project support (LANL)	3 months after funding
3. Data collection (Y-12)	6 months after funding
4. Data analysis (LANL, Y-12)	8 months after funding
5. Final design recommendations for GB operations (LANL)	10 months after funding
6. Write up results, submit for publication (LANL)	12 months after funding
7. Present results to AGS for future implementation into ergonomic standards (LANL)	12 months after funding

Anticipated Funding Requirements

Budget planning estimates FY17/18
Costs are burdened and each year is a partial fiscal year over an 18 month period

Year	Resource	Description	Total Cost
2017	Lead PI	10% level of effort	$20,426.51
	Contributing researcher	5% level of effort	$22,876.17
	Student	100% level of effort	$35,036.65
	Statistician	40 hours – statistical analysis	$27,059.17
	Fabrication	80 hours – labor for mock-up build	$13,408.22
	Y-12 consultant	160 hours – pilot testing & data collection	$46,000.00
	Travel	Collaboration at Y-12 (2 people)	$9,752.00
	Materials	Mock-up gloveport and misc equipment	$12,190.00
	Shipment	Misc mail and shipment costs for materials	$609.50
2018	Lead PI	10% level of effort	$31,995.05
	Contributing researcher	5% level of effort	$19,842.08
	Student	100% level of effort	$52,491.28
Grand Total			$291,686.63

Project Interfaces/Participants & Points of Contact

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Post-degree student(s) (TBD), Los Alamos National Laboratory

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[6] Cournoyer, M., Garcia, V., Gallegos, U., Wilburn, D., 2011, "Investigation of Injury/Illness Data at a Nuclear Facility," Journal of Chemical Health and Safety, **18** (5), pp. 17-25.