Ergonomic Design of Trowel Handle

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Abstract -*Plastering is an occupation requiring the use of hand and wrist movements. A variety of trowels has been developed and used for plastering and pointing work. Trowels differ from region to region which may or may not be manufactured on the basis of hand anthropometry. However, some masons experience discomfort or injury when plastering and using trowel. So in order to improve the quality of the trowels, it is necessary to rationalize its dimensions that should be used in its manufacture. A standard-design trowel was considered as reference to find out the optimal diameter of the trowel handle. Hand Anthropometric data of 40 participants, right hand dominant, was collected. The comfort ratings of all these participants were collected. This comfort rating was related to the Normalized Handle Size (NHS). The regression equation was found out using Minitab® 17.1.0.Software. The resulting regression equation was used to find out the dimensions of the optimal handle of the trowel. Optimal diameter handles were fabricated for a subset of the participants. Contact area on the trowel handle was evaluated for both standard-design trowel and ergonomically designed trowel.. EMG (Electromyography) activity of muscles used in grasping both the handles was also assessed for muscle fatigue.*

Key Words: NHS, MSD, Subjective Comfort Rating, Anthropometry, Muscle fatigue

1. INTRODUCTION

Construction is a high risk trade for musculoskeletal disorders. Trowels have been playing a critical role in plastering occupation. The uses of 'trowels' vary from non-professional use at domestic level to professional use at industrial level. The Masonry trowels had been used in brickwork or stonework for levelling, spreading and shaping mortar or concrete. They come in different shapes and sizes depending on the task.Most of the tasks carried out within construction trades involve the use of hand tools; require the use of several body regions, continuous movement in awkward positions.There are various methods of gripping the hand tools, but the most common type of grip is the 'Power Grip'.

Using ergonomic standards to enhance mason's comfort will improve productivity and make the job more appealing to young inhabitants choosing a career. Most manufacturers claim that they have always given emphasis to "user comfort" in their tool designs, but the minorities actually advertise ergonomic advantages in their manufactured goods literature. Some users say the handle should also minimize sweating, which can cause masons to grasp their trowels using more force. Tools with handles that extend beyond the base of the palm should be selected. Short or undersized tools press into the palm and squeeze nerves in the hand. Avoid tools with slim handles, which needs a tighter grip. A habitual matter was the commercial strains on workers which force them to work as rapidly as possible and therefore they risk compromising wellbeing or safety.

Use "ergonomically" designed hand tools, which maintain the wrist in the "neutral" pose. Hand tool ergonomics is an interdisciplinary technical discipline which concerns with understanding interactions among individuals and other elements of a system. In this context, the user has a vital role in product development process. Product ergonomics applies principles,theory, data and methods to optimize human well-being and overall system performance. Ergonomics is described as fitting the work or task to the worker in order to minimize the menace of musculoskeletal disorders (MSDs). These injuries extend slowly over time and arise in the soft tissues of user's body like the tendons, muscles, nerves, ligaments, and joints. Examples of musculoskeletal disorders are carpal tunnel syndrome, low back strain and tendonitis. The unnecessary twisting of the wrist, elbow, arm and shoulder is prevented by the use of ergonomic tools. Therefore, excessive force is needed to grip the trowel in between the fingers which results in hand muscle fatigue. Kong and Lowe proposed that the finger's maximal voluntary contraction (MVC) force is dependent upon diameter of the handle. So, the variability in sizes of the handle should be in accordance with finger and hand sizes [1].

The authors also explained that while gripping, the ring finger's contribution, for smaller handles, is higher than that of the index finger whereas for the larger handles, the order of contributions is overturned. There is increase in the role of the middle finger when the diameter of the handle is increased up to diameter of 40mm. Some examiners also used electromyography and force sensors, considering muscle activity and finger forces to identify the optimal diameters of cylindrical handle [2].

In some cases, where the trowels are not designed ergonomically, it may lead to various Musculoskeletal disorders (MSD). Ergonomically designed handle of trowel ensures a relaxed grip with the reduction of point pressures on palm's muscle enhancing grip of the trowel.

In real world, it is very difficult to examine the grasping of any object and depends on the user's comfort ratings[3]. The author has examined a strong correlation between user performance and perceived subjective comfort and suggested to incorporate this aspect during the design phase [4]. GregorHarih and BojanDolšak proposed that development of the digital human hand model using Magnetic Resonance Imaging (MRI) and following 3D printing of optimal diameter tool handle considering the anthropometric data will provide an anatomical profile to the tool handle [5]. This would enhance the perceived level of comfort.

The focus of the present work is to work out the optimal handle dimensions of the trowel handle that would outcome in increased contact area, increased user comfort rating and reduced muscle fatigue. The objective is to build up an approach that would, in conclusion, give optimal size for a range of various hand sizes based on the design for human variability. The paper is arranged along the following lines: Section 2 describes the processes used in present investigation; Results and discussion are specified in section 3 whereas conclusions are given in section 4.

2. METHODOLOGY

A. Subjects

Hand Anthropometric data of forty participants, right hand dominant, was collected. There was no grievance of hand muscle fatigue in their entire life. Consent to take part in the study was taken from the participants prior to the research. The averages of their ring finger length (from hand crease) and hand width were 171.5±20.5mm, 1780±42.0mm and 81.5±13.5mm respectively.

B. Equipment

Vernier caliper. Vernier caliper (least count of 1/20 mm = 0.05mm) was utilized to measure the hand anthropometric data of all the participants for the design purpose. Hand length was measured from the hand crease to the finger tip considered in design.

Electromyographic measuring system. The electromyographic activity was acquired, for the Extensor Digitorum (ED) muscle, at a sampling frequency of 1000 HZ. EMG is utilized in the experimentation to identify the muscle fatigue while grasping the trowel. Surface electrodes, used to detect the EMG activity of muscle, were placed over the Extensor Digitorum (ED) muscle corresponding to the longitudinal axis of the muscle fibers [6].

C. Experimental Design

The handle shape of a standard design trowel which is commonly available in market and used by most of the masons was considered as the reference due to its simple design. Procedure for experimentation is shown in Fig.2.Before the Fbeginning of the experiment, all participants were asked about complaints or injuries of their upper extremities which could affect the result. Brief purposes and processes of the experimentation were discussed with the participants. Experiment has been conducted in two phases as given below:

i. Phase 1 (Experimentation phase). Four different circumferences (27, 29, 31 and 33 mm) of handle at location of ring finger were fabricated and used in experimentation. Each subject was asked to rate all trowels with variable circumferences on the scale of 1 to 7 (1 - Very uncomfortable , 2 - Moderately Uncomfortable, 3 - Somewhat Uncomfortable , 4 - Neutral , 5 - Somewhat Comfortable , 6 - Moderately Comfortable and 7 - Very Comfortable). As the ratings for various trowels were taken in random order, therefore, it was a balanced design.

Hand Anthropometric measurements of the volunteers were assessed. All volunteers were asked to grip the trowels of various circumferences in their right hand and subjective comfort ratings were collected. For smaller handle, the ring finger has higher contribution than the index finger while gripping and vice-versa (Kong and Lowe, 2005). They also proposed that the contribution of the middle finger increases as the handle diameter increased up to 40 mm. Therefore middle finger and ring finger was considered during the experiment. The regression analysis was performed which showed the p-value significant ($p < 0.05$) for ring finger and insignificant ($p > 0.05$) for middle finger. This means that contribution the ring finger is more than that of middle finger when gripping. Then the regression analysis was done for single variable i.e. the ring finger. The resulting regression equation was used to find out the optimal handle dimensions.

ii.Phase 2 (Validation phase). Four trowels handles were fabricated using the optimal handle dimensions. The volunteers were provided with the trowel of optimized handle design and were asked to grip in their hand. The EMG muscle activity was recorded and analyzed to check the muscle fatigue. In surface EMG, for the assessment of muscle fatigue, Mean Frequency (MNF) and Median Frequency (MDF) are most useful frequency domain features. The MNF and MDF features, extracted from EMG signal are used to identify the muscle fatigue. Extensor Digitorum muscle was chosen to find out the Median Frequency (MDF) of the EMG activity. These muscles stabilize the wrist during gripping motions. The stronger the grip, the stronger the muscle (extensor digitorum) gets activated.

The contact area signifies the comfort level of any object. For handles, more the contact area more will be the comfort in gripping the handle. Paint was used on the handles during the experimentation and the volunteers were asked to grip the handle and trace it on the A4 size blank paper. The contact area was compared for the commercially available handle and the ergonomically designed handle and the results were assessed.

3. RESULTS

Experimentation – Phase 1

NHS is stated as a function of key hand anthropometric dimensions related to the grasping and the handle size. NHS is considered as the proportion of Handle Circumference (HC) at position of ring/ middle finger to hand length (HL) at ring/middle finger. NHS (Normalized Handle Size) was termed in an approach similar to that specified by Kong, 2001and is computed as:

$$NHS_{ij,k} = \left(\frac{HC_j}{HL_i}\right) * 100 \qquad (1)$$

where HL is the Hand Length(mm) of volunteer i, i is the subject, j is the handle, k is the subject number, HC is the handle circumference(mm) of handle j,NHS_j is the Normalized Handle Size based on hand length measured at middle finger, NHS_i is the Normalized Handle Size based on hand length measured at ring finger. These parameters are shown in Fig.1 and Fig. 2.

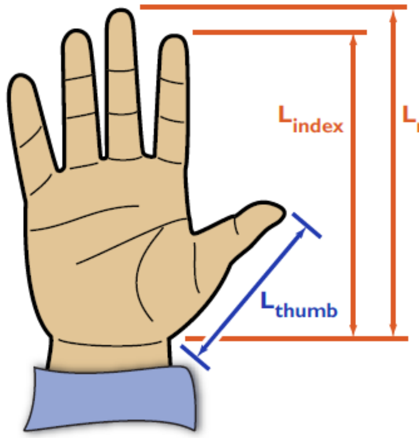

Fig -1. Hand length measurements for ring and middle finger

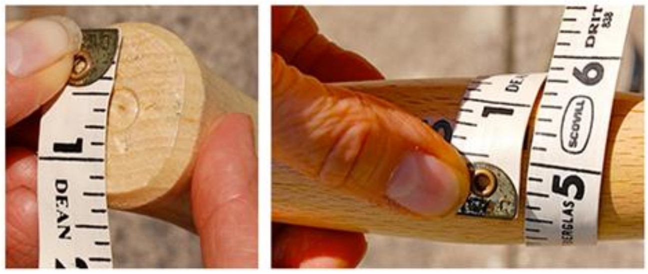

Fig -2. Handle diameter and circumference of the trowel

Subjective comfort rating for the grasping task was evaluated and relation between subjective comfort rating and NHS was evaluated using Minitab® 17.1.0.Software. The regression model was exercised for the relationship between the subjective comfort ratings and NHS. It was further employed to obtain the NHS maximizing the subjective comfort ratings for trowel handle.

The effect of both fingers (middle and ring finger) in grasping the trowel handle was worked out using Minitab® 17.1.0. A variety of Regression analysis i.e. Linear Regression, Quadratic Regression and Cubic Regression were done. Regression data is given in Table 1.

Table-1: Outcomes of linear, quadratic and cubic regression analysis

Regression	R-Square (%)	p-value		Significant factor
		Ring Finger	Middle Finger	

Linear	5.80	0.005	0.009	-
Quadratic	72.59	0.004	0.624	Ring Finger
Cubic	74.72	0.489	0.527	-

For Cubic Regression, the p values for both the fingers were 0.489 and 0.527 respectively, which were insignificant. Despite of the significant values of R-sq 74.72%, this regression was not undergone as the p-values were insignificant. For quadratic regression, the result was significant for Quadratic Regression with $\boldsymbol{R}^2$ value 72.59%. Moreover the NHS based on the ring finger shows the p value (p=0.004) less than 0.05 which is significant than that of the middle finger for this regression model. This shows that while gripping the trowel, the ring finger contributes more as compared to middle finger. Therefore the NHS based on ring finger was considered for the design purpose. For Linear Regression undergone during experimentation, the p-values were significant but the R-sq value was 5.80%, which is very low and hence was not considered for design purpose. Quadratic Regression analysis for ring finger

As from the outputs of quadratic regression model, it is clear that ring finger contributes more than the middle finger as the p-value for the ring finger came out to be significant. Therefore, ring finger was taken into consideration for the design purpose. The relationship between the subjective comfort ratings and NHS was assessed. The Quadratic Regression analysis for ring finger came out to be significant with $\boldsymbol{R}^2$ value 72.2%. Furthermore, the NHS based on the ring finger shows the significant p-value (p<0.05) for this regression model. The relationship between subjective comfort rating and NHS that maximizes subjective comfort rating of handle comfort is shown in Figure 3.

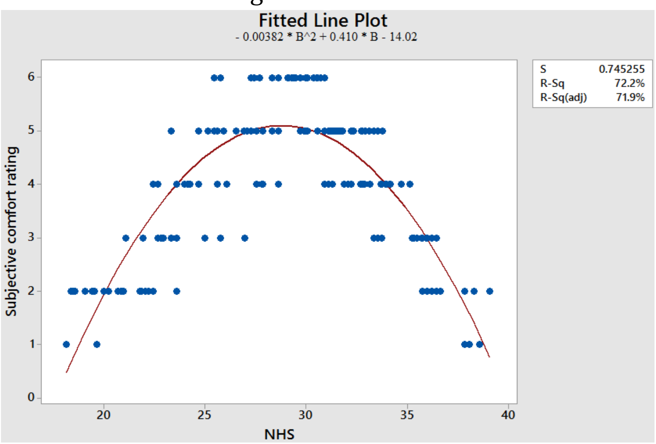

Fig -3: Relationship between subjective comfort rating and NHS

During quadratic regression for ring finger, R-sq value (R-Sq = 72.2%) came out to be significant along with a significant p-value. The following regression model (Eq. (2)), representing the relationship between subjective comfort rating and NHS, was used to derive the NHS that maximizes subjective rating of handle comfort. The relation between NHS and comfort rating works out to be in form of the regression equation as:

Subjective comfort rating= $-0.00382*(NHS)^2 + 0.410*(NHS) - 14.02$ (2)

The optimal value NHS obtained by first derivative of the Eq. (2) works out to be 53.66%, [NHS% = 0.410/ (2*0.00382)]. The Optimal NHS was used to find out the dimension of handle based upon user's hand length. The optimal NHS can be used to obtain recommended handle diameters according to the user's hand length [i.e. $HandleDiameter_{Optimal}$= (User's hand length*$NHS_{Optimal}$)/π]

The various hand sizes of masons was divided into three equal ranges (i.e. small, medium and large hand) according to which the optimal handle diameters for trowel handle was assessed. Recommended handle diameters for the specified range for maximizing subjective comfort are shown in the Table-2.

Table-2: Recommended handle diameters for maximizing subjective comfort

Hand size	Ring finger length(mm)	Handle diameter (mm)
Small	151 - 164	25.81 - 28.03
Medium	165 - 178	28.20 - 30.42
Large	179 - 192	30.59 - 32.81

Handle sections for 4 volunteers were evaluated. Four participants ring finger length was noted. Handles of optimal diameter based on their ring finger lengths were fabricated (see Table-3). The trowel was fixed with the handle of optimal diameter based upon the user's hand length.

Table-3: Optimal handle diameters for 4 volunteers

Volunteers	Hand Length (mm)	Handle Width (mm)	Handle Depth (mm)
1	178	17.9	10.7
2	180	18.1	10.8
3	156	16.1	09.7
4	167	17.2	10.2

Experimentation – Phase 2

Contact area

The contact area of both the trowel handles was assessed. These handles were painted and the volunteers were asked to grasp both the trowels one by one. After gripping, hand impressions on blank paper for both handles were obtained. Areas were calculated by Meshing/Triangulation technique. The results of contact area were compared for the hand impressions for both handles. It was seen that the contact area for the designed handle was more as compared to the standard-design trowel handle. The contact areas obtained on the blank sheets for both the handles are shown in Figure 4.

LEFT SIDE Impression- Using standard-design trowel

RIGHT SIDE Impression- Using ergonomically designed trowel

Fig -4(a)

Fig -4(b)

Fig -4(c)

Fig -4(d)

Figure 4. Experimentation for contact area

The contact area for the four trowel handles of the considered four volunteers is given in Table 4.

Table I: Contacts areas of both the handle

Volunteers	Areas (cm^2)	
	Standard-design trowel	Optimally designed trowel
1	36.80	37.70
2	37.10	37.70
3	41.00	41.60
4	38.53	39.17

Muscle fatigue

The EMG Activity during grasping of standard design handle as well as the ergonomically designed trowel handle was extracted. The muscle activity was recorded using EMG and analyzed to check the muscle fatigue.The graph between their Median Frequencies is plotted for all the 4 volunteers are in Figure 5.

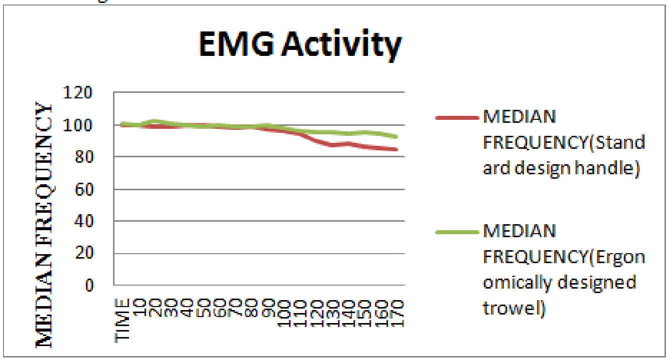

Figure 5(a). (Volunteer 1)

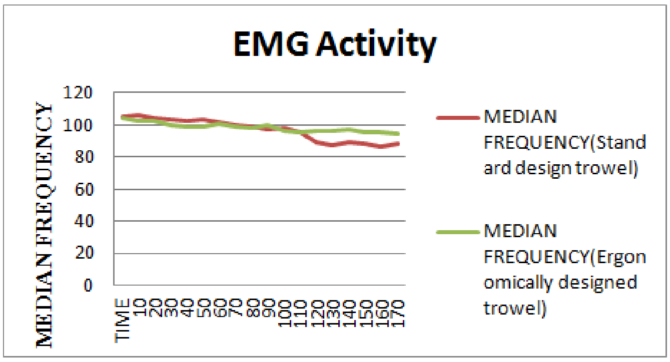

Figure 5(b). (Volunteer 2)

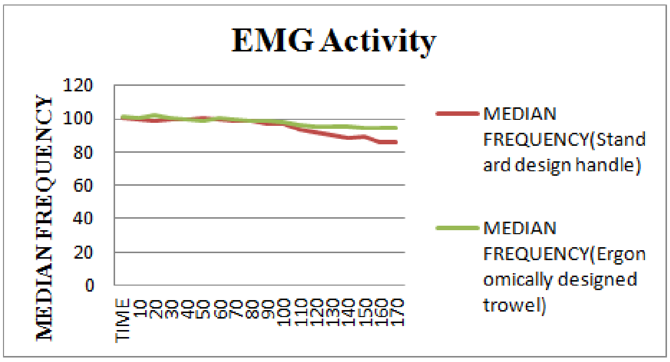

Figure 5(c). (Volunteer 3)

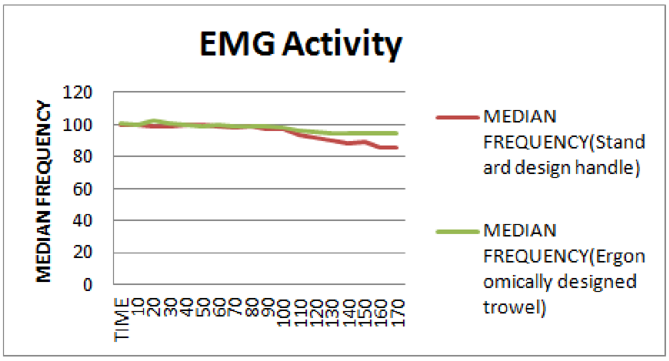

Figure 5(d). (Volunteer 4)

Figure 5: The Graph showing the Median Frequencies on both the handles for 4 volunteers

It was observed that the fatigue occurred earlier for the standard design handle the as compared to the ergonomically designed handle for all volunteers.

4. CONCLUSION

From the above study carried out, the following conclusions have been made:

1. The muscle fatigue was less in case of ergonomically designed trowel handles as compared to the standard design trowels. Experimentation shows that plastering with the ergonomically designed trowel handle result in increase of perceived comfort and reduction of muscle fatigue. This means that work time for user is increased as his muscle will get fatigue later than that for the standard design trowel. This will increase the user's efficiency.
2. In the ergonomically designed trowel the contact area is more than that of the standard trowel. This shows that there is no specific point of pressure on the palm, which means that the pressure is uniformly distributed all over the palm. Therefore, the risk of injuries will be minimized.
3. As the ergonomically designed trowel handle is fabricated based upon the hand anthropometric data, the force required by muscles to grip thetrowel handle will be minimum. This also minimizes the risk of muscle fatigue.

Therefore, occupational therapists should be careful when recommending a trowel that is labeled ergonomic. Not all tools that are ergonomic actually provide ergonomic benefits. Trowels need to be found for masons with physical problems that will help keep the wrist in a neutral position and decrease the amount of range used while plastering. Symptoms of musculoskeletal disorders may affect individuals differently so preference, comfort, and ease of use are just a few of the factors that need to be considered in order to fit the person with the right size of trowel handle. A variety of trowels should be tried out by clients prior to recommendation of a tool. A trowel handle should therefore be designed on the basis of suitable hand anthropometric parameters. This would include the hand length measured at ring finger. In future, effort would be made to consider different sections and designs of trowel handle and inclusion of additional anthropometric parameters for evaluation of dependent design parameters. Shape and surface properties (such as texture, surface roughness etc.) of trowel handle can be incorporated in the ergonomic design of trowel.

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