Evaluating the OSHA hand speed constant for stamping press applications

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ABSTRACT

Occupational Safety and Health Administration (OSHA) utilizes 'hand speed' as a critical machine guarding parameter. OSHA's current hand speed constant is based upon research conducted by Löbl (1935), who used a fixed hand starting position to estimate the maximum human hand speed of five males at 1.6 m/s (63 in./s). Sixty (60) college students participated in the present study to ascertain a more accurate estimate of the 95th percentile hand speed for machine guarding applications. Results indicated that the hand speed between the upper and lower dual palm button positions are significantly different, and for the upper button location OSHA's hand speed constant may not be conservative enough to protect some operators. Specifically, the 95th percentile hand speed from the lower button was 1.510 m/s (protective for > 95% of those tested), but the 95th percentile hand speed from the upper buttons was 2.825 m/s (protective < 10% of those tested). These results suggest that control location with respect to the point-of-operation should be considered since hand speed is significantly impacted by relative position.

1. Introduction

Stamping presses are power driven reciprocating machines designed to trim, blank, or pierce sheet metal (materials) using a formed die (NIOSH, 1987). Typical mechanical presses contain a large, heavy flywheel driven by an electric motor. Flywheel rotation is transmitted to a movable ram by an eccentric crankshaft linked by a clutch. To control the press, an operator engages the clutch, which transmits the rotation of the flywheel to the movable (up and down) ram through the crankshaft. Depending on the size of the flywheel and the gearing of the drive mechanism, a stamping press can close with a force between 30–600 tons and reciprocate at speeds between 125–1000 strokes per minute (Cattell, 2008). Stamping presses can be further divided into two categories depending on the design of the flywheel clutch. Full-revolution clutches remain engaged for a full stroke once they are actuated; meaning the ram fully cycles (cannot be stopped). Part-revolution clutches can be disengaged during the down stroke to halt a cycle. However, press rams are typically heavy and contain a significant amount of inertia, so stopping is not instantaneous with part-revolution machines. Since full-revolution presses cannot be stopped during a cycle, they pose increased risk to operators (NIOSH, 1987). Manually loaded presses (Fig. 1) have more production flexibility than those automatically loaded, but also present an increased risk of operator injury (Etherton, 1984; Pizatella & Moll, 1987).

2. Hazards and regulations

The metal working (fabrication) industry consistently ranks among the highest in machine related worker injury rates. For example, the incidence rate for lost-time injuries in metal fabrication in 2015 was 133.1 cases per 10,000 metal workers. In comparison, the average for U.S. private industry was 105.2 cases per 10,000. Amputations in metal fabrication are especially common, averaging 2.6 cases per 10,000 in metal working versus 0.6 cases per 10,000 in private industry (Parker et al., 2015). Stamping presses consistently rank among the most dangerous types of process equipment (Yamin et al., 2014, 2016), and it has been estimated that 10% of all amputations in manufacturing are caused by power presses (NIOSH, 1987). Furthermore, McCaffrey (1981) found that 49% of power press injuries were amputations.

OSHA is aware of the hazards associated with power presses and has developed standards to address press safety. OSHA's Mechanical Power Press standard, issued in 1971, was based on ANSI B11.1-1971 (Baldwin, 1976), which recommended the use of point-of-operation devices "preventing or stopping the normal stroking of the press, or both, if the operator's hands are inadvertently placed in the point-of-operation" (ANSI B11.1-1971 5.3(1)). This ANSI standard recommended the use of guards, presence sensing devices, pullback devices, sweeps, two-hand trips, two-hand control devices and so forth to accomplish this. This standard also required the "application of both of
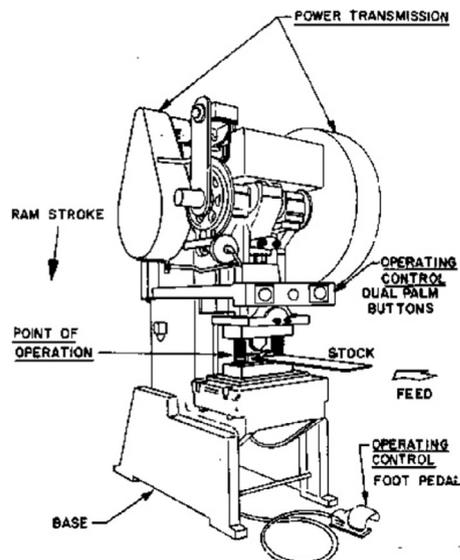

Fig. 1. Typical Manual Loaded Power Press. Figure Taken from "Amputation: A Continuing Workplace Hazard". CDC – NIOSH Publications and Products – Injuries and Amputations Resulting from Work with Mechanical Power Presses (NIOSH, 1987).

the operator's hands to the machine operating control during the die closing" (ANSI B11.1-1971 5.3(4)). ANSI did not provide guidance on the setback distance, but rather specified that the location must be far enough away that the press would complete its stroke "before the operator's hands can inadvertently reach into the point-of-operation" (ANSI, 1971). Hence, the original OSHA 1910.217 standard included all the ANSI B11.1-1971 recommendations, including the "no hands in die" requirement. After petitions from the metal working industry and the completion of an OSHA study that determined that a lack of guarding presented more risk than after-reach errors, the 1910.217 standard was revised in 1973 to allow "hands in die" loading. However, the revised standard included changes to improve machine control reliability and point-of-operation safeguarding (Baldwin, 1976).

The point-of-operation on a power press is an inherently dangerous area. To manually load a press an operator loads the stock into the "pinch point" generated by the ram closing into the die. This puts the operator in danger if the ram closes while his/her hand(s) are present. A number of safeguards (OSHA 1910.217, 2013) are typically installed on presses based on the design of the machine:

(a) For machines equipped with a foot switch: guarding, pullbacks and restraint devices.
(b) Dual palm buttons may be used for full and part-revolution clutch machines.
(c) Presence-Sensing Devices (PSD) may be used, but are only applicable to machines equipped with part-revolution clutches.

Machine cycle rates are faster using a foot switch since the press can be actuated immediately after the hands leave the point-of-operation (as opposed to after the operator's hands travel to the palm buttons). However, the risk of amputation injuries is not as high for dual palm buttons, since foot switches can be inadvertently actuated, while the operator's hands are in the point-of-operation (NIOSH, 1987). Palm buttons are designed to allow the machine to cycle only if both buttons are pressed at the same time, ensuring that an operator's hands cannot be in the die during the start of the downward stoke of the ram. The use of two-hand palm buttons also minimizes after-reach errors, which occurs when an operator attempts to reach into the press after the downward motion of the ram has been actuated. This is believed to be an inadvertent, reflexive operator response to clear a process upset in

the die (NIOSH, 1987). For example, the operator may notice scrap in the die or a miss-set blank and attempt to clear it after the machine cycle has started, but before the die closes. This may prevent damage to the die or creating a scrap part, but can result in the operator's fingers, hand, or arm being in the point-of-operation when the press cycles.

29 CFR 1910.217 contains several provisions related to the safe design of power presses using dual palm-button controls. Specifically, OSHA 1910.217(c)(3)(vii)(c) – The distance the start buttons are positioned from the point-of-operation is called the safe or setback distance. To reduce the after-reach hazard, a minimum safety distance between the point-of-operation and the dual palm buttons is required. The setback distance is calculated using the formula, $D(s) = 63\,in./s * T(s)$; Where $D(s)$ is the safe distance and $T(s)$ the hazard time or press closing time. Per the OSHA standards, 63 in./s (or 1.6 m/s) is the hand speed constant, which represents the speed at which workers can perform an after-reach movement. OSHA 1910.217(c)(3)(vii)(c) uses the 63 in./s (1.6 m/s) to calculate the safe distance (setback distance) for dual palm buttons and was added in 1974 to strengthen the standard (improve point-of-operation safeguarding) after the "no hands in die" requirements were removed.

The use of dual palm buttons (Fig. 2) is common on mechanical presses. A study of presses in Finland found that 54% of the presses surveyed included dual palm buttons in the start sequence (Suokas, 1983).

3. Concerns regarding OSHA's hand speed constant

OSHA's 63 in./s (1.6 m/s) hand speed constant is based on research performed by Löbl in 1935 (OSHA Etool Website, 2017). Presses in Löbl's day used full revolution clutches and did not have electromagnetic controls. Operators actuated mechanical levers to engage the flywheel clutch and begin the downward stroke. In an early attempt at two-hand-capture, presses were designed with two levers, so that both hands were required to actuate the clutch. No information was available at the time to determine how far away the start levers should be to prevent an operator from committing an after-reach error after initiation of the press cycle (Lobl, 1935). Löbl used oscillography to measure the time needed for a participant to push the start levers (in the horizontal plane), release the lever, and move his hand until he touched a "target plate" in a simulated stamping press. Löbl calculated hand speed based on elapsed time over an estimate of the distance the hand traveled, representing the average velocity along the participant's "hand path." His experiment consisted of 79 trials conducted using five (5) male participants. The calculated value of 1.58 m/s (rounded up to 1.6 m/s) was the maximum speed attained by one participant, and thought to be the maximum hand speed a human could obtain (Lobl, 1935).

ANSI reissued B11.1 in 1982 and mirrored OSHA's formula for safe

Fig. 2. Typical Dual Palm Button Start Station. Figure Taken from "Safeguarding Equipment and Protecting Employees from Amputations". OSHA 3170-02R 2007 (OSHA, 2007).

distance calculations, but the comments for B11.-1982 5.3.2(5) noted:

> "The 63 inch/s figure is derived from the OSHA (1974) regulations. Under certain circumstances a higher hand speed may be necessary. Small parts in conjunction with fast operator speed should be viewed with particular concern" (ANSI, 1982).

In the 1980s, NIOSH researchers began re-assessing machine safety and Löbl's conclusions on safe distance. McCaffrey studied work related amputations based on workers' compensation claims from the Bureau of Labor for 1977. He estimated that 21,000 amputations occurred in the USA in 1977. Sixty percent of these claims occurred in manufacturing even though manufacturing accounted for approximately 30% of employment at the time. According to his analysis, 91% of amputations were fingers and 56% of those amputations involved machines. Workers being caught in, under, or between machines accounted for 51% of the injuries (McCaffrey, 1981).

In 1983, Pizatella, Etherton, Jensen, & Oppold reproduced Löbl's experiment using a more sophisticated time measurement system. They built a simulated press with no moving ram and with dual palm buttons (rather than levers) to actuate the press, and used a photo-optic speed measuring system to capture hand speed. They tested the after-reach speed of operators with dual palm buttons located at waist height and shoulder height (the two most popular palm button locations for small power presses). The researchers used eight (8) participants between the ages of 29–38. Each participant performed 20 random after-reaches from each button location. Using the average hand speed from the waist and shoulder height, Pizatella et al. observed a statistically significant difference between the hand speeds of individuals. Based on these results, they determined "that standards based on a single-hand speed constant may be unnecessarily restrictive for some operators and not protective enough for others." All of the participants achieved faster hand speeds from the upper controls (average of 1.32 m/s) than from the lower controls (average of 0.94 m/s) (Pizatella et al., 1983).

In 1987, Pizatella and Moll published a definitive study on after-reach speed using a specially built simulator. Sixty (60) industrial workers of various ages (85% whom had previously worked on power presses) were measured four times at each button location. Only the fastest of the four hand speed trials (at each location) was used in the data analysis (Pizatella & Moll, 1987). Results indicated that the mean hand speed for the participants in their study was 1.34 ± 0.68 m/s, and significant inter-participant differences in hand-speed based on age and gender were observed. Male participants averaged 1.58 ± 0.72 m/s and female participants' averaged 1.07 ± 0.52 m/s. Younger workers (20–30 years old) could achieve speeds greater than 2.0 m/s significantly higher velocities than older workers. The location of the participant's start position (waist level vs shoulder level) also affected speed. Their study indicated that the 1.6 m/s hand speed constant was protective for the average worker, but also that operators exist in the general population that would not be protected, and that workers younger than 30 years old may not be fully protected. Their finding that hand speed is effected by age and gender has been supported in the literature (Era et al., 1986; Au et al., 2015; Welford, 1984).

In March 1987, NIOSH, in response to the evidence amassed by NIOSH Research scientists (Etherton, Pizatella, Moll, Horton, and others) issued Current Intelligence Bulletin (CIB) 49 (titled "Injuries and Amputations Resulting from Work with Mechanical Power Presses"). This bulletin warned employers that NIOSH believed the OSHA hand speed constant was not protective for all workers and that additional safety precautions were necessary for some workers:

> "Caution must be exercised in evaluating each power press set-up and operation to ensure that an adequate safety distance is maintained at all times. Employers should consider evaluating individual press operators to determine if they are exceeding the current OSHA hand-speed constant. If a worker is identified as being capable of exceeding the hand-speed constant, more positive means of point-of-

operation safeguarding should be considered, such as fixed barrier guards."

Jensen investigated the impact of palm button placement on after-reach speed (Jensen & Stobbe, 2016). Jensen's hypothesis was that hand speed was not a constant and was impacted by both button placement (shoulder height or waist height) and distance from the palm buttons to the point-of-operation. Jensen used nine male participants (without press work experience) to gather hand speed data at multiple button locations and geometries. He used young males because they had the fastest hand speeds in the Pizatella and Moll study. His participants averaged 1.59 m/s for the lower button and 2.24 m/s for the upper button placements, respectively. He recommended abandoning the "hand speed constant" concept in favor of a speed formula based on experimental data (Jensen and Stobbe, 2016; Jensen, 1989).

In an experiment to determine the safety system that would allow the highest production on a press, Katoh et al. found a difference in hand speed between older and younger workers. They conducted a simulated press study using four males in their twenties and four males in their fifties. Younger participants exhibited hand speeds faster than the OSHA constant using dual palm buttons. Both young and old participants exceeded the OSHA hand speed constant when using Presence Sensing Devices (PSD). They recommended PSD safety devices for part revolution clutch machines rather than two-hand palm switches to maximize loading speed and press production (Katoh et al., 2001).

It is clear that the OSHA hand speed constant (1.6 m/s) is not protective for all press operators. Multiple studies have found after-reach speeds that exceed the 1.6 m/s value and that hand speeds vary significantly between participants, and based on palm button placement and orientation (shoulder height vs waist height). While there may be no hand speed constant in the sense that OSHA uses it in the "safe distance" equation, it is possible to develop a maximum after-reach speed based on the two button locations typically found in presses. This maximum can be found by sampling the press operating population and determining the 95th percentile hand speed of the sample (as an estimator for the population). The 95th percentile value is an important number, since this value is typically considered a compromise between protection and practicality. Jensen used the 95th percentile concept to reinterpret the hand speed data developed by Pizatella and Moll and to recommend a hand speed 2.142 m/s for upper button placement and 1.877 m/s for lower button placement (Jensen, 2017). These values are based on the total 60 participant sample (male and female, 20–60 years old). A more conservative approach would be to sample the segment of the press operating population most at risk (those with the fastest hand speed) and determining the 95th percentile hand speed of that population. Based on the work of Pizatella and Moll, a hand speed constant based on younger workers (20–30 years of age) should represent the maximum hand speed of the worker population at large. (Pizatella and Moll, 1987).

The objective of the present study was to find the 95th percentile hand speed of a sample of men and women (20–30 years of age) on a simulated press from two dual palm button locations to determine if OSHA's 1.6 m/s hand speed constant is realistic.

4. Methods

The present study used optical motion capture (OMC) tracking technology (VICON, Oxford, 14 Minns Business Park, West Way, Oxford England, OX2 0JB) to capture the hand velocity of participants performing after-reach movements. VICON is a more sophisticated system than has previously been used for after-reach tracking, since it captures not only the start and stop times of the hand motion, but also captures the path of the participant's hand and instantaneous velocity and acceleration throughout the motion.

All the after-reach measurements in the literature were collected using some form of simulated press. The most sophisticated simulator
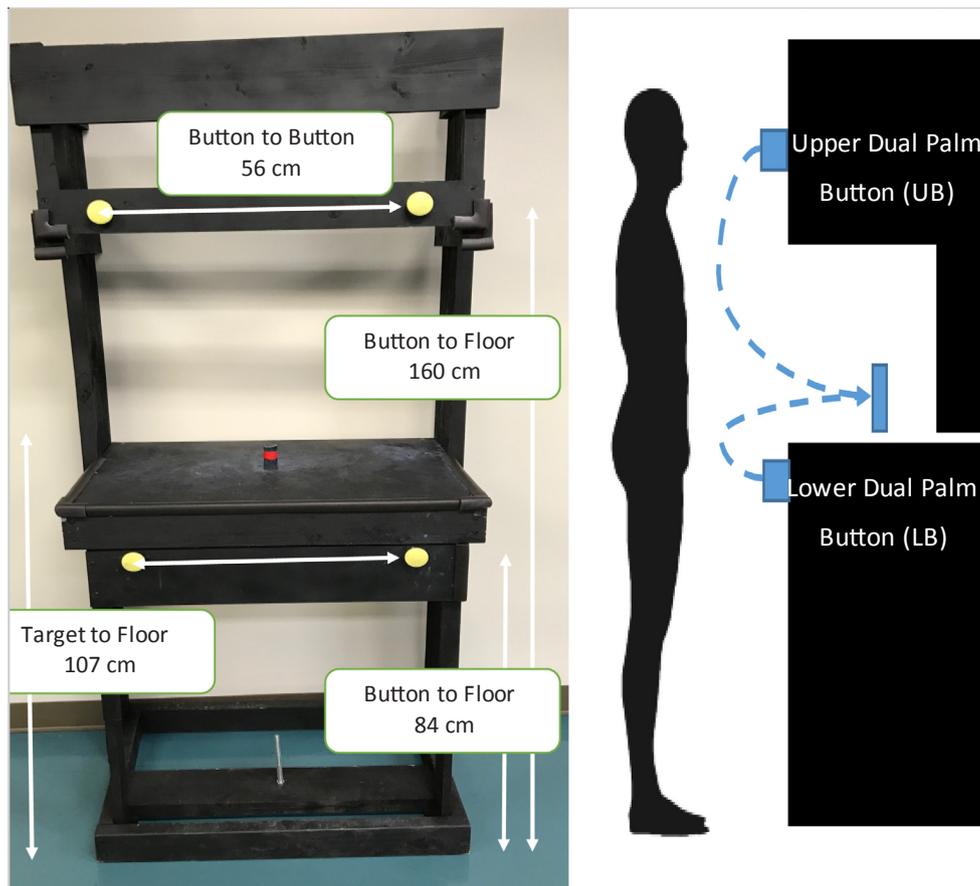
Fig. 3. Waist and shoulder height dual palm button layout for simulated press.

was built by Pizatella and Moll for their study and later used by both Horton and Jensen for their studies. Pizatella's simulator included a reciprocating ram, waist/shoulder height dual palm button stations, photo-optic sensor for speed sensors, simulated work pieces, and a mechanism to kick work pieces from the die and initiate an after-reach event. The construction of a fixture, which duplicated the geometry of the simulator built by Pizatella, was fabricated and used for the present study (Fig. 3).

The apparatus for this study included simulated two-hand start buttons (56 cm apart) at waist height (84 cm from the floor) and shoulder height (160 cm from the floor) with a near waist height after-reach target (107 cm from the floor). The apparatus was constructed of wood and counterweighted to prevent tipping, with all sharp edges padded to prevent injury. The device was painted flat black to minimize reflectivity that might interfere with the OMC system.

OMC systems use multiple cameras to triangulate the position of reflective markers attached to the participant. OMC is accurate [system error is less than 2 mm (Merriaux et al., 2017)] and is considered to be the gold standard for segmental kinematic measurements (Ceseracciu et al., 2014). The OMC system used to collect the hand speed data for this experiment used seven (7) VICON T010 cameras and the motion capture data was processed using Xsens MVN Studio BIOMECH Version 4.2.0 software.

4.1. Participants

The criteria for participants were to be 19–30 years old, with no history of heart disease, stroke or breathing disorder that prevented exercise, and no medical history or injury to their back, shoulders, arms or hands that would prevent rapid movement. The experiment was conducted using thirty (30) male participants and thirty (30) female participants. The male participants ranged in age from 20-29 (mean = 24, SD = 3.04) years old, and the female participants from 19-30 (mean = 23.5, SD = 3.19) years old.

4.2. Procedure

Participants were interviewed to insure they met the requirements of the study, reviewed the experimental procedure, and provided informed consent. Afterwards, anthropometric measurements were obtained (height and length measurements of their arms, legs, and arm reach). VICON reflective markers (Fig. 4) were placed on the
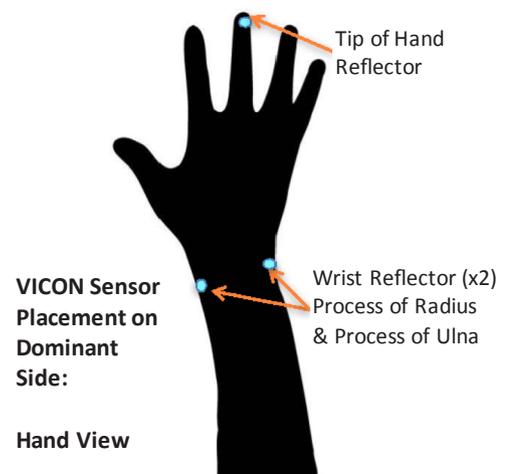

Fig. 4. Reflective markers to identify kinematic segments.

participant's wrist and fingertip of their dominant hand. Due to the set-up of the VICON camera system, only right hand dominant participants were used in this experiment.

The experiment was a randomized design with order of the trials decided based on a coin flip. The trial plan was explained and the participant was asked to practice each movement until they felt comfortable before any measurements were collected. They were instructed to reach for the target with their dominant hand. The participant was given a "one-two-three-go" signal and then asked to make a rapid hand movement from the fixed starting position to the target position. Each movement was repeated three times. After completing the three trials, the researcher explained the next start position. The participant was allowed to practice, and the next trial was performed.

The trials consisted of two elements: reaching from the lower dual palm button (LB) location to the target and reaching from the upper dual palm button (UB) location to the target of a simulated press. Each trial generated a set of VICON data which contained position data and a frame count (120 frames per second). Python (Version 2.7) was used to extract the average velocity of the movement of the fingertip marker over the path traveled from the dual palm button to the target based on a selected start point and end point. The velocity of the fingertip marker was assumed to be the hand speed during the motion.

Analysis of variance (ANOVA) was used on each data set (Male LB, Female LB, Male UB, and Female UB) to evaluate the potential for interaction between the three trial runs. Each trial run was considered a treatment and analyzed against a null hypothesis (H_o) of all means being equal. If this hypothesis was rejected (H_i = at least one mean is different), this would indicate that trials were different run to run. For example, if the means were increasing from trial to trial, it could mean that the participants were learning and improving their after-reach skill during the experiment. If the means were decreasing run to run, fatigue could be an issue. No statistically significant effects were observed for any of the trials, suggesting that the three experimental trials may be considered independent. To aid in data processing, the trials were averaged and calculations reported as the mean of the three trials.

5. Results

For the reach from the lower button (LB) to the target, the 30 male participants and 30 female participants generated sixty (60) data sets. Fifty-six (56) of these data sets could be read and analyzed by the Python program. Using Minitab to develop box plots of the data revealed that one of the male participants was an outlier (greater than 1.5 IQR from the third quartile). This participant was removed from the data since outliers skew the statistics and normality on small data sets. A summary of the trials results are found below (Table 1):

The hand speed reached by participants for the upper button trials was significantly higher than the lower button trials. For the reach from the upper button (UB) to the target, the thirty male participants and thirty female participants generated sixty (60) data sets. Fifty-eight (58) of these data sets could be read and analyzed by the Python program. Using Minitab to develop box plots of the data revealed that one of the male participants was an outlier (greater than 1.5 IQR from the third quartile). This sample point was removed from the data since outliers skew the statistics and normality on small data sets. A summary of the trials results are found below (Table 2):

Table 1
Male and female LB average hand speed.

	Average	SD	Range
Male LB Position (Outlier Included)	1.243 m/s	0.169 m/s	0.950 m/s to 1.929 m/s.
Male LB Position (Outlier Removed)	1.217 m/s	0.104 m/s	0.950 m/s to 1.447 m/s
Female LB Position	1.262 m/s	0.205 m/s	0.876 m/s to 1.648 m/s

Table 2
Male and female UB average hand speed.

	Average	SD	Range
Male UB Position (Outlier Included)	2.234 m/s	0.429 m/s	1.365 m/s to 3.559 m/s
Male UB Position (Outlier Removed)	2.186 m/s	0.352 m/s	1.365 m/s to 2.756 m/s
Female UB Position	2.180 m/s	0.429 m/s	1.553 m/s to 3.205 m/s

Table 3
Hand speed ANOVA with gender as a between participants variable and button position (UB versus LB) as a within participants variable.

Source	DF	SS	MS	F	p
Gender	1	0.1286	0.1286	0.81	0.3742
Error: Gender * Participant	34	5.3932	0.1586		
Button	1	24.7743	24.7743	405.67	0.0000
Gender * Button	1	0.0116	0.0116	0.1900	0.6646
Error: Gender * Participant * Button	74	4.5192	0.0611		
Total	111				

To further analyze the data, a split plot ANOVA was developed using Statistx 8.0. The ANOVA analyzed the hand speed data with gender as a between participants variable and button position as a within participants variable (Table 3). The ANOVA comparing the means of male and female hand speed from the UB and LB position (H_0 = means are equal) found no significant difference between males and females (failed to reject H_0, at p_{value} = 0.3742). The ANOVA compared the means of hand speed (H_0 = means are equal) between the LB and UB buttons and found a significant difference between LB and UB trials (reject H_0, p_{value}, < 0.0000) for this study.

Evaluating the UB and LB data set using the Anderson-Darling Normality Test (H_0 = data follows a normal distribution) found for the LB distribution p_{value} = 0.2470, and for the UB distribution p_{value} = 0.6333. At these p_{values}, we would not reject H_0 and so the LB and UB hand speed follow a normal distribution. Since both sets of the data are normal, it is possible to construct percentile tables based on the mean and standard deviation of the samples for the population (Table 4).

6. Discussion

The purpose of this study was to measure the hand speed of younger workers (20–30 years of age) and compare it to the OSHA hand speed constant (1.6 m/s). Based on the work of Pizatella and Moll (1987), younger workers should represent the maximum hand speed of the working population. If the hand speed of younger workers is greater than 1.6 m/s, it could mean that OSHA's standard may not be

Table 4
Percentile Values and corresponding after-reach speeds for LB and UB positions (m/s).

Population Percentile	LB Estimated Speed	UB Estimated Speed
10th	1.031	1.684
20th	1.103	1.856
30th	1.155	1.979
40th	1.199	2.085
50th	1.241	2.183
60th	1.282	2.282
70th	1.326	2.388
80th	1.378	2.511
90th	1.450	2.682
95th	**1.510**	**2.825**
100th	1.832	3.594

Table 5
Summary of LB hand speed, various studies.

Study	Estimated hand speed (m/s)	Basis/comment
Present study		
Results Based on All Trials	1.510 m/s	Age 20–30, 95th percentile hand speed based on the average of three trials for the sample, n = 58
Results Based on Max Trials	1.610 m/s	Age 20–30, 95th percentile hand speed for the maximum of three trials, n = 58
Pizatella and Moll (1987)	1.34 m/s	Age 20–60, mean based on fastest of four trials, n = 60
	1.75 m/s	Age 20–30, mean based on fastest of four trials, n = 38
Jensen and Stobbe (2016)	2.24 m/s	Age 20–30, mean based on the fastest of four trials, n = 9
Horton et al. (1986)	1.74 m/s	Not older than 40 years old, mean based on fastest of four trials, n = 10
Jensen (2017)	1.877 m/s	95th percentile based on data generated by Pizatella & Moll, age 20–60, mean based on four trials, n = 120

conservative enough to protect some operators in power press applications. As Jensen noted, standard-setting bodies often consider the "percentage of protected workers" when setting standards. Typically standards are set to protect 95% of the working population as a compromise between "protection and practicality" since the cost of protecting 100% of the population can be very high (Jensen, 2017). For the reach from the lower palm buttons to the target, the 95th percentile hand speed for the population would be 1.510 m/s. Based on the present study the OSHA constant would appear to be protective for over 95% of the population. This value is lower than the estimates of the studies produced by others (Table 5) and represents the differences in the test fixture and the use of the average hand speed as opposed to the maximum hand speed for the calculations. Repeating the calculations using the maximum hand speed of the males and females would give a mean after-reach speed of 1.323 m/s with a standard deviation of 0.175 m/s. With these values, the 95th percentile hand speed would be 1.610 m/s. Under these conditions, the OSHA constant would protect about 94% of the population.

From the Upper Buttons to the target, the 95th percentile hand speed would be 2.825 m/s (Table 6). Based on this experiment the OSHA hand speed constant would protect less than 10% of the population. Repeating the calculations using the maximum hand speed of the males and females would give a mean after-reach speed of 2.340 m/s with a standard deviation of 0.438 m/s. Using these values, the 95th percentile hand speed would be 3.120 m/s and would protect less than 5% of the population. Based on the results of the present experiment, the OSHA hand speed constant is un-protective of press workers 20–30 years old using shoulder height dual palm buttons.

Pizatella and Moll (1987), Jensen (1989), and Horton et al. (1986), all found significant differences in after-reach speed between button positions. An ANOVA of Lower versus Upper Button Hand Speeds using the data from the present study found similar results. The null hypotheses that the UB and LB hand speeds are equal was rejected with a p_{value} of less than 0.0001. The reason for this speed difference is not clear. Pizatella theorized that the difference in hand speed between LB and UB was due to the "change in direction" required to disengage from the lower button. He noted "This change of the direction appears to have a considerable influence on the speed with which the hand can travel in an after-reach situation" (Pizatella and Moll, 1987).

A review of the VICON motion paths adds some credence to this

theory. When the operator presses the lower button he/she is required to assume a supinated wrist position. To disengage from the button, the operator's hand must move backwards and then begin the motion toward the target (Fig. 5). This backward movement can be seen on the VICON track as a "looping" hand movement required for the operator to reach over the bolster to the target. The hand movement from the upper button begins from a pronated wrist position and does not require a backward movement (Fig. 6). It is a more direct and gravity assisted movement.

A ballistic movement (which generates the fastest hand-speed) consists of a rapid hand or foot motion that is "triggered automatically" and "is carried out without any form of feedback monitoring once it is initiated" (Flowers, 1975). A ballistic movement consists of "an initial impulse accelerating the hand/foot toward the target, followed by a decelerating impulse to stop the movement. There is no mid-course correction." (Prasad et al., 2006). A plot of the hand speed data from the UB and LB positions shows the impact of the reorientation on hand speed (Fig. 7). The plot shows that, from the LB position, the hand has a distinct acceleration/deceleration as it moves back from the button, reorients, and then a second acceleration/deceleration movement is seen as it moves toward the target. The movement from the UB position is a typical ballistic movement without a mid-course correction.

The ergonomic hurdle of disengaging from the supinated wrist position may explain part of the speed difference between LB and UB hand speeds. This is an area for future research. The setback distance (or safe distance) for dual palm buttons is a balance between safety (preventing after-reach injury) and machine productivity. Smaller set back distances increase machine productivity by reducing machine loading/unloading time. If engineers better understand the ergonomic hurdle associated with the LB position, it could be applied to other positions to minimize the setback requirement.

Pizatella and Moll found significant differences in mean hand speed between genders (Pizatella and Moll, 1987). Since their work is considered the benchmark for after-reach measurement, it is often stated in the literature that male operators have faster hand speeds than females. In the present study, with participants between 20–30 years old, no significant difference were found between genders for the LB or UB position (failed to reject H_0, at p_{value} = 0.3742). Pizatella's sample of females, 20–30 years old, was a small portion of his study (n = 7 out of 60). Horton (five (5) male participants and five (5) female participants)

Table 6
Summary of UB hand speed, various studies.

| Study	Estimated hand speed (m/s)	Basis/comment
Present study		
Results Based on the Average of All Trials	2.825 m/s	Age 20–30, 95th percentile hand speed based on three trials for the sample, n = 58
Results Based on Max Trials	3.120 m/s	Age 20–30, 95th percentile hand speed for the maximum of three trials, n = 58
Pizatella and Moll (1987)	1.34 m/s	Age 20–60, mean based on fastest of four trials, n = 60
	2.18 m/s	Age 20–30, mean based on fastest of four trials, n = 38
Jensen and Stobbe (2016)	1.59 m/s	Age 20–30, mean based on the fastest of four trials, n = 9
Horton et al. (1986)	2.16 m/s	Not older than 40 years old, mean based on fastest of four trials, n = 10
Jensen (2017)	2.401 m/s	95th percentile based on data generated by Pizatella & Moll, age 20–60, mean based on four trials, n = 120
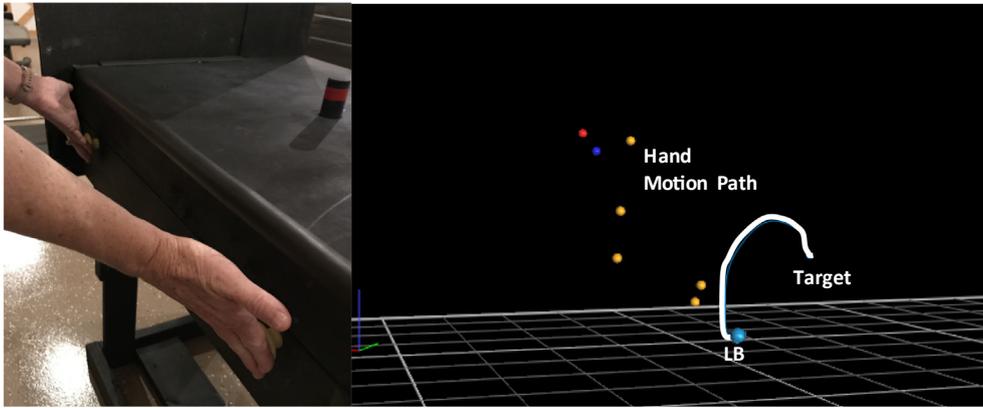
Fig. 5. Hand orientation at LB position and VICON track of LB to target.
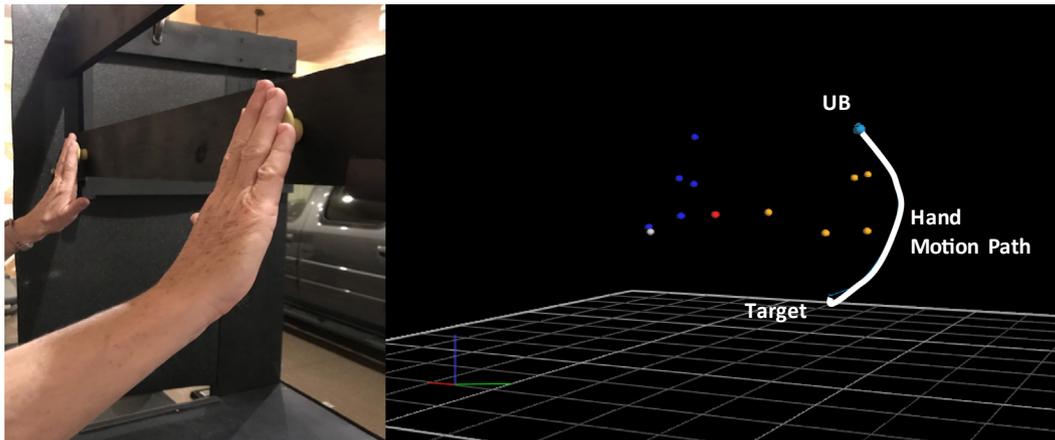

Fig. 6. Hand orientation at UB position and VICON track of UB to target.

did not see a statistically significant difference in gender hand speed. (Horton et al., 1986) Based on Horton's work and the present study, the assumption that females have slower hand speeds than males is suspect and should not be assumed when developing set back distances for participants between 20–30 years old.

7. Limitation of the study

The intent of this study was to provide a detailed analysis of the 95th percentile after-reach speed of a sample of men and women (20–30 years of age). To accomplish this, we applied motion capture technology to measuring hand speed on a simulated press. For this

study, as with any study there were limitations:

(a) The geometry for the simulated press was based on the simulator developed by Pizatella (Pizatella and Moll, 1987; Pizatella et al., 1983). However, the researchers also evaluated the press size of 29 commercial units (in the 30–100-ton range). The commercial press geometry was similar to the Pizatella device and the device we built. We believe the layout of the upper and lower buttons are a reasonable approximation of machine mounted dual palm buttons used in industry. However, the buttons were non-functions and provide little tactile feedback. This may have impacted the hand speed measured in the experiment.
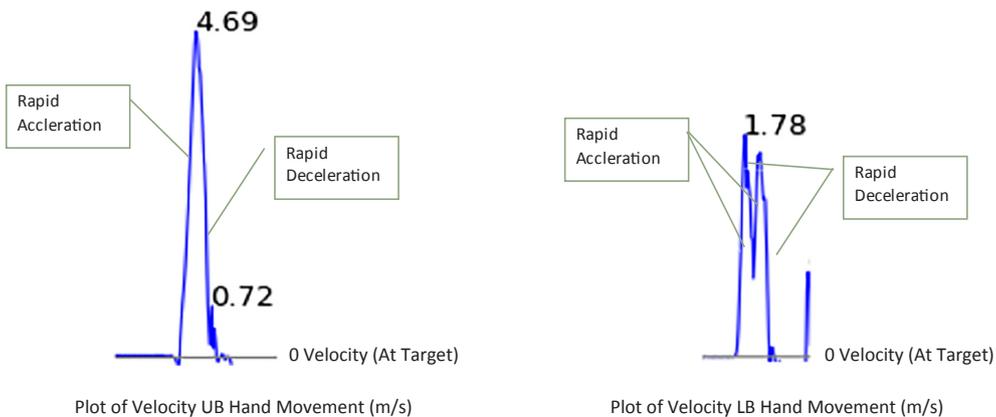

Fig. 7. Velocity of movement from UB and LB position to target.

(b) The simulated press for this experiment was constructed of wood with all sharp edges padded. It contained no moving ram, moving flywheel or active parts, so the subjects were under no jeopardy during the experiment. The lack of danger may have allowed the subjects to move more aggressively than a press operator who faces a true risk of amputation during an after-reach movement.

(c) The subjects in this experiment were college students with no press experience. As noted by Jensen & Stobbe, "Because the subjects in this study were not drawn from a large population of industrial machine operators, applying the findings beyond this study should be done cautiously" (Jensen and Stobbe, 2016).

(d) This paper is focused on the hand speed of the subjects during an after-reach movement. In general, press operators stand at the press (or in some applications sit at the press), so the speed of the hand is driven by the upper back, shoulder and upper arm. There is little lower body movement. The upper body during rapid hand movement is an interesting research topic, however, no attempt was made to quantify this movement for this paper.

8. Conclusions

Operator after-reach speed (and hence palm button set back distance for presses) remains a complex issue. Multiple studies have found differences in after-reach speed from the LB/UB locations. In the present study, the 95th percentile hand speed for the reach from the lower buttons was measured to be 1.510 m/s. The OSHA constant would appear to be protective for over 95% of those tested at the LP position. For the reach from the upper buttons, the 95th percentile hand speed was 2.825 m/s, and the OSHA constant would protect fewer than 10% of those tested. The study found that the hand speed between the UB and LB positions are significantly different, which implies that the use of a single hand speed constant for both locations is inappropriate. Hand speeds were computed using 'typical' button distances from the point-of-operation and average hand speeds, not maximums were computed. Distances greater than or less than the distances tested here could result in significantly different average and maximum hand velocities. The present study casts doubt on the assumption that females have slower hand speeds than males for workers between 20–30 years old. Future work should consider variation of button to point-of-operation distances.

Acknowledgement

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