Ergonomic evaluation of effects of handle shape and task orientation on human performance in screw driving task.

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Abstract

This study was designed to ergonomically evaluate the effects of Handle shape and Task Orientation on human performance in screw driving task under applications of different combinations of Handle Shapes and Orientation of Work Surface. To begin with pilot study was performed prior to main study to find out the most affected muscle in screw driving, to find the correct posture and also to decide the type of screw driver. The results of pilot study suggested that PT is the most affected muscle in screw driving and productivity was maximum in standing posture with Philip headed screw. The main study "Ergonomic Evaluation of the effects of Handle Shape and Task Orientation on Human Performance in Torquing Tasks" was investigated. Eight (male and female) participants volunteered in the study. Nine different handles of Triangular, Hexagonal & Circular Shapes were used on three Orientation of the work surface were tested (Horizontal, Vertical and Inclined at 45 Degrees). To enhance the grip one handle from each shape was provided with rubber grip while the surface of one handle of each shape was textured. The result of the study showed that Orientation of the work surface was having the significant effect on all the dependent variables. On analysis of the results, it can be concluded that Vertical Orientation of the work surface was best suited for screw driving task as discomfort was minimum and productivity was maximum and also muscle was least fatigued on this orientation. However, Handle shape's effect was only significant on discomfort Score and best results were obtained for Rubber Gripped Circular Handle.

Keywords: *Screw Driver, EMG, Discomfort, Productivity*

1. Introduction

Screw Driver is one of the most commonly used hand tool employed in assembly tasks in every industry. The use of hand tools (like screwdrivers, scrapers and pliers) frequently leads to feelings of discomfort during work. These feelings of discomfort can reduce efficiency and job satisfaction of workers [4]. Therefore it is required to design the tool and the task in such a manner that the user experiences a lesser degree of discomfort to reduce biomechanical stresses and risk factors for cumulative disorders of musculoskeletal system. On a longer term, the use of hand tools can also cause musculoskeletal disorders [1]. For these reasons, employers are interested in comfortable hand tools for their employees.

The important factors in designing a hand tool are handle's size, handle's shape, material of the tool and working conditions [4]. The handle diameter is one of essential criteria in tool designs to maximize performance, reduce stress on the forearm muscles and finger tendons while hand tool use [10]. Kong et al. investigated the effect of screw driver handle shape and work piece orientation on subjective discomfort, number of rotations and finger contact forces in screw driving task [11]. They have suggested the handle size for different shapes of screw driver (diameter for circular handle was 45mm, for triangular 42mm and for hexagonal shape was 44.5mm). The torque output was directly proportional to the size of the handle [9]. Lee et al. tested five grip spans (45 to 65 mm) to evaluate the effects of handle grip span and user's hand size on maximum grip strength, individual finger force and subjective ratings of comfort using a computerized digital dynamometer with independent finger force sensors [12]. Results showed that the 55- mm and 50-mm grip spans were rated as the most comfortable sizes and showed the largest grip strength (433.6 N and 430.8 N, respectively). Dempsey et al. investigated two types of screwdrivers to determine the effects of work height, work piece orientation, gender, and screwdriver type (Phillips or flat head) on productivity and wrist deviation during a screw driving task [3]. Participants performed better with the Phillips-head screwdriver and there were strong interactions between work piece orientation and work height on productivity and measures of wrist deviation. You et al. evaluated two design modifications (rubber grip and torsion spring) to the conventional manual Cleco pliers by electromyography (EMG), design satisfaction and hand discomfort [15]. Use of rubber on the handle largely increased satisfaction with the texture of the plier handle.

In continuation of the above studies, this present study is an attempt, to further investigate the finding of Kong et al. in context of a particular muscle in the human hand, which gets most affected in screw driving [11]. The handles which were investigated in the present study were of same shapes as suggested by Kong with an addition that the outer surface of one handle from each group was textured and rubber grip was provided to one handle of each shape. This investigation was performed on three different orientations rather than two with an addition of inclined orientation of 45 degrees with the horizontal. Therefore this present study was designed to investigate the effect of different types of handles combined with work place orientations on perceived discomfort, productivity and electrical activities (EMG) of forearm muscles.

2. Methodology

The methodology consists of two parts, Pilot Study and Main Study.

2.1 Pilot Study

Pilot Study was performed prior to main study to find out most affected muscle in screw driving, to define the correct posture and to select the type of screw and screw driver. To achieve the above said objectives two separate experiments were designed. First experiment was to find out the most affected muscle in screw driving. In this regard a surface EMG electrode was attached to PT and ECRB muscle. EMG signals were recorded and analyzed by extracting the EMG work done, EMG RMS and regression of median frequency from raw EMG signals. This analysis provides the basis for the selection of muscle in screw driving. Second experiment was designed to find out the correct posture for screw driving and also for the selection of screw driver. Two types of screw drivers (Philip and Flat Headed) were tested at standing and sitting Posture. Productivity (i.e. no of screws tightened) was the basis of selection of screw driver and Posture.
Five Participants performed screw driving task for 2 minutes in standing and sitting posture, on an experimental rig that was prepared in lab, with two types of screw drivers in this Pilot study. While the task was performed the muscle activity of ECRB and PT muscles was recorded by

Surface EMG sensor. For this study the Datalink software and hardware of M/s Biometric Ltd. (UK) was used to record the electrical muscle activities**.** The EMG activities were recorded at the sampling rate of 1024Hz using Surface EMG sensor (Model:SX230 EMG sensor; Make: Biometrics Ltd. UK)**.**

2.2 Main Study

As per the plan, few changes were applied over the design of original handle of screw driver. The main aim was to improve the productivity and reduce the discomfort/muscle fatigue during the screw driving task. Here, PT muscle was selected for the observation as it was found the most affected muscle while working with the screw driver.
The experiments that were performed in the main study are listed below:

1. Find out the discomfort rating in using screw driver with the new handles and the original handle on the basis of discomfort score given by each participant on for performing the given task.
2. Recording of EMG activity during the given task.
3. Observing the productivity for the task duration in terms of number of screws done.

A two factor experimental (9 types of handles and 3 orientations of the work station) design was used. Surface EMG electrode was attached to the PT muscle, before the task was started, to record the EMG activity. The procedure for recording the EMG signals was same as in Pilot study. In this experiment, time of operation, length of screw and type of screw were the fixed factors. Handle type and Orientation were independent variables & productivity, discomfort score and EMG activity of the muscle falls in the category of dependent variables. 8 participants (both male and female, right and left handed, of age group 22-28 years) performed in the study and each of them was asked to perform the task of screw driving with each handle one by one for two minutes on a particular orientation. The duration of task was fixed for 2 minutes because of the fact that on continuous screw driving muscle was getting fatigued very quickly, and it was becoming very tough for the participants to perform the screw driving even for three minutes. After the completion of task with each handle on a single orientation, that orientation was changed and so on. When the task of 2 minutes with a particular handle was completed participant was given a rest for at least three minutes or till no discomfort in the forearm was reported.

3. Results

3.1 Pilot Study

Table 1 represents the EMG data of Pilot Study for different participants while Table 2 represents the productivity at different postures with different screw drivers.

It is quite clear from table 1 that the slope of trend line of median frequency is more negative for PT muscle as compared with ECRB muscle which indicates that PT muscle gets more fatigued in screw driving task. The value of Mean RMS was more for PT muscle giving an indication that the muscle activity was more for PT muscle. Lastly EMG work done by the PT muscle was again more in comparison to ECRB muscle. Hence on this basis it can be said that PT is the most affected muscle in screw driving task. The observations recorded in table 2 clearly suggested that productivity was more when the task was performed in standing posture with Philip headed screw driver. Therefore, standing posture with Philip headed screw driver is best suited for the present study.

Table 1: EMG activities of ECRB and PT Muscle

Participant	Muscle	Trend Line			Mean Value RMS	Work Done
		Med. Freq.	Slope	RMS Value		
1	PT	Y=-0.17t+118.2	-0.17	Y=-0.0001t+0.1163	0.1125	12.345
	ECRB	Y=-0.04t+78.35	-0.04	Y=-0.0002t+0.1463	0.105	10.464
2	PT	Y=-0.11t+98.87	-0.11	Y=-0.0002t+0.1385	0.1012	11.327
	ECRB	Y=-0.07t+89.45	-0.07	Y=-0.0001t+0.0428	0.074	9.985
3	PT	Y=-0.21t+105.53	-0.21	Y=0.0003t+0.123	0.141	10.891
	ECRB	Y=-0.01t+103.25	-0.01	Y=0.0004t+0.0632	0.065	8.912
4	PT	Y=-0.15t+109.2	-0.15	Y=-0.0001t+0.1163	0.1109	10.245
	ECRB	Y=-0.04t+84.41	-0.04	Y=-0.0004t+0.1289	0.1025	7.467
5	PT	Y=-0.18t+89.45	-0.18	Y=-0.0005t+0.0419	0.379	10.185
	ECRB	Y=-0.01t+53.36	-0.01	Y=0.0001t+0.0232	0.04	4.367

Table 2: Productivity at different Postures with different Screws

Participant Number	Posture	Productivity with Philip Headed Screw	Productivity with Flat Headed Screw
1	Standing	8	7
	Sitting	6	5
2	Standing	9	7
	Sitting	7	6
3	Standing	9	6
	Sitting	6	5
4	Standing	10	8
	Sitting	7	6
5	Standing	10	7
	Sitting	8	6

3.2 Results of Main Experiment

The summary of the data (Productivity and Discomfort Score), which was collected for PT muscle, is presented in Table 3 and the summary of EMG data is presented in Table 4. The statistical analysis of the recorded data was done using MANOVA (Multi variate analysis of Variance). The results of MANOVA are shown in Table 5.

It can be noticed from Table 5 that there was a significant effect of handle type on discomfort score (with a p-value of 0.001). On rest of the parameters like EMG Work Done, EMG RMS, etc handles don't have any significant effect. Orientation of the workstation has significant effect on number of screws tightened (i.e. productivity), discomfort score, maximum EMG work done and mean RMS of the EMG signals. Also the effect of handle type was significant on discomfort score. Thus to check the statistically significant difference between Handles and discomfort score, Student-Newman-Keuls Post Hoc tests were conducted. The results of Post Hoc test suggested that Rubber circular handle's effect on discomfort score was statistically different effect of rubber triangular and grooved triangular handles. Plane circular Handle's effect on discomfort score was statistically different from effect of grooved triangular handle. Rubber triangular handle's effect on discomfort score was statistically different from effect of rubber circular handle. Lastly the effect of groove triangular handle's effect on discomfort score was statistically different from effect of rubber circular handle. Rest all the handles are having statistically same effect on discomfort as compared with others.

Student-Newman-Keuls Post Hoc tests were also conducted between Orientation & Productivity, Orientation & Discomfort Score, Orientation & maximum EMG work done, Orientation & Mean RMS of EMG signals. It was found that the effect of horizontal orientation on Productivity was statistically different from inclined and vertical orientation. Inclined and vertical orientations were having statistically same effect on productivity. The effect of Vertical orientation on Discomfort Score was statistically different from Inclined and Horizontal orientation. Inclined and Horizontal orientations were having statistically same effect on Discomfort Score. The effect of horizontal orientation on maximum EMG work done was statistically different from inclined and vertical orientation, whereas inclined and vertical orientations were having statistically same effect on maximum EMG work done. The effect of horizontal orientation on mean RMS was statistically different from inclined and vertical orientation. Inclined and vertical orientations were having statistically same effect on mean RMS value of EMG signals.

Table 3: Summary of Observations for Productivity and Discomfort Score.

Handle Type	Orientation	Productivity		Discomfort Score	
		Mean	Std. Deviation	Mean	Std. Deviation
Plane Circular	Horizontal	8.18	0.961	4.62	1.597
Plane Hexagonal	Horizontal	8.43	0.979	4.62	0.867
Plane Triangular	Horizontal	8.75	1.488	4.93	1.347
Textured Circular	Horizontal	8.87	1.505	4.62	1.093
Textured Hexagonal	Horizontal	8.68	1.307	4.56	2.128
Textured Triangular	Horizontal	8.62	1.329	5.75	1.439
Rubber Circular	Horizontal	9.18	1.361	3.68	1.222
Rubber Hexagonal	Horizontal	9.50	1.535	3.56	0.942
Rubber Triangular	Horizontal	9.18	1.412	4.68	0.372
Plane Circular	Vertical	8.93	1.498	3.12	1.660
Plane Hexagonal	Vertical	8.68	1.831	4.62	1.026
Plane Triangular	Vertical	8.56	1.265	4.375	1.505
Textured Circular	Vertical	9.43	1.178	3.31	0.923
Textured Hexagonal	Vertical	9.87	1.274	4.06	1.699
Textured Triangular	Vertical	9.50	1.133	4.31	1.412
Rubber Circular	Vertical	9.93	1.208	3.18	1.487
Rubber Hexagonal	Vertical	10.12	1.157	3.87	1.329
Rubber Triangular	Vertical	10.14	1.324	4.87	1.246
Plane Circular	Inclined	9.12	1.157	3.06	1.545
Plane Hexagonal	Inclined	9.25	1.133	4.31	1.307
Plane Triangular	Inclined	9.18	1.032	4.18	1.688
Textured Circular	Inclined	9.31	0.842	3.50	1.336
Textured Hexagonal	Inclined	9.12	1.274	4.43	1.971
Textured Triangular	Inclined	8.87	0.624	4.62	1.995
Rubber Circular	Inclined	9.68	1.731	3.43	1.498
Rubber Hexagonal	Inclined	9.56	1.522	4.12	1.433
Rubber Triangular	Inclined	9.37	1.552	4.93	1.545

Table 4: Summary of observations for EMG data.

Handle Type	Orientation	EMG Work Done		Slope of Trend line of Median Frequency		Mean RMS	
		Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
Plane Circular	Horizontal	7.155	3.541	-0.003	0.06	0.835	0.341
Plane Hexagonal	Horizontal	9.207	4.981	-0.021	0.051	0.914	0.353
Plane Triangular	Horizontal	9.156	4.931	-0.008	0.032	0.861	0.295
Textured Circular	Horizontal	10.234	4.757	-0.053	0.058	0.952	0.284
Textured Hexagonal	Horizontal	9.561	3.79	-0.048	0.027	0.924	0.23
Textured Triangular	Horizontal	8.906	3.874	-0.041	0.04	0.93	0.21
Rubber Circular	Horizontal	10.126	4.254	-0.048	0.047	0.959	0.231
Rubber Hexagonal	Horizontal	9.846	3.934	-0.025	0.045	0.974	0.196
Rubber Triangular	Horizontal	9.4	3.671	-0.036	0.043	0.93	0.224
Plane Circular	Vertical	8.491	3.126	-0.028	0.032	0.738	0.298
Plane Hexagonal	Vertical	9.267	3.71	-0.03	0.037	0.793	0.289
Plane Triangular	Vertical	9.043	3.406	-0.016	0.039	0.768	0.319
Textured Circular	Vertical	12.257	4.085	-0.03	0.032	0.908	0.283
Textured Hexagonal	Vertical	12.499	3.515	-0.04	0.045	0.954	0.24
Textured Triangular	Vertical	11.677	3.334	-0.006	0.049	0.902	0.277
Rubber Circular	Vertical	11.23	2.747	-0.029	0.04	0.885	0.163
Rubber Hexagonal	Vertical	12.048	3.189	-0.033	0.027	0.908	0.189
Rubber Triangular	Vertical	11.927	3.098	-0.034	0.062	0.937	0.231
Plane Circular	Inclined	12.99	5.472	-0.024	0.039	0.968	0.341
Plane Hexagonal	Inclined	11.501	5.573	-0.023	0.036	0.919	0.322
Plane Triangular	Inclined	11.567	5.675	-0.024	0.023	0.916	0.318
Textured Circular	Inclined	13.201	5.413	-0.05	0.053	0.981	0.255
Textured Hexagonal	Inclined	12.075	3.194	-0.044	0.041	0.963	0.184
Textured Triangular	Inclined	12.244	4.692	-0.038	0.033	0.925	0.263
Rubber Circular	Inclined	11.122	3.846	-0.008	0.045	0.999	0.186
Rubber Hexagonal	Inclined	11.247	3.694	-0.056	0.058	1.005	0.214
Rubber Triangular	Inclined	11.571	3.983	-0.024	0.018	0.993	0.197

Table 5: Results of MANOVA

Source	Dependent Variable	Type III Sum of Squares	Degree of freedom	Mean Square	F - Value	Sig (p-value)
Handle Type	No. of Screws	26.843	8	3.355	1.908	0.061
	Discomfort	55.396	8	6.924	3.349	0.001
	Max EMG Workdone	110.276	8	13.784	0.704	0.687
	Slope Median Frequency	0.020	8	0.003	1.380	0.208
	Mean RMS	0.420	8	0.001	0.762	0.908
Orientation of Work Station	No. of Screws	15.530	2	7.765	4.415	0.013
	Discomfort	14.424	2	7.212	3.488	0.033
	Max EMG Workdone	259.372	2	129.686	6.627	0.002
	Slope Median Frequency	0.001	2	0.000	0.267	0.766
	Mean RMS	0.343	2	0.016	2.490	0.001
Handle * Orientation	No. of Screws	11.407	16	0.713	0.405	0.980
	Discomfort	21.889	16	1.368	0.662	0.829
	Max EMG Workdone	133.908	16	8.369	0.428	0.974
	Slope Median Frequency	0.023	16	0.001	0.800	0.685
	Mean RMS	0.185	16	0.001	0.168	1.000
Error Residual	No. of Screws	332.438	189	1.759		
	Discomfort	390.781	189	2.068		
	Max EMG Workdone	3698.776	189	19.570		

	Slope Median Frequency	0.344	189	0.002		
	Mean RMS	13.021	189	0.002		
Corrected Total	No. of Screws	386.218	215			
	Discomfort	482.490	215			
	Max EMG Workdone	4202.332	215			
	Slope Median Frequency	.388	215			
	Mean RMS	13.969	215			

4. Discussion

4.1. Discomfort Score

In the final experiment for overall discomfort, the results showed that the different handles were having significant effect on overall discomfort (p-value 0.001). Out of the three different shapes, triangular handles were causing most discomfort whereas circular handles were causing least discomfort as resulted from SNK test. The maximum discomfort occurred with textured triangular handle while minimum discomfort occurred with rubber circular handle. This may be happening because of the fact that triangular handles were having three edges and thus holding became difficult, and because of textured surface holding becomes more difficult. Whereas in case of circular handles there were no edges present and because of covering of rubber, holding becomes even more comfortable. The screw driver that combined the characteristics of large handle diameter (3.8 - 4.1 cms), smooth rubber covered handle surface, circular shape and adequate handle length (11 cms) has the greatest supination torque and the smaller discomfort rating of the upper extremity [14].

Also the orientations were also having the significant effect on the overall discomfort with p-value of 0.033. Out of three different orientations the maximum discomfort occurred at horizontal orientation while the minimum discomfort occurred at vertical orientation. Inclined orientation was causing intermediate discomfort. While performing the task in horizontal position, holding the tool becomes quite difficult because of the awkward position of the arm, thus leading to muscle fatigue. Therefore, the ability of the muscle to perform the task reduces and hence the end result was pain in the upper arm of the participant.

This finding may also be explained by use of body weight, to transfer the downward force, against the screw driver handle in the horizontal work piece orientation. Thus participants may have used their body weights passively resulting in more axial screw driving force in the horizontal orientation [11]. Working on a vertical plane with rubber covered circular in line screw driver is better suited then rubber covered triangular screw driver [14]. Similar results were obtained by Kong et al. which stated that participants reported least discomfort for circular handles, slightly more in hexagonal handles and maximum discomfort in triangular handles, also greater preference was given to rubber surface handles by the participants [11].

4.2 Productivity

The result of this study shows that the effects of handle on productivity was not significant (p-value 0.061) for a 95% confidence level. This may be happening because the sizes of the handles weren't very much different from each other circumferentially. Thus during supination the rotation of the arm was almost same leading to the same amount of movement of screw inside the work piece. A part from this effect of orientation on productivity was significant (p-value

0.013). The productivity was maximum on vertical position of the work station and was minimum on horizontal position. This may be happening because on vertical orientation of the work surface, the discomfort was minimum, leading to the less fatigue. Hence ability of the muscle to perform was more on vertical orientation. Same reason can be suggested for having less productivity on horizontal position. This variation can be visualized in the two graphs shown below in figure 1.

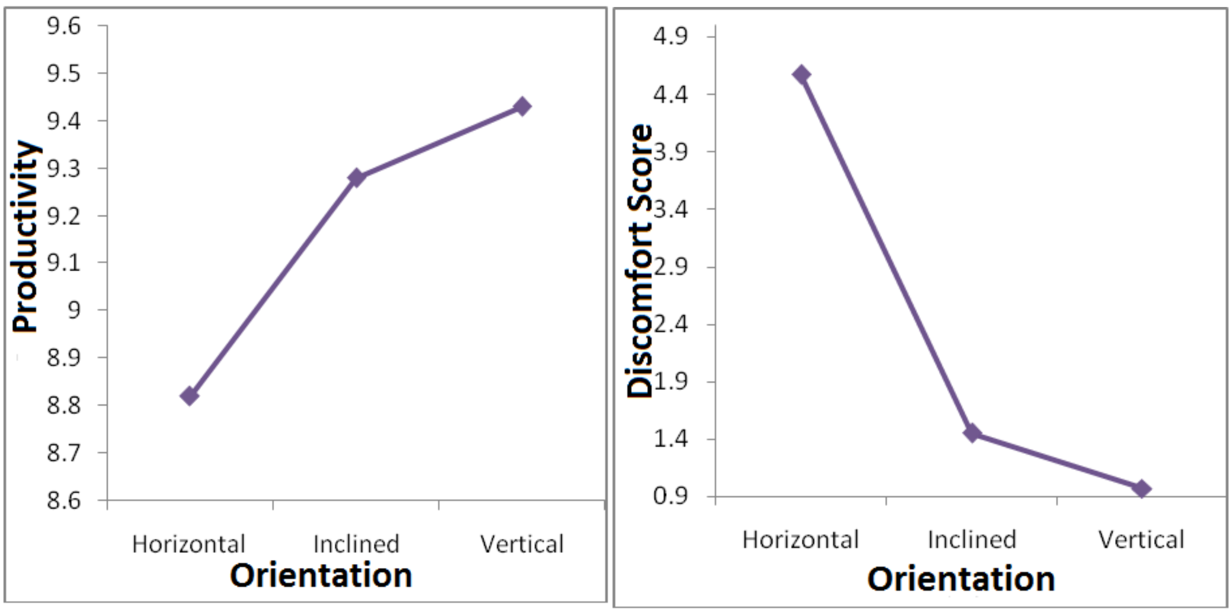

Figure 1: Comparison of graphs Productivity Vs Orientation & Discomfort Score Vs Orientation.

According to Hagberg et al., pain and discomfort experienced by an operator reduces his performance [7]. Hagberg et al. investigated the effects the relationship between reduced productivity and musculoskeletal disorders. It was also found that among the operators that has greater persistence of pain or discomfort, there was a higher prevalence and magnitude of productivity reduction. In another study of relationship between high physical load jobs and productivity Meerding et al. found that the discomfort received during the task leads to MSDs in construction and industrial workers and because of this performance of the operator gets reduced [12].

4.3 EMG Activity

Electromyography (EMG) is a technique for evaluating and recording the electrical activity produced by skeletal muscles. These signals can be analyzed to detect medical abnormalities, activation level, and recruitment order or to analyze the biomechanics of human and hence mechanical performance can be observed [2]. It can be observed from Table 5 that the effect of handles was not significant on EMG activity but change of work surface orientation has a significant effect on EMG activity (i.e. on EMG work done and mean RMS value of EMG signals). Results of post hoc test suggested that effect of horizontal orientation on EMG activity of PT muscle was statistically different from effect of vertical and inclined orientation on EMG activity. It can be noticed that Planer family of handles were having the minimum RMS value and EMG work done while grooved family of handles were having the maximum RMS value and EMG work done. Rubber griped family of handles was having the intermediate values. Talking about a particular handle, maximum work was done by the muscle with textured circular handle while maximum RMS value of EMG signals was obtained in case of rubber hexagonal handle. Minimum value of both RMS and Work was obtained for plane circular handle. This might be happening because textured handles were difficult to hold due to their geometry. Hence they cause the undue stress in the palm and holding becomes difficult. Thus during operation muscle has to done more work in order to overcome this inconvenience. Rubber gripped handles were easy to hold. So because of ease of use a subject perform better with rubber gripped handles giving rise to muscle activity and hence RMS increases.

The RMS value was maximum on vertical orientation, minimum on inclined orientation and was having intermediate value at horizontal orientation. EMG Work done was maximum on inclined orientation and was minimum at horizontal orientation. Thus muscle was performing more work so that productivity increases despite of having some discomfort and while doing so, gets fatigued. Slope of trend line of median frequency was also most negative on inclined orientation giving a clear idea that muscle was most fatigued at inclined orientation. On horizontal orientation discomfort was so high at it restricts the muscle to perform and thus work done was minimum on this orientation. Talking about the vertical orientation, discomfort was minimum here, thus muscle was able to perform the task without getting fatigued. Slope of trend line of median frequency was also least negative in case of vertical orientation which also favors the findings of the study.

5. Conclusions

Statistical analysis shows that the effect of handles on discomfort score was significant. Results of the study suggested that discomfort was least in screw driving task when the handle used was of circular shape of diameter 45mm and was provided with rubber grip. The effect of handles on productivity and EMG activity was not significant. Hence it can be concluded on the basis of discomfort score that rubber gripped circular handle was the best possible design for the screw driving task. The effect of orientation was significant on Productivity, Discomfort Score and EMG activity. The Discomfort Score was minimum on Vertical orientation. Productivity was maximum on vertical orientation. Hence it can be concluded that vertical orientation was best suited for screw driving and screw driving task was most comfortable with rubber gripped circular handle on vertical orientation.

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