FEATURE

Rotator cuff strength balance in glovebox workers

Gloveboxes are essential to the pharmaceutical, semi-conductor, nuclear, and biochemical industries. While gloveboxes serve as effective containment systems, they are often difficult to work in and present a number of ergonomic hazards. One such hazard is injury to the rotator cuff, a group of tendons and muscles in the shoulder, connecting the upper arm to the shoulder blade. Rotator cuff integrity is critical to shoulder health. This study compared the rotator cuff muscle strength ratios of glovebox workers to the healthy norm. Descriptive statistics were collected using a short questionnaire. Handheld dynamometry was used to quantify the ratio of forces produced for shoulder internal and external rotation. Results showed this population to have shoulder strength ratios significantly different from the healthy norm. Strength ratios were found to be a sound predictor of symptom incidence. The deviation from the normal ratio demonstrates the need for solutions designed to reduce the workload on the rotator cuff musculature in order to improve health and safety. Assessment of strength ratios can be used to screen for risk of symptom development. This increases technical knowledge and augments operational safety.

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INTRODUCTION

Gloveboxes are essential to the pharmaceutical, semi-conductor, nuclear, and biochemical industries. They can be used either to protect the worker from the toxic materials within the glovebox or to protect the product from the surrounding environment.[1] Gloveboxes used for toxic materials are maintained at a lower pressure than the surrounding room atmosphere, so that relatively small leaks result in air inflow rather than a toxic release. Gloveboxes used to protect the product from the surrounding environment are maintained at a higher pressure than the surrounding room atmosphere, so that relatively small leaks result in air outflow rather than an excursion of contaminants into the glovebox.

While gloveboxes serve as effective containment systems, they are often difficult to work in and present a number of ergonomic hazards. One such hazard is the frequency and extent of shoulder rotation in the glovebox. Many glovebox work tasks require moving objects weighing 7–12 kg, using a significant amount of shoulder rotation at extreme ranges of motion.

Glovebox use requires the operator to work with his or her arms inserted into the gloveports, which typically maintains the shoulders bent at angles near 90°. Maintaining the shoulder bent at angles greater than 70° shoulder has been associated with the development of shoulder symptoms and injury, particularly shoulder impingement syndrome.[2] Not only does glovebox activity involve a constant state of shoulder elevation, but many glovebox tasks require lifting and moving objects in this posture. Such motions place glovebox workers at greater risk for developing shoulder issues.

Common activities include transferring items into and out of airlocks and passing objects down the length of a glovebox, see Figure 1.

These types of activities extensively lengthened or shortened the rotator cuff. The rotator cuff is a group of tendons and muscles in the shoulder, connecting the upper arm to the shoulder blade, see Figure 2.

The rotator cuff muscle group has been identified as one of the primary stabilizing factors of the shoulder.[3] This muscle group serves to depress the shoulder ball joint while elevating the arm, and to internally or externally rotate the arm.

Extensively lengthening or shortening this group of tendons and muscles may cause undue strain on the rotator cuff. The well-researched concept of the length-tension relationship of muscle fibers explains this phenomenon.[4,5] Muscles in either of the extensively lengthened or shortened states experience a reduced tension-developing capacity, which renders the rotator cuff vulnerable to injury.

Past studies have shown muscular imbalance to be directly correlated with orthopedic symptoms, pain, and injury in various muscle groups.[6] Pathologic symptoms in the rotator cuff can include: inability to sleep on

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Figure 1. Shoulder external rotation while transferring objects through an airlock.

the affected shoulder, pain along the upper lateral arm, pain with overhead motions, pain when reaching behind the back.[7]

For the past eight years, ergonomists and physical therapists have monitored the effects of the high workload associated with glovebox work in over 400 glovebox workers at Los Alamos National Laboratory (LANL). Previous efforts of this team have been reported in this journal.[8] The ergonomics team and occupational medicine clinic at LANL have tracked injury and symptom incidence in this population via medical screens, worker-completed surveys, and independent reports. This data collection revealed injuries to both the elbow and shoulder joints, and more specifically to the rotator cuff muscle group. Both are prevalent issues seen amongst glovebox workers. Accordingly, this rotator cuff muscle group study has been designed to examine rotator cuff injury and symptom risk of glovebox workers by looking at their shoulder internal and external rotator strength ratios, and to compare these ratios against the established healthy norm.

Past research has found, in a normal healthy population, the ratio of shoulder internal rotator strength to external rotator strength is typically **3:2**.[9,10] While most published literature refers to this ratio using the **3:2** notation, this study will refer to the ratio using **1.5:1** notation. It is generally accepted that optimal shoulder function requires "normal" shoulder strength. Because muscle strength is a potential modifiable risk factor for shoulder injury, it is important to implement effective and proper techniques for strengthening the musculature to reach "normal" ratio.[9,10] No previous research has been done regarding muscular imbalances in a glovebox worker population.

The purpose of this study is to investigate the rotator cuff strength ratio in a glovebox worker population and surveyed symptom incidence. The primary objective is to observe for any possible correlation between the rotator cuff strength ratio among glovebox workers and surveyed symptom incidence. The secondary objective of this study is to try to establish rotator cuff strength ratio criteria that can be used for risk assessment for future shoulder injury or symptoms development.

DEFINITIONS

Dynamometry

The measurement of force or power.

External rotation

When the arm is rotated at the shoulder so that the fingers change from

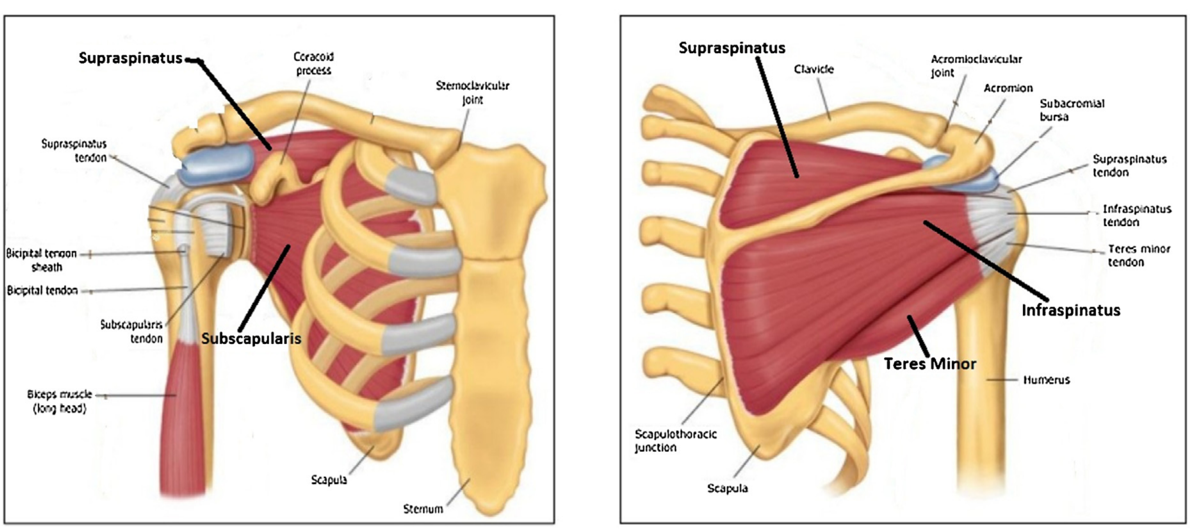

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Figure 2. Muscles of the rotator cuff.
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pointing across the body to pointing straight forward.

Force gauge
A small measuring instrument used across all industries to measure the force during a push or pull test.

Goniometer
An instrument that either measures an angle or allows an object to be rotated to a precise angular position.

Internal rotation
When the arm is rotated at the shoulder so that the fingers change from pointing straight forward to pointing across the body.

Isokinetic dynamometry
The measurement of force or power at a constant speed.

Manual muscle testing
A procedure for the evaluation of the function and strength of individual muscles and muscle groups based on the effective performance of a movement in relation to the forces of gravity and manual resistance.[11]

Pearson product-moment correlation coefficient
A measure of the linear correlation between two variables *X* and *Y*, giving a value between +1 and −1 inclusive, where 1 is total positive correlation, 0 is no correlation, and −1 is total negative correlation.

METHOD

Subjects

In accordance with 45 CFR 46, *Protection of Human Subjects*, and LANL's *Federal-Wide Assurance with the Office for Human Research Protection*, Department of Health and Human Services, FWA#00362, forty participants were used as subjects for this study. An email was sent out to the glovebox worker population of LANL, and forty volunteers self-selected into the study. All subjects voluntarily participated in and completed testing without issue. No subjects reported pain or symptom expression during testing.

The mean subject age was 46.7 years (Standard Deviation (SD) = 9.8 years, range = 24–64 years). Subjects with less than one year of glovebox work were excluded from this study. The volunteers' average career length as a glovebox worker was 12.7 years (SD = 8.5 years, range = 1–37 years).

Apparatus

A hand-held dynamometry (HHD) was used to perform the muscular force assessment. The ergoFET300 push/pull force gauge manufactured by Hoggan Health Industries was also used.

Numerous studies have found HHD to measure peak torque with an intra-tester reliability correlation coefficient of as high as 0.99, provided that the strength of the clinician exceeds that of the muscle group being tested.[12,13] Specific to rotator cuff strength assessment, it has been determined that HHD is most accurate when internal and external rotation are tested in the scapular (shoulder related) plane, within a range of 15–45 degrees.[13,14]

Procedure

Prior to initiating testing, the procedure of the study was presented to the subject and an informed consent form was signed. Each participant first completed a short questionnaire, see Table 1.

A symptom was defined as any sensation of physical pain, discomfort, numbness, or tingling. After completing the questionnaire, each subject was asked to assume a standing position with feet placed shoulder width apart. Floor markers were used to indicate the proper positions of the subject's feet. Goniometry was used to place the subject's elbow at a 90° angle and 30° shoulder blade plane elevation. The physical therapist then used one hand to stabilize the subject's arm at the elbow and the other hand to

Figure 3. External rotation of the arm.

Table 1. Glovebox worker rotator cuff strength ratio study questionnaire.

No.	Question	Answer
1	What is your current age (years)?	
2	Approximately how long have you been a glovebox worker (years)?	
3	Approximately how many hours do you work in a glovebox per day (hours)?	
4	Are you currently or have you previously experienced any physical pain, tingling, or numbness in either/both shoulder(s)?	
5	Present symptoms (YES, NO)	
6	If yes, which shoulder? (RIGHT, LEFT, BOTH)	
8	Past symptoms(YES, NO)	
9	If yes, which shoulder? (RIGHT, LEFT, BOTH)	

operate the HHD. The same physical therapist conducted muscular testing on all subjects to ensure reliability.

In testing external rotation, the HHD was placed perpendicular to the posterior surface of the forearm, see Figure 3.

To test internal rotation, the HHD was placed perpendicular to the anterior surface of the forearm, see Figure 4.

Prior to beginning, subjects were allowed one practice test for each motion.

In each trial, subjects were allowed to build up a maximal contraction for 2 s and asked to sustain the contraction for 3 s, which resulted in a total trial time of 5 s.[15,16] A thirty second recovery period was allowed between each test. Three trials of each motion were performed on each arm. The subject alternated between testing internal and external rotation on one arm until 3 trials of both tests had been performed. Testing was then conducted on the other arm using the same alternation between internal and external rotation. The use of HHD to assess both linear and rotational force produced by skeletal muscles has been shown to be an effective and reliable means of accurately quantifying muscular strength, so long as testing procedures are consistent.[9,15]

Data analysis

The average of three maximal effort contractions was used to analyze the data collected during shoulder rotator strength testing. The ratio of internal rotator strength to external rotator strength was calculated for each subject on both the right and left arms. One-way analysis of variance (ANOVA) was used to assess the difference between the measured strength ratios and the standard healthy ratio. Statistical significance was established, a priori, as 0.01 for all analyses. Descriptive statistics for age, years as a glovebox worker, hours worked in a glovebox per day, and rotator cuff strength ratios were computed to describe the mean and standard deviations of the indicated variables. Additionally, the Pearson product moment correlation coefficient (r) was used to investigate associations between average strength ratios and the variables of interest. Calculations were performed comparing the total number of workers experiencing shoulder symptoms and strength ratios.

RESULTS

An overall measured strength ratio was also calculated using the average of the right and left arm ratios. See Table 2.

Testing showed that the shoulder strength ratios of glovebox workers ranged from **1.4:1** to **4.2:1** with a mean ratio of **2.7:1** (SD 0.59). Only 2.5% ($n = 1$) of subjects were found to have the normal ratio (less than or equal to **1.5:1)** while Strength ratios greater

Figure 4. Internal rotation of the arm.

Table 2. Data collected from shoulder strength testing and surveying.

Participant	Right shoulder ratio	Left shoulder ratio	Average ratio	Symptom incidence
1	2.7	2.6	2.6	Symptomatic
2	2.8	2.7	2.7	Asymptomatic
3	1.8	2.4	2.1	Symptomatic
4	2.4	1.7	2.1	Symptomatic
5	2.1	1.9	2	Symptomatic
6	2.7	2.5	2.6	Asymptomatic
7	2.2	1.5	1.9	Asymptomatic
8	3	2.1	2.6	Symptomatic
9	3.4	3.3	3.4	Symptomatic
10	2.8	2.3	2.6	Symptomatic
11	2.4	2.5	2.4	Asymptomatic
12	2.9	2.9	2.9	Asymptomatic
13	1.9	1.8	1.8	Symptomatic
14	4.2	3.9	4.1	Asymptomatic
15	3.1	3.2	3.1	Asymptomatic
16	3.7	1.8	2.7	Symptomatic
17	1.9	1.6	1.7	Symptomatic
18	1.4	1.6	1.5	Asymptomatic
19	3.3	2.6	3	Symptomatic
20	3.2	2.8	3	Symptomatic
21	3.9	3.9	3.9	Symptomatic
22	3.1	2.9	3	Asymptomatic
23	4	2.9	3.4	Asymptomatic
24	3.8	3.1	3.5	Symptomatic
25	3.8	2.5	3.1	Symptomatic
26	2.8	2.7	2.7	Asymptomatic
27	3.4	1.6	2.5	Asymptomatic
28	2.5	2.5	2.5	Asymptomatic
29	2.9	2.6	2.8	Asymptomatic
30	1.7	1.6	1.7	Asymptomatic
31	2.3	1.8	2.1	Asymptomatic
32	2.1	1.8	1.9	Asymptomatic
33	2.7	3.2	3	Symptomatic
34	3	2.7	2.9	Symptomatic
35	2.8	2.9	2.9	Asymptomatic
36	1.7	3.7	2.7	Asymptomatic
37	2.6	3	2.8	Symptomatic
38	3.3	3.4	3.3	Symptomatic
39	2.7	3.6	3.2	Asymptomatic
40	3	2.6	2.8	Symptomatic

than **2.5:1** occurred in 67.5% of glovebox workers, as shown in Figure 5.

Fifty percent ($n = 20$) of workers reported having current or past shoulder symptoms attributed to glovebox work. As shown in Table 3, the vast majority of symptomatic workers exhibited strength ratios that were greater than **2.5:1**.

Figure 6 illustrates the significant increase in symptom incidence among GB workers with ratios that exceeded **2.5:1**.

Overall, 75% of all symptomatic workers and 60% of asymptomatic workers exhibit ratios that exceed the **2.5:1** criterion. As shown in Figure 7, prior to the 10 year mark, 100% of workers with ratios less than or equal to **2.5:1** were asymptomatic while an average of 45% of workers with ratios above **2.5:1** were symptomatic.

Table 3. Percentages of symptomatic/asymptomatic workers and strength ratio categories.

Shoulder strength ratio	1.0-2.5:1	2.6-4.1:1
Symptomatic GB workers	25% (5)	75% (15)
Asymptomatic GB workers	40% (8)	60% (12)

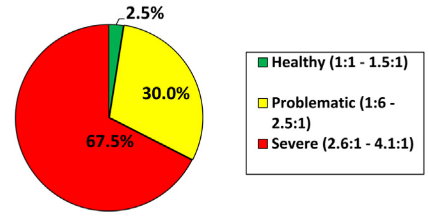

Figure 5. Glovebox worker rotator cuff strength ratios.

Lastly, increasing age and total years as a glovebox worker were both found to be only weakly correlated, ($r = 0.22$ and $r = 0.03$ respectively), with increasing ratios of internal rotator to external rotator strength.

STUDY LIMITATIONS

This exploratory study used a limited subject pool with modest inter-individual differences. Additional research with a larger, more diverse glovebox worker population may allow sharper insights into the impact of personal characteristics, such as strength, gender, stature, and age, on rotator cuff strength ratios. Furthermore, a convenient control population from previous literatures has been used to compare results from this study and may not be wholly representative of an accurately matched control group. Further research with an age-gender matched control group regarding rotator cuff strength ratios is required to standardize the comparisons.

DISCUSSION

In order to ensure the ethical involvement of human subjects, this study was approved by the LANL Human Subjects Research Review Board prior to subject recruitment. Studies involving muscular force assessment traditionally involve the use of isokinetic dynamometry, HHD, or manual muscle testing (MMT). HHD was elected for

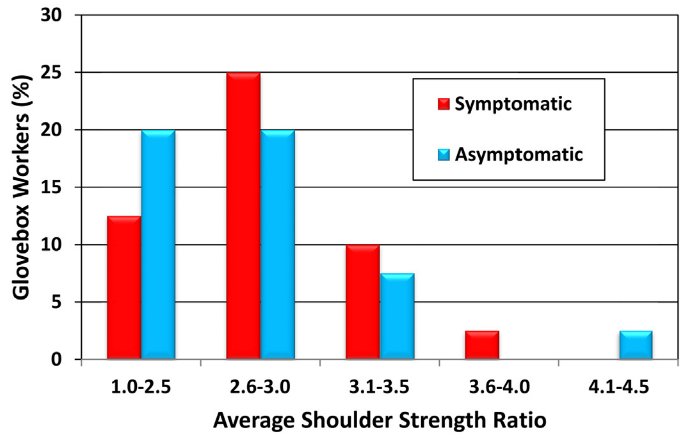

Figure 6. Relationship between shoulder strength ratio and symptom incidence.

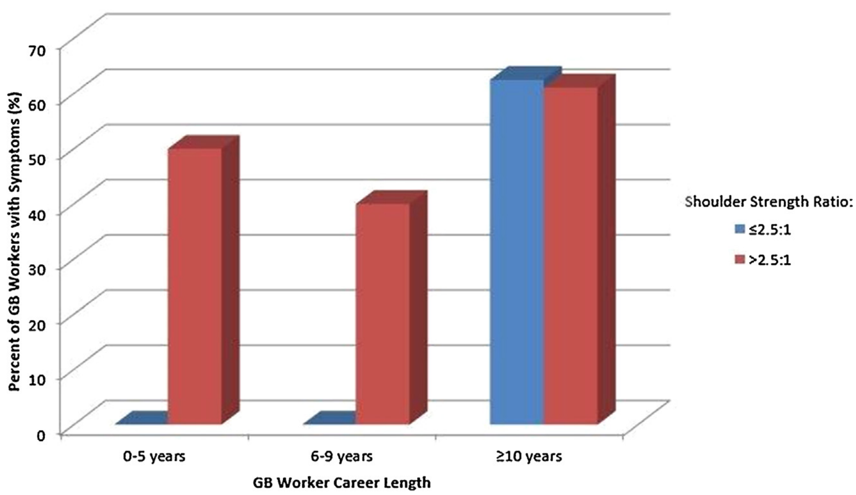

Figure 7. Changes in symptom incidence with respect to strength ratio throughout glovebox worker career.

use in this experiment. HHD has also been found to have comparable inter-rater reliability to both MMT and isokinetic dynamometry.[17] However, HHD has been shown to be more sensitive to small variations in muscle strength than is MMT.[18]

The cutoff point for symptom development in terms of ratio magnitude is established to be a ratio of approximately **2.5:1**, as shown in Table 2. The large percentage of glovebox workers that manifested severely abnormal strength ratios demonstrates the need for preventative measures implemented by occupational medicine clinics in industries involving high shoulder workload. A controlled longitudinal study is recommended to further examine the effectiveness of this criterion in determining risks of shoulder injuries and symptom developments.

Data presented in Table 3 indicate that abnormally large strength ratios are directly related to symptom incidence. One third of glovebox workers have strength ratios that are greater than or equal to twice the healthy norm (**3.0:1**). This may be attributable to excessively strong internal rotators, excessively weak or impaired external rotators, or some combination of the two.

On average, the presence of symptoms increased with age and total years as a glovebox worker, as shown in Fig. 6. While it is known that absolute muscular strength, including rotator cuff strength, decreases with age, no research has been done on the effects of age in specific regards to the strength ratio of the rotator cuff muscles.[19,20] This study assessed glovebox workers shoulder strength ratios with respect to age, but found only a weak positive correlation. However, career length as a glovebox worker is higher among symptomatic workers than among asymptomatic workers. This indicates a prominent opportunity for preemptive screening to identify shoulder strength ratios early and to implement appropriate solutions in order to reduce the risk of glovebox workers developing shoulder symptoms.

As strength ratios appear to have little effect on symptom incidence once workers reach a career length of approximately 10 years suggests that symptom presentation is a result of cumulative trauma and is influenced not only by abnormal strength ratios, but by other factors as well. Time spent working in a glovebox per day appeared to have no effect on either the presence of symptoms or the magnitude of the rotator cuff strength ratio, as shown in Figure 7.

As mentioned above, glovebox work requires much repetitive motion of the upper extremities and involves working with the hands at or near shoulder level. The U.S. Bureau of Labor Statistics found musculoskeletal symptoms involving the shoulder to be the most severe type of symptom in terms of the time required away from work.[21] Therefore, this type of screening merits consideration and application in industries known to impose high workloads on the shoulder.[22,23]

As abnormal strength ratios are multifactorial issues, their successful improvement is most likely to occur as a result of a multifaceted approach that addresses both internal and external influences on shoulder musculature. The implementation of a rotator cuff strengthening program is one means of enhancing shoulder strength. Controls designed to reduce the external stressors applied to the rotator cuff while working in a glovebox will also be critical to reducing the risk of symptom and injury development.

Some such controls may include the introduction of equipment and policies that reduce the need for external rotation at end range of motion. For example, over the last 2 years, the LANL Ergonomics team has been in the process of developing and introducing a new airlock sliding tray that will allow workers to transfer items between gloveboxes using significantly reduced external rotation of the shoulder. Another engineering control that could improve glovebox worker shoulder health is the provision of assistive lifting devices to aid in routine glovebox tasks that involve lifting and sustaining heavy objects. An administrative control already in place is The American Glovebox Society's recommendation of a maximum of 15 lbs. for two-handed lifts within a glovebox.[7] A variety of controls in occupational settings can be implemented as preventative measures for reducing the risk of developing rotator cuff symptoms and injuries.

The results of this study demonstrate the increased incidence of symptoms associated with a ratio of greater than **2.5:1**. This is the first step in the process to identify accurate screening criteria. Occupational medicine clinics could use this preliminary criterion to identify at-risk individuals within an asymptomatic population. Injury prevention, in turn, may ultimately forestall the need for a surgical rotator cuff repair and, thereby, eliminate per capita direct and indirect expenses of $50,000 to $200,000 and as much as 9–18 months of worker recovery time.[24,25]

Many organizations now maintain an employee health and wellness program. Rotator cuff strength ratio assessment could be introduced as a screening tool for detecting at-risk individuals. In addition, rotator cuff strength ratio assessment could provide opportunity for the preventative implementation of appropriate administrative and engineering controls could be a valuable asset to such programs.

In summary, the primary purpose of this study was to investigate the rotator cuff strength ratios in glovebox workers, a population frequently subjected to high workload placed on the shoulder, and its significance in the risk of shoulder injuries and symptoms development. A vast amount of existing literature has suggested that the healthy individual should have a ratio of internal to external rotator strength of **1.5:1**. Testing conducted in this study found that, on average, the rotator cuff strength ratios of glovebox workers is significantly higher from those of the normal healthy population. The incidents of symptoms seems to increase substantially among those workers with ratios exceeding **2.5:1**. Previous studies show that various muscular imbalances contribute to the development of physical pain and pathology. Identifying and addressing asymptomatic workers with abnormal strength ratios is critical to restoration of strength balance and prevention of future symptom development. Other results include the weak correlation between increasing age and total years as a glovebox worker with increasing ratios of internal rotator to external rotator strength. Remedying the observed imbalance in glovebox worker shoulder strength ratios may aid in improving worker health, safety, comfort, and productivity.

CONCLUSION

Abnormally high rotator cuff strength ratios have been observed among glovebox workers. Rotator cuff strength ratios may be used as a screening tool for the determination of symptom risk in this population. Preventative measures designed to improve shoulder strength ratios and reduce workload on the shoulder joint could be helpful in avoiding symptom development and maintaining worker health and safety within an effective work environment.

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