Journal of Scientific & Industrial Research
Vol. 82, September 2023, pp. 938-946
DOI: 10.56042/jsir.v82i9.4009

Ergonomic Evaluation of Different Working Posture and Handle Designs of Mason Trowel during Wall Plastering Work based on Shoulder and Arm Muscle Activity

R. Naveen Kumar[1], S. Venkatachalam[2], S. Shankar[3]*, R. Nithyaprakash[3], A. J. Elavarasan[2], E. Krishnashankar[2], K. Dharmadurai[2], T V Srinivasan[2], C. Prakash[4]

[1]Department of Mechanical Engineering, [2]Department of Civil Engineering, [3]Department of Mechatronics Engineering, Kongu Engineering College, Erode, Tamil Nadu, India

[4]School of Mechanical Engineering, Lovely Professional University, Phagwara, Punjab, India

Received 01 September 2021; revised 19 June 2023; accepted 26 July 2023

This study aims to identify the impact of the three ergonomically designed mason trowel handles at two working postures on the arm and shoulder muscles activation through experimental and subjective analysis. Prolonged usage, poor ergonomic design of trowels, and working at awkward postures results in Work-related Musculoskeletal Disorders (WMSD) among workers performing wall plastering task. Three mason trowels with different handle shapes were designed by modifying existing mason trowels and developed with 3D printing technology. Twelve student volunteers took part in this experimental study and simulated the wall plastering work at two commonly adopted working postures. Muscle activation and fatigue characteristics of five muscles on the arms and shoulder region were studied using Electromyography sensor (sEMG) sensors. Borg's CR-10 scale was employed to carry out the subjective analysis to find mean discomfort among the models. The results revealed that handle shape and working position have an influence on the shoulder muscle engagement and less effect on the arm muscles. Subjective analysis results revealed that Model B and Model C were rated with higher preference by the participants. Results have revealed that shoulder muscle is activated more and subjected high muscle fatigue while performing wall plastering tasks. Also, circular-shaped handles with varying cross sections and curved shape handles were rated as highly compared to wall plastering work. Findings from this study can be used for studying the relationship between mason trowel designs and working posture with muscle activation.

Keywords: Construction workers, Muscle activity, Plastering work, Surface electromyography, WMSD

Introduction

Construction workers are at a very high risk of getting affected with job related injuries due to various factors like poor working environment, repetitive movement, forceful extraction, awkward postures while performing different tasks.[1–5] Workers of construction industries were exposed to high level of occupational risks resulting in getting affected with work WMSDs on nerves, tendons and muscles etc.,[6–8] Among various workers in the sections of construction industry, mason were exposed to high level of WMSD, especially in their lower back region and shoulders because of their nature of work that involves repetitive arm movements, poor hand tool design, handling heavy loads etc.[9–11] Wall plastering is one of the toughest task performed by masonry workers using trowels for fine finishing of walls, floor at awkward posture resulting in serious chronic injuries in upper body extremities.[12] Various job related risk factors associated with plastering task has affects the productivity and job tenure of mason due to reduced joint movement range and ability to produce high force.[13]

Hand tools used in plastering task also associated with the occurrence of WMSD on the upper body extremity, nearly 24% of hand injuries in different occupations are related with the usage of hand tools and its poor ergonomic designs.[14,15] Occurrence of WMSD on the hands and shoulder region can be minimized by ergonomically redesigning the hand tool by modifying its griping area, shapes, materials, textures.[16,17] An cross sectional study[18] was conducted by modifying the handle shapes of trowel on hand muscle activity. It is found that handle with varying diameter and providing curve on trowel has impact on muscle engagement. Similar study[19] conducted with different cross sectional design of trowels found that,

*Author for Correspondence
E-mail: shankariitm@gmail.com

circular handle with varying cross section of trowel improves the usability and performance during plastering tasks. Another study[20] conducted reveals that the shape of the mason trowel influences the hand grip forces and usability by simulating the plastering work in laboratory condition.

From literature survey it is found that few experimental studies are attempted to evaluate the impact of trowel shape on arm muscle engagement, practicability and discomfort rating by simulating the plastering work at laboratory conditions. Limitation of the existing studies is that they didn't study the muscle engagement at different work posture and the influence of handle shape on shoulder muscle activation is not addressed so far. The present study aims in overcoming the above stated limitation by analysing the influence of handle shapes on hand and shoulder muscle at two different working posture. For this purpose, three handle shapes with varying cross section for mason trowel is modelled and developed using 3D printing technology as shown in Fig. 1 (a-d) and its impact on muscle engagement is studied by comparing it with the traditional trowel. Additionally Borg CR-10 scale is used to perform subjective analysis to obtain the preference on usability and mean discomfort rating to support the findings from sEMG analysis.

Methodology

Study Participants

Twelve civil engineering student studying in the Kongu Engineering College, Erode, Tamil Nadu, India had voluntarily participated in this study trail. All the volunteers are right handed, and those free from any musculoskeletal related injuries are alone allowed to participate in the study. Details about the musculoskeletal injuries are obtained from participants through oral consent before the experimental trail. Study population selection and procedure was carried out in line with previous works.[18,21] Demographic and anthropometric data collected from the participants are given in Table 1. Before the experiment got started, the scope and protocol of the experimental trail were thoroughly explained to each participant. Guidelines of ethic committee of Kongu Institutions (KEC/R&D/EC/2020-21/001) was followed during this experimental trail.

Table 1 — Anthropometric data of participants (n=12)

Parameters	Mean (SD)	Range
Age (years)	21.13(0.64)	20–22
Height (cm)	174(8.85)	159–185
Weight (kg)	74.13(10.52)	55–90
Palm length (mm)	103.5(4.41)	98 –110
Palm width (mm)	85.63(3.96)	80–93
Hand thickness (mm)	24.13(4.7)	18–30

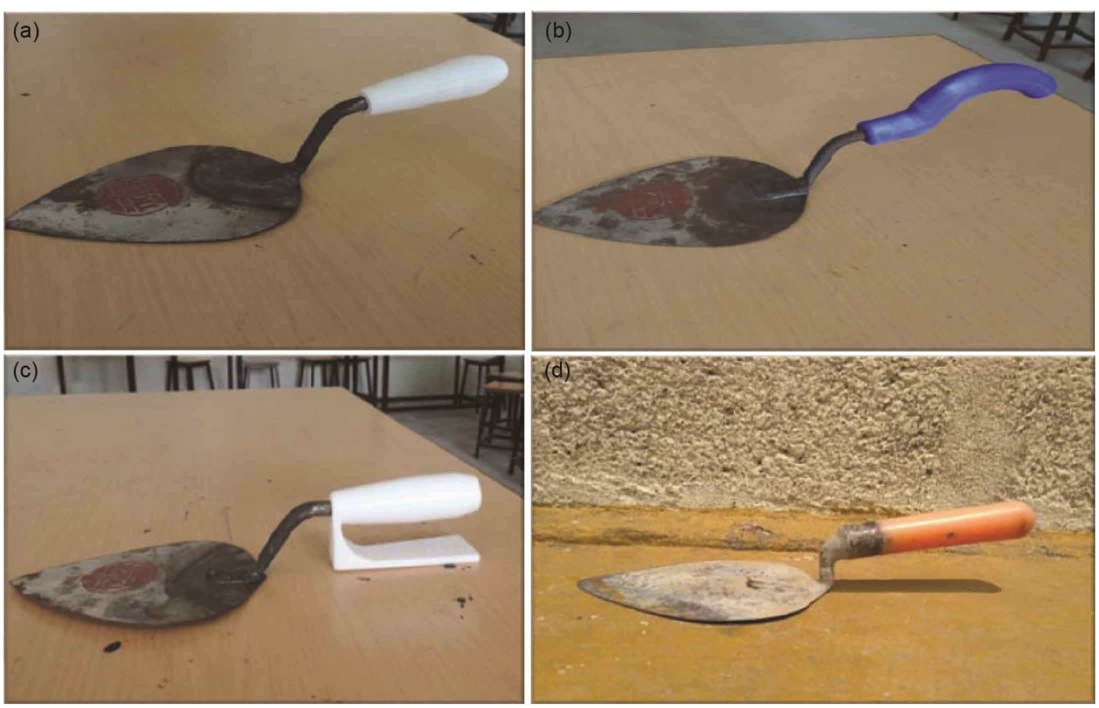

Fig. 1 (a-d) — Various types of Trowel employed in this experimental study

Trowel Prototypes

Three prototype of trowel used in this experimental study was designed by modifying the cross sectional shape of the commercially available trowel handle by providing slip gauge and varying handle cross sections. The anatomy and anthropometric details of the hand is used while designing the trowel to improve the usability and reduce muscle engagement, for this purpose the 3D modelling software SolidWorks 2016 was used. The prototype handle were manufactured using 3D printer (Ultimaker, S5). Polylactic Acid (PLA) material was employed to fabricate the prototype as it close to the properties of polymers used in conventional trowel. The dimension details of the proposed trowel prototypes are shown in Table 2.

Model A and C were designed with circular shape with variable diameters to improve the usability and gripping strength (Fig. 1). The diameter of Model A is larger than the traditional design to improve the contact area, as mentioned in the previous study that circular cross section with variable diameter has impact on the usability and comfort.[22]

Model B was provided with curved handle with a concave and convex surface for providing good gripping to both fingers and palm during plastering work. In this model and extra provision for placing the thumb was provided on the one end.[19]

Model C was designed with base plate which will act as a slip guard with circular cross sectional variable diameter handle. Slip guard prevents the injury to fingers and circular cross section improves the gripping force.[20]

Table 2 — Physical characteristics of the Prototype handles

Trowel Type	Handle length (mm)	Handle diameter (mm) range	Weight (g)
Model A	140	25-40	125
Model B	170	30	98
Model C	130	25-30 Base plate – 6 mm thickness	90
Traditional	120	20–25	80

Task and Protocol

The participants were asked to simulate the plastering procedure with traditional trowel and three newly designed trowels in a two working position namely normal position (arm below hip level) and overhead position (arms above shoulder level) as shown in Fig. 2. A wall surface with a dimension 1.76 × 1.26 m is used for simulation of the plastering task with zero loading at overhead position. Table with 2.70 × 1.10 m (0.89 m from ground level) area is used for the simulation of the plastering task using all four trowel with zero loading at normal position. Guiding stickers are provided with different marks in the wall and horizontal surface to guide the participants to simulate the plastering task at two positions as shown in Fig. 2.

During the experimental study, participants are instructed to simulate the plastering task using the three modified trowels and traditional one at both overhead position and normal position for the period of two minutes with 10 min break between the trails.[23] During the plastering task at both overhead and normal position, participants were asked to move the trowel along the guiding sticker path to simulate the

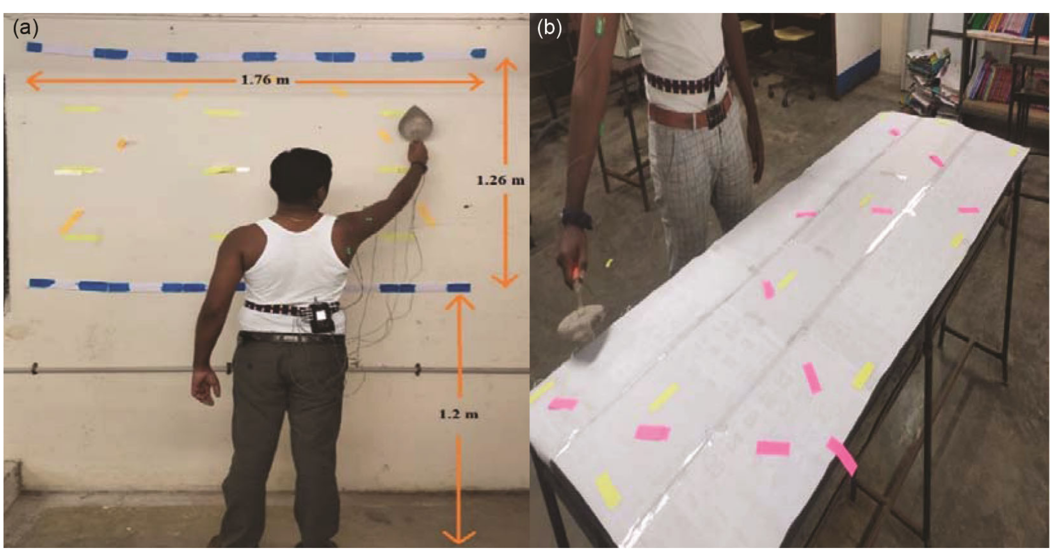

Fig. 2— Simulation of wall plastering task at different arm posture

task with three hand action namely horizontal, circular and vertical movement in a random order. During the entire duration of this study, the study population were instructed to hold the handle of trowels firmly and participants were trained to use all four trowels utilized in the study to eliminate the errors. Participants were asked to maintain uniform pace during the experimental study to maintain uniformity.

Instruments

Muscle engagement during the experimental trial was recorded using Data LOG sEMG system (Biometrics, UK). The continuous muscle activity was recorded by employing five surface electromyography (sEMG) sensors. The laptop and Data LOG were connected, and the laptop was used to store the raw data from the sEMG sensors. The raw sEMG signals were recorded with sampling rate of 60000 samples per minute and has an input impedance of >100 MΩ.

Selection of Muscles

The muscles that have been associated with plastering process were studied through literature survey and pilot study by simulating the plastering action prior to the experimental study. Infraspinatus, Trapezius, Deltoid, Biceps Brachii and Flexor Carpi Radialis muscles were chosen for the study. The maximum isometric voluntary contractions (MVIC) of the selected muscle were determined by simulating the task as shown in Table 3.[(24–27)] Each participant was asked to do three repetition and rest of 10 min between the repetitions. The participants applied a maximum amount of force and resistance for all muscles to have high sEMG activity. The participants were monitored continuously and were asked to repeat again if any error occurs during the execution of test. MVIC was used for compute the normalized root mean square value of EMG signal to the investigation and analysis of muscle contractions.[28]

Table 3 — Postures for Identifying MVIC

Muscles	MVIC postures
Deltoid	Arm abduction at 90º
Infraspinatus	Upper arm abduction at 0º and bending of elbow at 90º followed by external rotation of hand.
Flexor carpi radialis	Wrist flexion with forearm supination and then a table-based slouch.
Biceps brachii	Performing Bicep curl exercise by lifting forearm 90º
Trapezius	Shoulder abduction at 90º

Electrode Placement

Surface electromyography (sEMG) sensors are fixed on the surface of five muscles namely trapezius, deltoid, flexor carpi radialis, biceps brachii, and infraspinatus as shown in Fig. 3 using double sided stickers. The electrode placements based on the similar studies as presented in Table 4.[(29–31)] Before the placement of electrode, skins on the muscle surface were cleaned to prevent peeling of stickers because of sweating during experimental trials. The participants were then asked to maintain a calm posture without activating any of the selected muscle groups and the sEMG sensors were calibrated to zero.

Data Analysis

The sEMG data collected during the experimental trail was analyzed using MATLAB R2017b. Second order Butterworth band pass filter of range 20–400 Hz was employed to filter the raw sEMG signal. The filtered signal data was separated into four equal halves with each half consists of 30 sec which is used to identify the muscle engagement during the task.

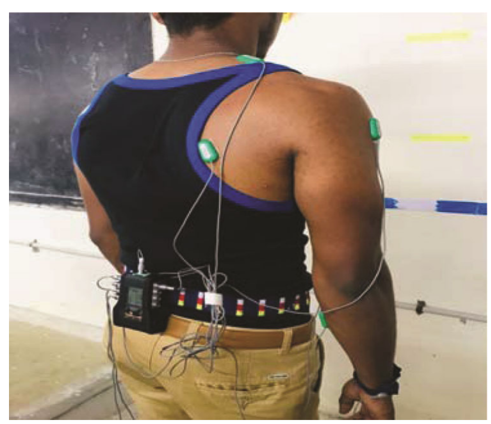

Fig. 3— Placement of Electrodes

Table 4 — Position of EMG electrode placement

S.NO	Muscles	Electrode placement
1	Deltoid	On the lateral side of the arm, around 3 cm under the acromion.
2	Infraspinatus	About 4 cm under the scapular spine and over the infrascapular fossa
3	Trapezius	Halfway in-between the seventh cervical vertebra and the acromion.
4	Biceps Brachii	Middle if the muscle belly
5	Flexor Carpi Radialis	About 5-7 cm from the distal end of the bicep tendon to the medial epicondyle

Mean power frequency has a linear relationship with muscle fibre velocity and reducing MPF value indicates the occurrence of muscle fatigue.[32]

The root mean square (RMS) values of the sEMG data (millivolts) was normalized using MVIC value to infer the muscle engagement. One way ANOVA test along with post hoc test with turkey adjustment was performed to find the effect of different design trowels on muscle.[33]

Subjective Analysis

Borg's CR-10 scale rating was employed to determine the usability and discomfort level of participants while working with trowels during tasks[34]. The scale ranges from 0 to 10 in an increasing order. The participants were told to rate the discomfort they were with particular muscle parts after completing each job and to rate the usefulness of different trowel prototypes. Score 0 relates to no effort, no discomfort or less usability, whereas score 10 represents maximum discomfort, maximum usability or maximum effort and these average scores were then tabulated.

Results

The major findings of this study were given in Figs. 4–6, which includes the MPF values and % of MVIC value of acquired sEMG data. MPF value plot of muscles engaged during the plastering process in both normal and overhead positions is shown in Fig. 4. Average MPF value plotted against time during the plastering task with different trowels in normal position and overhead position respectively is shown in Fig. 4(a-e) and Fig. 5 (a-e). The MPF (Hz) average for the muscles trapezius right, deltoid right, biceps brachii right, flexor carpi radialis right and infraspinatus right started at peak values and decreases gradually till the end of plastering process in both the position indicating the presence of muscle fatigue. Previous research has shown that decreasing trend of MPF value was indicators of muscle fatigue.[35]

Muscle engagement during the wall plastering task at two different hand positions is shown in Fig. 6. It was inferred from Fig. 6 that muscle engagement was very high at overhead position compared to normal position. Trapezius muscle was activated more in the overhead position except for Model B. There was not much deviation in activation of infraspinatus during the wall plastering task at both positions because of trowel design. Deltoid muscle was activated more while performing the task in the normal position. Biceps brachii and flexor carpi radialis were less active during the plastering work among the selected

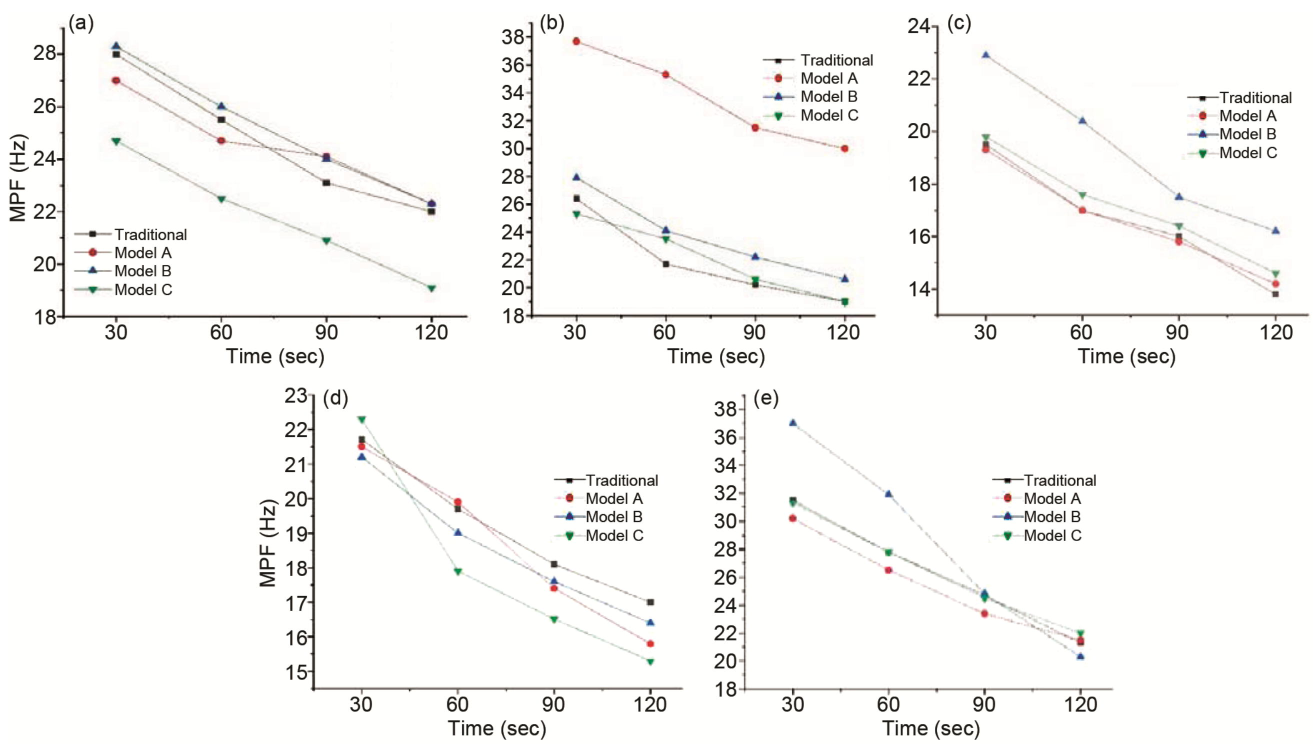

Fig. 4 (a-e) — MPF average (Hz) for the muscles during the plastering process in normal position

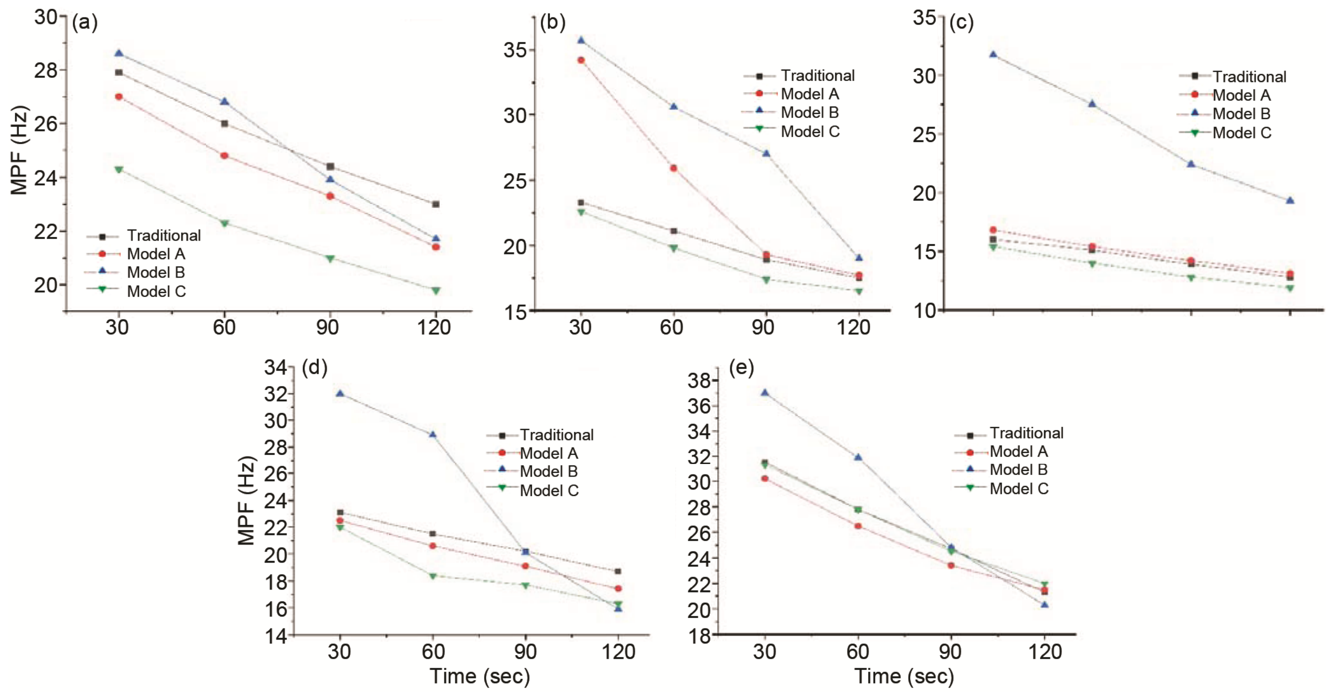

Fig 5 (a-e) — MPF average (Hz) for the muscles during the plastering process in overhead position

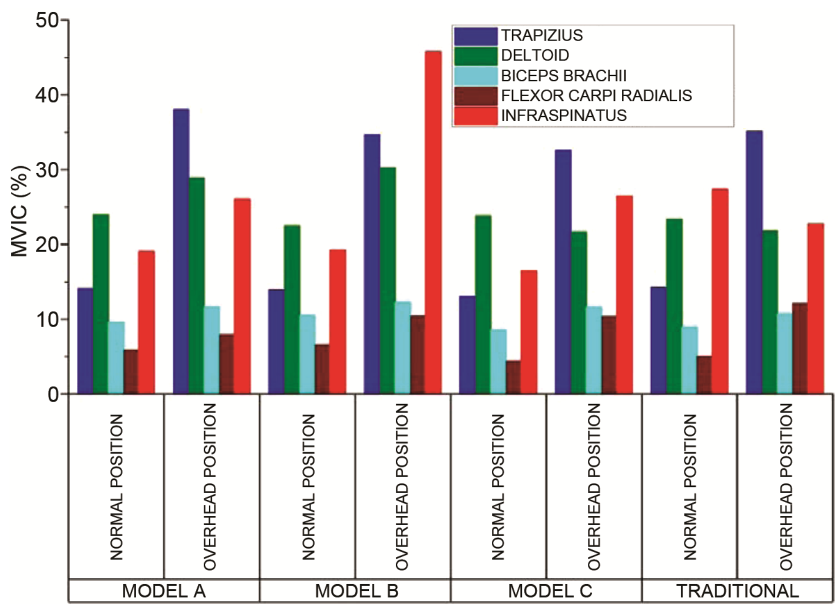

Fig. 6 — Normalized sEMG at two different working postures

muscle group. Muscle activation was high while using Model B trowel in overhead posture and Traditional trowel exhibits higher muscle activation in normal working posture.The tests of the one-way ANOVA search were performed using SPSS 21.0 with a post hoc analysis to verify the relevant observations. There were no statistical significance among the five muscle groups (p >0.05).

Results of the Borg's CR-10 scale reference rating is shown in Table 5, it infers from the subjective analysis that Model B and Model C were chosen as their comfortable models. Even though Model B has been reported for higher muscle activity of infraspinatus, the participants found it as easy for plastering in both positions. The participants reported that more discomfort in muscle on shoulder muscle

Table 5 — Mean Discomfort level at various muscle region using Borg's CR-10

Muscles	Traditional		Model A		Model B		Model C	
	Normal Position	Overhead Position	Normal Position	Overhead Position	Normal Position	Overhead Position	Normal Position	Overhead Position
Trapezius	6	5	5.2	6	4.3	4.2	4.1	4.9
Deltoid	5	4.8	5.6	5.6	3.8	5.8	5.4	4.5
Biceps Brachii	4	4.9	4.8	5.1	5	4.4	3.8	5.1
Flexor Carpi Radialis	4.8	5.5	5	4.6	4.7	4.9	4.4	4.6
Infraspinatus	6	5	4.6	5.5	4.8	5.8	4.2	5.5
Discomfort Rating	5.16	5.04	5.04	5.36	4.52	5.02	4.38	4.92

during overhead simulation task. The participants reported that Model A was less convenient for working due to its increased diameter. Based on Borg's CR-10 scale rating both traditional and Model A holds last place in preference and comfort rating.

Discussion

In this experiment study, the effect of three different handle shapes of trowel at two working posture during the simulated wall plastering task on the muscle engagement was studied by comparing it with the traditional trowel. It was found from the study that working posture and ergonomic design of trowel has impact on the muscle activation on selected shoulder muscles namely Trapezius, Deltoid and Infraspinatus. The hand muscle chosen for the study was not influenced by the shape of the handle and working postures. For this purpose, sEMG sensors were employed to acquire the electrical signals from the muscles to evaluate the its activation pattern and fatigue characteristics.[36]

The muscle engagement of the selected muscles namely deltoid, trapezius and infraspinatus were higher compared to other muscles in both normal and overhead positions. This was due to the repetitive motion of the hand during simulation of the plastering works. This repetitive motion and forceful exertion to increase the arm reach position has minimized the shoulder stability and resulting in elevated muscle activation and fatigue in rotator cuff muscles.[37] Also in overhead position, Traditional and Model A trowel reported the higher activity in trapezius muscles followed by deltoid and infraspinatus. This may be due to the variation in the hand gripping regions and the forced extension of arm reach distance to complete the plastering task.[38] Biceps brachii and flexor carpi radialis muscles were engaged low compared to other muscle activities, may be due to the zero loading condition adopted during the simulation of wall plastering work which has transferred the muscle loading from hand to shoulder muscles.[39]

The MPF plot of all five muscles were recorded for a period of 2 min during the simulation of wall plastering task at normal and overhead position, was shown in Fig. 4 and Fig. 5 respectively. All the muscle exhibits decreasing trend in MPF value with respect to time in both working position representing the occurrence of muscle fatigue. Among the selected muscle group, the trapezius, infraspinatus and deltoid exhibit high degree of linearity indicated the higher muscle fatigue compare to hand muscles. During the simulation task, participants have to extend their arm to maximum reach and come to normal position within the short duration repetitively for completing the simulation task, which causes increased scapulothoracic motion resulting in the direct fatigue of shoulder muscles.[40,41] Model B and Model C has more linear MPF trend line compared to other models and in overhead position Model B shows significant decline MPF value which indicates an higher rate of muscles fatigue.[42]

The subjective evaluation results obtained using Borg's CR-10 Scale were similar to experimental results and the participants reported discomfort in trapezius, deltoid and infraspinatus muscles. The main reason was the forceful extension of the arm during the simulation of the plastering tasks. The study participants selected Model B and Model C as their favourite models. Even though Model B has been reported for higher muscle activity of infraspinatus, the participants found it easy for plastering in both positions. The curved shape with provision for placing the thumb may be the reason for this. The participants reported that Model A was less convenient for working due to its larger varying diameter. Based on subjective evaluation using Borg's CR-10 scale rating both traditional and Model A holds last place in preference and comfort rating. In this study, the body mass index was not taken into considerations.

Conclusions

Three models (Model A, Model B, Model C) were fabricated using 3D printing technique and wall plastering task was simulated in zero loading condition at two commonly adopted working postures to study the muscle characteristics and subjective preference by comparing it with traditional mason trowel. The results revealed that handle shape and work posture has impact on muscle characteristics and subjective preference. Shoulder muscles were activated more during the wall plastering task compared to arm muscles, also working in overhead posture demands more muscle activation irrespective of handle design. The subjective preference analysis results also suggested that the round shape with variable diameter handle model and curved handle (Model C) was preferred compared to traditional mason trowel. These experimental works gave an insight into the application of mason trowels in workplace to reduce the work related musculoskeletal disorders in future. The limitation of the present study is that simulation of wall plastering task was carried out at zero loading condition, in future with load on trowel may be considered. Weight of the new trowels are slightly heavier than conventional, it may be eliminated in our future study. Also muscle engagement on dominant shoulder alone was studied due to practical limitations, in future bilateral analysis may be done to get a clear insight of shoulder muscle behaviour in different working postures.

Conflict of Interest

Authors declare no conflict of interest in this work

Reference

1 Goldsheyder D, Weiner S S, Nordin M & Hiebert R, Musculoskeletal symptom survey among cement and concrete workers, *Work*, **23**(**2**) (2004) 111–121.

2 Zhou Z, Goh Y M & Li Q, Overview and analysis of safety management studies in the construction industry, *Saf Sci*, **72** (2015) 337–350.

3 Chakraborty T, Das S K, Pathak V & Mukhopadhyay S, Occupational stress, musculoskeletal disorders and other factors affecting the quality of life in Indian construction workers, *Int J Constr Manag*, **18**(**2**) (2018) 144–150.

4 Yang K, Ahn C R & Kim H, Deep learning-based classification of work-related physical load levels in construction, *Adv Eng Informatics*, **45** (2020) 101104.

5 Basahel A M, From the prospective of ergonomics: Estimating overall stressors and task demands in the construction sites in Saudi Arabia Using an Analytical Hierarchy Process (AHP), *J Sci Ind Res (India)*, **78**(**10**) (2019) 651–658.

6 Ekpenyong C E & Inyang U C, Associations between worker characteristics, workplace factors, and work-related musculoskeletal disorders: A cross-sectional study of male construction workers in Nigeria, *Int J Occup Saf Ergon*, **20**(**3**) (2014) 447–462.

7 Antwi-afari M F, Li H, Edwards D J, Pärn E A, Seo J & Wong A Y L, Automation in construction biomechanical analysis of risk factors for work-related musculoskeletal disorders during repetitive lifting task in construction workers, *Autom Constr*, **83** (2017) 41–47.

8 Zubar H A & Alamoudi R, Analysis of body postures of employees in manufacturing industry by using ergonomic tools, *J Sci Ind Res (India)*, **78**(**3**) (2019) 144–147.

9 Anton D, Rosecrance J C, Gerr F, Merlino L A & Cook T M, Effect of concrete block weight and wall height on electromyographic activity and heart rate of masons, *Ergonomics*, **48**(**10**) (2005) 1314–1330.

10 Hess J A, Kincl L, Amasay T & Wolfe P, Ergonomic evaluation of masons laying concrete masonry units and autoclaved aerated concrete, *Appl Ergon*, **41**(**3**) (2010) 477–483.

11 Karmegam K, Ismail M Y, Sapuan S M & Ismail N, Conceptual design and prototype of an ergonomic back-leaning posture support for motorbike riders, *J Sci Ind Res (India)*, **67**(**8**) (2008) 599–604.

12 Rahman M N A, Rani M R A & Rohani J M, Investigation of work-related musculoskeletal disorders in wall plastering jobs within the construction industry, *Work*, **43**(**4**) (2012) 507–514.

13 Nugent R & Fallon E, Temporal patterns of discomfort reported by plasterers over a five-day workweek, *Work*, **51**(**4**) (2015) 683–701.

14 Mital A & Kilbom A, Design, selection and use of hand tools to alleviate trauma of the upper extremities: Part II - The scientific basis (knowledge base) for the guide, *Int J Ind Ergon*, **10**(**1**-**2**) (1992) 7–21.

15 Veisi H, Choobineh A, Ghaem H & Shafiee Z, The effect of hand tools' handle shape on upper extremity comfort and postural discomfort among hand-woven shoemaking workers, *Int J Ind Ergon*, **74** (2019) 102833.

16 Jain R, Sain M K, Meena M L, Dangayach G S & Bhardwaj A K, Non-powered hand tool improvement research for prevention of work-related problems: A review, *Int J Occup Saf Ergon*, **24**(**3**) (2018) 347–357.

17 Lohasiriwat H & Chaiwong W, Ergonomic Design for Sausage Packing Hand Tool. In: *Procedia CIRP*. Vol 91, 2020 789–795.

18 Bakhtiari N, Dianat I & Nedaei M, Electromyographic evaluation of different handle shapes of masons' trowels, *Int J Occup Saf Ergon*, **27**(**1**) (2021) 106–111.

19 Dianat I, Bakhtiari N, Nedaei M & Afshari D, Ergonomic design and evaluation of masons' trowels for construction work, *Int J Hum Factors Ergon*, **6**(**1**) (2019) 18–34.

20 Dianat I, Nedaei M & Mostashar N M A, The effects of tool handle shape on hand performance, usability and discomfort using masons' trowels, *Int J Ind Ergon*, **45** (2015) 13–20.

21 Shankar S, Kumar N, Raman S J, Hariharan C P S & Raja S K, Ergonomic evaluation of ergonomically designed chalkboard erasers on shoulder and hand-arm muscle activity among college professors. *Int J Ind Ergon*, **84** (2021) 103170.

22 Kong Y K & Lowe B D, Optimal cylindrical handle diameter for grip force tasks, *Int J Ind Ergon*, **35**(**6**) (2005) 495–507.

23 Subramanian S, Raju N, Srinivasan P, Jeganathan K & Jayaraman S, Low back pain assessment using surface electromyography among industry workers during the

repetitive bending tasks, *Int J Hum Factors Ergon*, **5**(**4**) (2018) 277–292.
24 Ekstrom R A, Soderberg G L & Donatelli R A, Normalization procedures using maximum voluntary isometric contractions for the serratus anterior and trapezius muscles during surface EMG analysis, *J Electromyogr Kinesiol*, **15**(**4**) (2005) 418–428.
25 Boettcher C E, Ginn K A & Cathers I, Standard maximum isometric voluntary contraction tests for normalizing shoulder muscle EMG, *J Orthop Res*, **26**(**12**) (2008) 1591–1597.
26 Fischer S L, Belbeck A L & Dickerson C R, The influence of providing feedback on force production and within-participant reproducibility during maximal voluntary exertions for the anterior deltoid, middle deltoid, and infraspinatus, *J Electromyogr Kinesiol*, **20**(**1**) (2010) 68–75.
27 Rota S, Rogowski I, Champely S & Hautier C, Reliability of EMG normalisation methods for upper-limb muscles, *J Sports Sci*, **31**(**15**) (2013) 1696–1704.
28 Meldrum D, Cahalane E, Conroy R, Fitzgerald D & Hardiman O, Maximum voluntary isometric contraction: Reference values and clinical application, *Amyotroph Lateral Scler*, **8**(**1**) (2007) 47–55 .
29 Jensen C, Vasseljen O & Westgaard R H, The influence of electrode position on bipolar surface electromyogram recordings of the upper trapezius muscle, *Eur J Appl Physiol Occup Physiol*, **67**(**3**) (1993) 266–273.
30 Ahamed N U, Sundaraj K, Badlisha A R, Rahman M, Islam A & Ali A, Analysis of the effect on electrode placement on an adolescent's biceps brachii during muscle contractions using a wireless EMG sensor, *J Phys Ther Sci*, **24**(**7**) (2012) 609–611.
31 Dickerson C R, Meszaros K A, Cudlip A C, Chopp-Hurley J N & Langenderfer J E, The influence of cycle time on shoulder fatigue responses for a fixed total overhead workload, *J Biomech*, **48**(**11**) (2015) 2911–2918.
32 Arendt-Nielsen L & Mills K R, The relationship between mean power frequency of the EMG spectrum and muscle fibre conduction velocity, *Electroencephalogr Clin Neurophysiol*, **60**(**2**) (1985) 130–134.
33 Balasubramanian V & Jayaraman S, Surface EMG based muscle activity analysis for aerobic cyclist, *J Bodyw Mov Ther*, **13**(**1**) (2009) 34–42.
34 McGorry R W, Lin J H, Dempsey P G & Casey J S, Accuracy of the Borg CR10 scale for estimating grip forces associated with hand tool tasks, *J Occup Environ Hyg*, **7**(**5**) (2010) 298–306.
35 Halim I, Omar A R, Saman A M & Othman I, Assessment of muscle fatigue associated with prolonged standing in the workplace, *Saf Health Work*, **3**(**1**) (2012) 31–42.
36 Lee K S & Jung M C, Ergonomic evaluation of biomechanical hand function, *Saf Health Work*, **6**(**1**) (2015) 9–17.
37 Gaudet S, Tremblay J & Dal Maso F, Evolution of muscular fatigue in periscapular and rotator cuff muscles during isokinetic shoulder rotations, *J Sports Sci*, **36**(**18**) (2018) 2121–2128.
38 Amar M R, Cochran D & Woldstad J, The effect of single-handed lifting tasks on the activation of the neck-shoulder shared musculature, *Int Biomech*, **4**(**1**) (2017) 1–8.
39 Antony N T & Keir P J, Effects of posture, movement and hand load on shoulder muscle activity, *J Electromyogr Kinesiol*, **20**(**2**) (2010) 191–198.
40 Voight M L, Allen Hardin J, Blackburn T A, Tippett S & Canner G C, The effects of muscle fatigue on and the relationship of arm dominance to shoulder proprioception, *J Orthop Sports Phys Ther*, **23**(**6**) (1996) 348–352.
41 Ebaugh D D, McClure P W & Karduna A R, Effects of shoulder muscle fatigue caused by repetitive overhead activities on scapulothoracic and glenohumeral kinematics, *J Electromyogr Kinesiol*, **16**(**3**) (2006) 224–235.
42 Yumeng L, Surface EMG analysis of biceps brachii fatigue during isometric contraction: A preliminary study, *J Bone Muscles Study*, (2017) Published online 2017 41–44.