Development of Thumb Endurance Curves Applicable for Deadman Switches in Sandblasting Machines

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Abstract. Thumb operated deadman switches used in sandblasting machines are designed to prevent serious bodily injury from unintentional discharge of high velocity sand. The force required to hold down the switch is significant, causing fatigue and pain to set in very quickly in operator's thumb. The objective of this study was to determine the thumb force capacity and muscle fatigue curves for thumb flexion, applicable for design of these devices. Maximum thumb pressing force (MTPF) and endurance times (ET) for holding down at force levels of 10, 20, 40, and 60% of MTPF were measured from 10 male and 10 female participants in a laboratory experiment. The best fit curves of ET as a function of %MTPF were modeled with $R^2 > 95\%$. These models should be used in matching the worker strength capacity to the thumb force requirements in deadman switch design to improve safety standards in sandblasting.

Keywords: Thumb pressing · Muscle fatigue · Endurance time · Deadman switch · Sandblasting

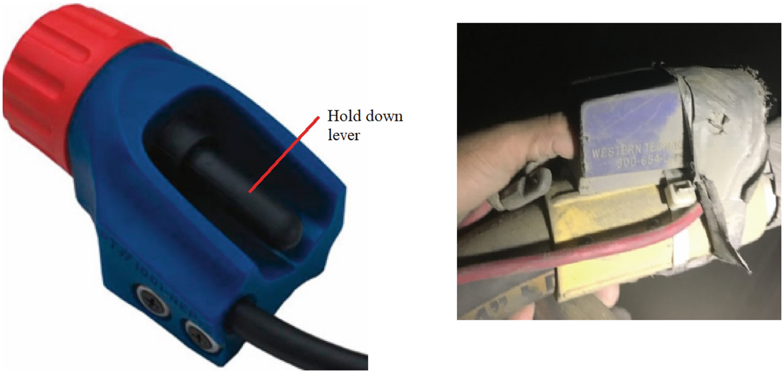
1 Introduction

Sandblasting machines use a compressed air source connected to a container of sand, and a flexible hose with a hand-held nozzle to propel high velocity sand on a surface for cleaning or removing paint or rust etc. Apart from the health risks from dust inhalation, silicosis and high level of noise, accidental body contact with the sand discharge can develop serious injuries and death [1]. This type of accident can happen if the operator loses balance or trip on an uneven floor while sandblasting. To prevent such accidents, blast nozzles are equipped with a deadman switch that cuts of sand discharge in the event the nozzle is accidentally released from the operator's hand. Deadman switch shuts off the equipment when the worker is not holding it down. When it is properly used, a worker who drops a hose is protected because the flow of abrasive material is stopped by the switch not being held down. However, in some cases, workers bypasses the switch, and this can result in the equipment not shutting off, and the hose can spray everybody in the vicinity. Occupational Safety and Health Administration (OSHA) [2] mandates that "the blast cleaning nozzles shall be equipped with an operating valve which must be held

N. L. Black et al. (Eds.): IEA 2021, LNNS 222, pp. 190–195, 2021.
https://doi.org/10.1007/978-3-030-74611-7_26

open manually”. An accident search in OSHA website with a keyword “sandblasting” [3] reveals a number of similar accidents in recent years with serious injuries and death.

A typical electrical deadman switch uses a thumb operated trigger (Fig. 1a) that needs to be actively pressed down (Fig. 1b) to maintain the sand discharge. The inch long trigger is stiff and guarded from two sides to prevent discharge if the nozzle is accidentally dropped from hand. This trigger creates a significant and static force on the user’s thumb, and fatigue sets in very quickly. This muscle fatigue manifests as pain in the thumb muscles under static tension. To avoid pain, many operators modify these deadman switches by taping the trigger in an open position or placing a rock under the switch forcing it into an open position. Either of these two methods creates risk in the event of an accident.



(a) (b)

Fig. 1. (a) A Typical electrical deadman control switch; (b) assembled sandblasting hose with the deadman control switch.

Clearly the safety problem is related to thumb muscle fatigue. The only thumb fatigue model found in literature was developed by Choi et al. [4] for physiotherapist’s work, and pipette-based laboratory work. The thumb positioning and the muscle group involved in their study were entirely different from operating a “deadman” switch in sandblasting. Many other muscle fatigue models, reviewed by El Ahrache et al. [5], were developed for different large muscle groups. Their review reported remarkable variances between ET values for different muscle groups. Thus none of the muscle fatigue data are applicable for deadman switch design. This lack of data in thumb muscle fatigue means that engineers designing these deadman switches do not have appropriate baseline of human capabilities to reference. Thus objective of this study was set to determine relationship between ET and the submaximal thumb pressing force (in terms of %MTPF) applicable to deadman switch design, with a goal to improve safety of sandblasting operation.

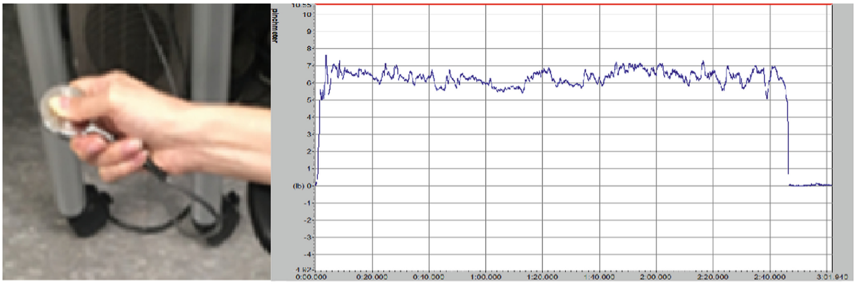
2 Methods

2.1 Participants

The experimental study was approved by the Institutional Review Board. Ten male and ten female subjects participated in this study with mean (standard deviation) of age 31 (11) years, height 67.3 (3.9) inches and weight 148.7 (33.3) lbs. Only healthy adults with no contraindicated health conditions or history of pre-existing thumb, hand or wrist injury, were eligible to participate in the study. The participants were paid $20 for their service.

2.2 Apparatus and Data Collection

A Datalog module (MVX8), a Pinch-meter (P200) and Datalite data acquisition system (Biometric Ltd.) were used to collect thumb force and holding time data. Participants pressed on the Pinch-meter (Fig. 2a) by the thumb area, between the interphalangeal joint and the middle of their nail plate, while keeping the wrist straight. The data acquisition software displayed real-time thumb force data on a moving timeline on the computer screen (Fig. 2b). The pinch-meter was calibrated prior to data collection.



(a) (b)

Fig. 2. (a) Pinch meter (P 200, Biometric Ltd.) is pressed by thumb, and (b) thumb force level display over time line for %MTPF trials.

2.3 Experimental Procedure

At the beginning of the experimental trial, the MTPF of a participant was measured over a duration of 4 to 6 s. The measurement was repeated three times with two minute rest pauses between trials. The maximum from these three trials was taken as the MTPF for the participant.

Following the MTPF measurement, endurance times (ET) were measured for targeted static exertions of 10, 20, 40, and 60% of MTPF, presented in a randomized order. Participants pressed the Pinch-meter to the targeted %MTPF force level and was instructed to hold the force level constant until they could no longer maintain the force level due to discomfort or pain from muscle fatigue. For time constraint, any trial that reached 20 min was terminated. Only three 10% MTPF trials reached 20 min. Five minutes or more rest pauses were given between trials to recover from muscle fatigue. During this time, participants filled in a feedback form noting down their level of pain, discomfort, numbness, and cramping in a scale of 0 (none) – 9 (highest). Each participant took about 1.5 h to complete the experiment.

2.4 Data Processing and Model Development

The participants tried to maintain the targeted %MTPF, however, there was some minor fluctuations of force over the ET, as seen in Fig. 2b. For fatigue modelling, the average thumb force over the ET was calculated, and %MTPF values were recalculated from the MTPF. The difference from the target %MTPF were nominal. For targeted %MTPF of 10, 20, 40, and 60% the corrected %MTPF's averaged at 10, 19, 37 and 54%, respectively, when calculated over all participants. The corrected %MTPF values were used in fatigue modeling.

Curve fitting function in Excel was used to obtain least square fit between ET and %MTPF values for all participants. The exponential function gave the best curve fit with coefficient of determination $R^2 > 0.95$.

3 Results

Figure 3 shows the least square fitted, exponential curves superimposed on the data points from male and female participants. As expected, the nonlinear curves show that when the %MTPF levels have decreased, the ET values have increased. In the range of 40 to 100% MTPF, the ET values were small, less than a minute. For lower than 40% MTPF, the endurance times have increased substantially.

The exponential functions for (i) combined male and female, (ii) male, and (iii) female populations are provided in Eqs. (1), (2) and (3), respectively. The coefficient of determinations R^2 were 0.95, 0.95 and 0.97, respectively.

$$Combined : ET = 18.177e^{-5.875^{*}\%MTPF} \tag{1}$$

$$Male : ET = 13.823e^{-5.625^{*}\%MTPF} \tag{2}$$

$$Female : ET = 24.381e^{-6.196^{*}\%MTPF} \tag{3}$$

Participants noted different symptoms, ranging from shaking, numbness, tingling, burning, cramping, and pain at the end of ET measurement trials. The average discomfort levels (0–9 scale, 9 being most sever) at 10, 20, 40, and 60% MTPF levels were 6.4, 5.4, 5.5 and 5.4, respectively. At 10% MTPF, discomfort levels were generally higher. The discomfort levels indicated onset of localized muscle fatigue at the end of ET trials.

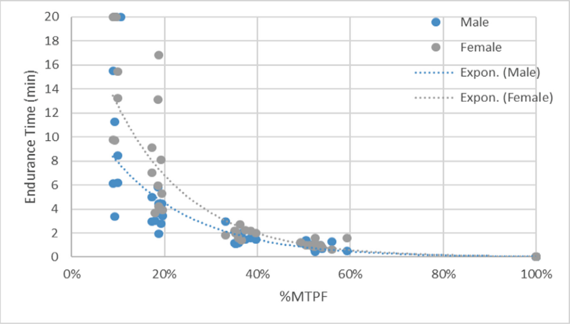


Fig. 3. Least square fitted exponential curves relating ET (min) to %MTPF values for both genders.

4 Discussion

The fatigue curves show that when %MTPF is less than 40%, the ET value increases noticeably – this trend was similar to the results from previous studies on muscle fatigue [5]. Female ETs were longer than males, especially at lower %MTPF levels (10 & 20%), which was also observed by other researchers [4, 5]. While the endurance time for female was 13.1 min at 10% MTPF, the male could perform 7.9 min for the same relative force level. The absolute thumb force was obviously higher for male compared to female. The average male MTPF (26.5 lbs) was 45% more than female MTPF (18.3 lbs). This study produced smaller ET values for 10% MTPF (7.9 min) and 20% MTPF (4.5 min) for male population, when compared to Choi et al. [3] results (12.4 and 6.1 min, respectively). This difference supports our hypothesis that different muscle groups of thumb will have different fatigue curves.

A typical deadman switch (Fig. 1a) requires approximately 3.4 lbs. of holding down force. At this force level, Eq. (2) predicts thumb fatigue would set in after 6.7 min for an average male, which is less than the usual continuous operating time of at least 15 min for sand blasting operations. With the present design, muscle fatigue and pain is unavoidable as the operating time exceeds ET. Equation (2) predicts that 3.2% MTPF can be maintained for an ET of 15 min. Similar calculation can be performed for any desired ET for combined male-female, male or female population using Eqs. (1), (2) and (3), respectively .

Sandblasting operators wear protective clothing, helmets, breathing apparatus, and they also experience high level of noise. All these factors, not been considered in present study, should adversely affect the worker's ET. Thus the ET values from this study should be further adjusted down when designing deadman controls.

This analysis shows that the design improvement of deadman switch is essential by substantially reducing the hold down force. Reducing hold down force may require an additional safety switch to prevent inadvertent actuation of the deadman switch. Two switch designs are used in many existing power tools to prevent inadvertent actuation. Another alternative could be using a lever that can be actuated by a power grip, instead of thumb alone to reduce muscle fatigue.

Acknowledgements. This publication was supported by the Grant Number, T42OH008422, funded by the Centers for Disease Control and Prevention. Its contents are solely the responsibility of the authors and do not necessarily represent the official views of the Centers for Disease Control and Prevention or the Department of Health and Human Services.

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Editors

Proceedings of the 21st Congress of the International Ergonomics Association (IEA 2021)

Volume IV: Healthcare and Healthy Work

Springer

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ISSN 2367-3370 ISSN 2367-3389 (electronic)
Lecture Notes in Networks and Systems
ISBN 978-3-030-74610-0 ISBN 978-3-030-74611-7 (eBook)
https://doi.org/10.1007/978-3-030-74611-7

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Part II: Healthcare Ergonomics (Edited by Marijke Melles)