Anatomically Shaped Tool Handles Designed for Power Grip

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Abstract. The work proposes two different approaches to ergonomically design and evaluate tool handles considering optimal power grasp posture. The first investigation deals with the evaluation of handles of different shapes for fitness in hand, preferred subjective gripping experience and maximum hand-handle contact area. Initially 67 participants were utilized to determine optimal diameter for power gripped based cylindrical handles. On the basis of preferred optimal diameter, six handles of different shapes were developed. Based on a cluster analysis, a group of 17 participants were used to evaluate these handles through subjective responses and an image mapping technique. The second investigation involved the evaluation of an anatomically shaped handle for a kitchen paring knife. Five different commonly used knife handles and one anatomically shaped knife handle were evaluated by 27 participants using subjective comfort questionnaire.

Keywords: Hand tools. Anatomically shaped tool handle. Comfort questionnaire for hand tools (CQH). Point cloud digitized data.

1 Introduction

Hand tools have been tremendously important to the human species in its progress to the technology advanced state of today. Hand tools are one of the most important product segments for any domestic, outdoor and industrial use. Ergonomic hand tools being more comfortable and usable are being produced today that can be used easily by different kinds of users. Do it yourself (DIY) trend has gained pace and many people, earlier less familiar to hand tools are now increasingly buying and using hand tools.

Researchers like Taylor et al. [1] and Kuijt-evers et al. [2] have conducted assessment of hand tools like screwdrivers in DIY shop. Similarly, Vergara et al. [3] employed users with experience in do-it-yourself (DIY) in their study on understanding perceptual constructs of interaction with hammer designs.

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Poor design of hand tools can also lead to health problems. Researchers like Lipscomb et al. [4] have pointed at the extensive scale of occupational injuries among carpenters. Adoption of ergonomic principles helps in the design of tool handles with increased comfort and performance enhancement along with user safety. Paivinen et al. [5] found that tool design factors such as length of the handle and the blade's cutting ability / sharpness, affect subjective experience of the users with axes [6]. Presently, in the design process there have been a big paradigm shift from a use-centered model to a user-centered model. Research on design and evaluation of tools such as drywall sanding tools and screwdrivers by employing techniques such as user centered task analysis [7,8], stakeholder mapping and user modeling [9] illustrates this fact. Anthropometry plays in important role in design and evaluation of hand tools. Many researchers have used anthropometric data for the design of hand tools and equipment for agriculture, screen textile printing, laparoscopic surgery, etc. [10,11,12].

Handle shape plays an important role in determining user comfort and tool usability. Various studies have been conducted to assess subjective preferences through subjective comfort questionnaires, physical responses, ratings of discomfort, acceptability of reaction forces, etc. [13,14,15,16] and objective physiological capabilities such as electromyography, static and dynamic contact pressure distribution, tool productivity, etc. [16,17,18].

The present work shows two different user centric approaches to design more comfortable power grip based tool handles. In Study I, six different handles based on optimal diameter selection have been fabricated and evaluated for comfort, fit to hand and greater hand-handle contact surface area. Subjective comfort evaluation has been performed on fabricated handle prototypes. An image mapping based objective evaluation has also been conducted to determine the optimal handle shape for best fit and comfort. In Study II, a kitchen paring knife with an anatomically shaped handle has been designed to evaluate its performance with five existing handle designs.

2 Design and Evaluation of Tool Handles

Two different methodologies for studying tool handle designs on the basis of user evaluation were adopted by the authors. In the first method, the relation of optimum grip diameter was utilized to determine optimal diameters using anthropometric data of the selected participants. Based on this reference size, six handles of different cross-sectional shapes were fabricated and compared to find the best handle shape. The second methodology focused on comparing the overall comfort in the use of an anatomically shaped kitchen paring knife handle against five existing designs.

2.1 Evaluation Study I: Optimal Handle Shape Determination

Sixty seven participants, mostly students from undergraduate and post graduate programs having soft hands with no cuts were chosen for this study. This group consisted of fifty eight males, age range of 20-33 years (median 22, mean 22.84, SD 2.65) and nine females, age range of 22-24 years (median 22, mean 22.33, SD 0.82). The experimental protocol was explained to the participants, and an informed consent for their participation prior to the study were provided. The first step was to collect relevant hand anthropometric data of the participants.

Anthropometry Measurement

The hand anthropometry parameters collected for this study were (a) hand length, (b) hand breadth without thumb (at metacarpals), (c) distal phalange length of the thumb, (d) distal phalange length of the middle finger, and (e) grip inside diameter. Anthropometry data was measured using a digital vernier calliper, a steel rule and a wooden cone fabricated specifically for measuring inner grip diameter. Relevant images from the anthropometric survey are provided in Fig. 1(a). A generic relation of optimal handle diameter (D_{opt}) and maximum grip inner diameter (D_{grip}) were utilized to determine the optimum diameter of handle. The relation can be expressed as [20,21],

$$D_{opt} = (D_{grip} \times \pi - C) / \pi \quad (1)$$

where, C is a constant with a value of 10 mm. Again, optimum grip diameter is obtained using lengths of the distal phalanges of thumb and the middle finger using the following relation [22],

$$D_{opt} = (D_{grip} \times \pi - (L_{d,3} + L_{d,1}) / 2) / \pi \quad (2)$$

where, $L_{d,3}$ is the length of distal phalange of digit 3 (middle finger) and $L_{d,1}$ is the length of distal phalange of digit 1 (thumb).

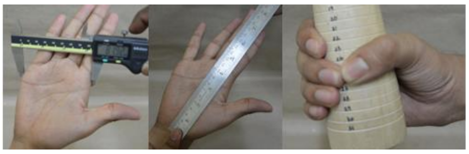

Fig. 1(a). Anthropometric measurements using a digital vernier calliper, a steel rule and a wooden cone (left to right)

Fig. 1(b). Prototypes for handles of diameters 35 mm and 41 mm (left to right)

Comfort Assessment

Optimal handle dimension values were found using equations (1) and (2) to calculate D_{opt} by utilizing the collected anthropometry data. Two different dimensions (35mm and 41mm) resulted for the optimum handle diameter, one from each equation. A cylindrical prototype of each dimension is fabricated (as shown in Fig. 1(b)) and then tested for fit and comfort. As the shape of the hand can be roughly defined by the length and breadth of the hand, the participants were grouped into three groups of relatively homogeneous hand shape by performing a hierarchical cluster analysis. Hand length and breadth is taken as input variables for cluster analysis. In order to reduce the number of participants (67; initially selected), one of these groups with seventeen participants were selected to participate in the next phase of study.

A subjective study was conducted to compare the two cylindrical handle prototypes (Fig. 1(b)). Each participant was asked to rate how well each of the two handles fit into their hands, and what was the overall comfort level in handling each of these handles. The rating scale for responses in each of these questions was 1-5 (1 being the worst rating and 5 being the best rating). On the basis of the optimal diameter of 35mm preferred by most of the participants, six handles with different cross-sectional shapes were fabricated. The shapes used in this study were circular, triangular, pentagonal, hexagonal and two combinations of circular and triangular (Fig. 2). The size of those cross sectional shapes corresponds to a periphery enveloped by a circle of diameter equal to the preferred D_{opt}. Fig. 3(a) shows the five different prototypes that were fabricated. Fig. 3(b) shows two different hand grip orientations corresponding to the cross-sectional shapes of design V and VI of Fig. 2 respectively.

Comfort evaluation was conducted in two stages. First, subjective responses were collected from the participants to determine their overall comfort with each of the six different handles. Second, an image mapping technique is adopted to determine the hand-handle surface contact area. Temporary water based paint was applied on the surface of each prototype and each participant was instructed to hold the prototype in a power grip position, with no grip adjustments. Each participant was then asked to put its hand on a white paper to create a hand print. This hand print provided an estimate of the extent of volar hand region that came in contact with the handle. An estimate of the area covered by paint was calculated by importing the scanned images of hand prints for pixel count in Adobe Photoshop. This pixel count data corresponded to the area of contact. Greater area of contact with the handle is a desirable quality for design of an ergonomic handle [13]. However, not every case of greater hand-handle contact area should qualify as an indicator of user comfort. For e.g., in case of a convoluted, hand-hugging handle, the contact area with hand might be high, but the complex geometry might impede any adjustments to hand grip during work. But, as none of the six configurations considered in this study was a complex one, the authors concluded that hand-handle contact area could safely be used as a determining factor for comfort in this study. Hence, the most favorable handle shape was determined on combining the results from the subjective comfort preference exercise and the surface contact area data evaluation.

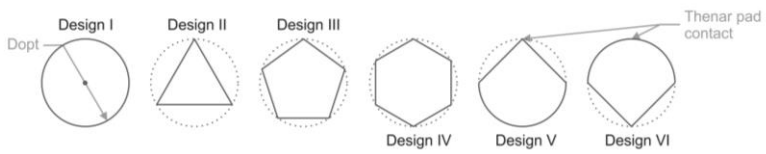

Fig. 2. Six different cross-sections used for comfort evaluation (Design I-VI) taking D_{opt} as the common peripheral circular dimension enveloping each shape

Fig. 3(a). 3D prototypes of tool handles corresponding to chosen five cross-sections: Design I-V)

Fig. 3(b) Hand grip orientations for Design V and VI of Fig. 2 (Left to right)

Results and Discussion

Table 2 present comparative results of the subjective analysis test for fitness in hand and overall comfort conducted using in house fabricated optimum diameter handle prototypes. As can be inferred from the table, nine as against two subjects rated the 35 mm diameter handle to be an excellent fit in comparison to the 41 mm diameter handle. Also, ten subjects as against one rated the 35 mm diameter handle to be overall comfortable in comparison to the 41 mm diameter handle. It is also evident that none of the two handles was rated less than neutral by the subjects. So, considering the optimal diameter selection for cylindrical cross-section, among the selected diameters, 35 mm diameter handle provided better fit and was also rated more comfortable.

Table 2. Comparative results of the subjective analysis test for fitness in hand and overall comfort for handles with diameter 35 mm and 41 mm

Handle diameter	Subjective response data					
	Rating Scale	5	4	3	2	1
35 mm / 41 mm	Fitness in hand	Fits excellent	Fits good	Cannot say / Neutral	Fits bad	Fits extremely bad
	No. of subjects	**9** / 2	**7** / 3	**1** / 11	**0** / 0	**0** / 0
	Overall comfort	Extremely comfortable	Moderately comfortable	Cannot say/neutral	Moderately uncomfortable	Extremely uncomfortable
	No. of subjects	**10** / 1	**6** / 15	**1** / 1	**0** / 0	**0** / 0

Table 3. Comparative results of the analysis using subjective comfort evaluation and pixel count feature to calculate hand-handle surface contact area

Handle designs	Ratings by selected 17 candidates					Score (max 85) A	Hand- handle contact area for 17 subjects (in pixels) B	Normalized total score (Rank)
	Extremely uncomfortable (1)	Moderately uncomfortable (2)	Cannot say (3)	Moderately comfortable (4)	Extremely comfortable (5)			
Design I	0	0	1	15	1	68	182,879	93.59 (3)
Design II	3	12	0	1	1	36	120,924	56.14 (6)
Design III	0	2	10	5	0	54	161,126	78.67 (5)
Design IV	0	0	3	12	2	67	166,781	88.55 (4)
Design V	0	0	2	9	6	72	174,855	93.96 (2)
Design VI	0	0	0	7	10	78	178,445	98.79 (1)

Table 3 shows the combined and comparative result of comfort evaluation using our extensive subjective study and image mapping based objective assessment to measure maximum hand-handle surface contact. Equal weights for comfort score (A) and hand-handle surface contact area (B) were assigned to calculate normalized total score (NTS) for each of the handle designs. The mathematical relation for NTS is expressed as,

$$NTS_i = \left(\left(W_1 . \frac{A_i}{A_{\max}} \right) + \left(W_2 . \frac{B_i}{B_{\max}} \right) \right) .100 \quad (3)$$

where i is an index for handle design; W_1 and W_2 (0.5 each) represent the weights assigned to each of the factors A and B respectively.

Design VI, defined by a contour shape combination of semicircle and triangle, and gripped with the circular section towards the fingers was rated the overall highest by the participants. However, maximum area of hand surface contact with the handle was observed for design I, the circular contour. Triangular handle (design II) performed the poorest, both in terms of total subjective comfort and the hand-handle contact area.

2.2 Evaluation Study II: Anatomically Shaped Knife Handle

27 candidates, all students from undergraduate and post graduate programs having soft hands with no cuts were chosen for this study. This sample was composed of 11 female subjects in the age range of 21-22 years (median 22; mean 21.5; SD 0.49) and 16 male subjects in the age range of 20-23 years (median 22; mean 21.8; SD 0.85). Each subject has been given an informed consent for their participation prior to the study.

Prototype Development

Twenty different families were asked to send images/videos of preferred kitchen knife used at their homes. From this information, the most common hand grip posture was identified for kitchen paring knife operation (Fig. 4(a)). This posture was used to create impression on a clay handle stock mounted on the handle of a reference paring knife. A 35 mm diameter stock of clay was used for impression. This was found to be the preferred dimension during evaluation study I. The representative candidate from a fairly homogeneous group of twenty seven participants was asked to hold the clay handle in the most common knife holding position identified to create impression of the hand grip. Before releasing the clay stock, the candidate was asked to wiggle each finger a little bit in order to create some extra room around each finger.

The impression on the clay was scanned using 7-axis based Faro Arm laser scanner. The captured digitized point cloud data was converted to a surface mesh. The mesh was repaired and smoothened in CATIA V6 environment. The surface generated in CATIA is exported in the stereolithography file format and transferred to a RP system for prototype development. An ABS (Acrylonitrile butadiene styrene) based anatomical shaped handle prototype was fabricated using Stratasys Dimension 1200es RP system. Fig. 4(b) shows two different views of the anatomically shaped handles developed using clay and corresponding digitized point cloud data and an ABS based 3D prototype via RP system fitted with a blade respectively. This handle was fitted with a blade and used for a comparative evaluation with five other designs of knives.

Fig. 4(a). Most common hand grip posture when using kitchen paring knife

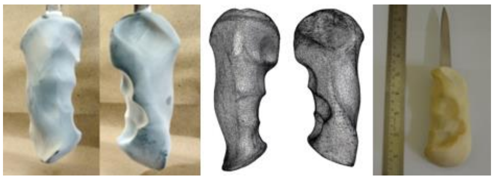

Fig. 4(b). Two different views of anatomically shaped handles over clay, corresponding digitized point cloud data and an ABS based 3D prototype with fitted blade (Left to right)

Comfort Assessment

Fig. 5(a) shows the six different knife handles used for comfort evaluation. A comfort questionnaire for hand tools (CQH) with seventeen different questions (Table 4) was used for assessing these six knives. The questionnaire was synthesized from existing research in the field of hand tool comfort [1,2]. Each of the twenty seven subjects were asked to first rate each comfort descriptors in terms of its relative importance to the subject in buying decision. This exercise provides the information on the relative weights of the seventeen factors of CQH among the selected group of candidates. Then, the subjects were asked to perform a simulated cutting task. The candidates used each of the six knives to cut ten slices of a standard block of clay (Fig. 5(b)). They were asked to rate (on a rating scale of 1-7; 1 = poorest, 7 = best) each of the six knives based on the factors listed in the CQH.

Fig. 5(a). Six knife handles used for the evaluation (Knife 1-6,

Fig. 5(b). Experimental task, a soft clay block (left) and a candidate cutting the clay block using knife having anatomically shaped handle

Results and Discussion

Based on the aggregated scores from the evaluation (Table 4), it was found that the three factors considered most important in buying decision of the users are ‘safe to use’, ‘functional’ and ‘ease to use’. All these factors roughly correspond to core functionality associated with knife use. Safety assumed highest priority in terms of buying decisions of participants. It was also observed that the anatomically designed handle (knife 6) was rated highest in terms of safety. This may be due to the steadiness and stability this knife offers as a result of anatomical features available on the handle. Another reason might be the hand-handle contact area being higher in case of anatomically designed handles. The three factors considered relatively least important in the buying decisions for the subjects in the order of decreasing priority were 'styling', 'has a nice feeling' and 'looks professional'. These factors roughly correspond to user's emotional experience with the handle. Knife 1 was perceived the best on the factor of 'looks professional' (factor with least importance rating/weight of 6.2 in Table 4), and so it is greatly disadvantaged in the overall performance score.

In terms of user evaluation of the six knives with corresponding knife handles – the newly designed anatomically shaped handle based knife was rated best in ten of the seventeen different factors from the CQH. These 10 factors are 'functionality', 'ease of use', 'high task performance', 'do not cause pain', 'low hand grip force supply', 'does not slip', 'does not cause sweat', 'comfortable working position', 'safe to use' and 'styling'.

Table 4. Overall performance score considering ratings of the relative importance in buying decisions and subjective evaluation performances of different knife handles against various comfort descriptors (* IS = Individual actual score of knife handle; ** WS = Weighted score of knife handle (IS multiplied by rating of each factor))

Comfort descriptors	Importance rating(1-10) 1 = least important 10 = most important (Averaged for 27 subjects)	Knife performance											
		Knife 1		Knife 2		Knife 3		Knife 4		Knife 5		Knife 6 (Ergonomic)	
		IS*	WS**	IS*	WS**	IS*	WS**	IS*	WS**	IS*	WS**	IS*	WS**
Is functional?	9.0	5.96	35.76	5.75	34.49	5.48	32.85	5.13	30.76	4.11	24.64	5.99	35.91
Is easy to use?	8.6	4.53	27.15	5.22	31.31	5.6	33.61	4.73	28.37	4.06	24.35	5.61	33.68
Has high task performance	8.5	5.23	31.37	5.05	30.31	4.78	28.69	4.64	27.84	3.95	23.67	5.41	32.43
Has good force transmission	7.7	4.66	27.98	3.96	23.74	4.1	24.62	4.06	24.33	2.81	16.85	4.25	25.51
Has good friction between hand and handle	8.0	4.87	29.24	4.63	27.77	5.25	31.51	4.88	29.30	3.85	23.08	5.06	30.38
Does not cause peak pressure	7.6	4.25	25.48	3.97	23.84	4.25	25.48	4.29	25.74	3.18	19.10	4.27	25.61
Does not cause pain	8.6	4.96	29.77	5.01	30.06	5.07	30.42	4.46	26.77	4.03	24.19	5.49	32.92
Low grip force requirement	7.5	4.35	26.11	4.47	26.80	4.1	24.62	4.08	24.49	4	23.99	4.79	28.73
Does not slip	8.2	4.34	26.03	4.77	28.63	4.44	26.64	4.97	29.79	3.52	21.09	5.4	32.40
Does not cause sweat	7.3	3.69	22.11	3.99	23.93	4.05	24.3	4.07	24.42	3.87	23.20	4.74	28.43
Light weight	7.8	2.91	17.48	4.92	29.52	4.59	27.51	4.91	29.46	5.73	34.38	4.46	26.74
Offers comfortable holding posture	8.1	4.05	24.31	4.44	26.62	4.86	29.13	4.49	26.96	3.96	23.77	5.47	32.80
Has a nice feeling	6.7	3.49	20.93	4	24.00	4.24	25.46	3.6	21.60	2.92	17.53	3.91	23.45

Looks professional	6.2	4	23.99	3.69	22.14	3.24	19.46	2.69	16.11	2.39	14.36	3.67	21.99
Good finishing	7.4	4.63	27.77	5.09	30.56	4.28	25.66	3.68	22.07	3.06	18.35	4.39	26.35
Safe to use	9.3	5.35	32.12	5.73	34.37	5.12	30.73	5.16	30.96	4.61	27.63	6.03	36.15
Good styling	6.9	4.32	25.91	4.53	27.17	4.05	24.31	3.63	21.80	2.85	17.12	4.59	27.51
Overall performance		75.59	453.51	79.22	475.26	77.5	465	73.47	440.77	62.9	377.3	83.53	500.99

3 Conclusion and Future Work

In terms of the comparison between the two studies, the handles involved in the first study (six configurations) can be labelled as purely geometric forms. The handles in the second study (knives) can be broadly termed as organic in form. And hence, these two sets could be seen as complementary to each other. However, different sets of methodologies were employed to evaluate these two sets of handles, and therefore the authors believe that any generalizations that could be drawn from the two sets of results should be verified through a common set of methodological framework before any direct application. There are certain generalizations that could be drawn as a consequence of the results from this work. First, it can be safely claimed that greater hand-handle contact area is an important factor to design comfortable handles. Design I, V, VI in the first study (Table 3), and the anatomically designed handle in the second study (Table 4) illustrate this fact. Second, slimmer and sleeker designs, sometimes with sharp creases on the surface could lead to overall discomfort in general (Table 3), but such designs may value additions in terms of their lighter weight, professional looks, good force transmission, etc. (Table 4).

Two methodologies suggested for the design of tool handles have immense potential for designers to conceptualize and assess tool handle geometries. From the first study, it can be inferred that in terms of surface area, circular cross section geometry offered the greatest hand-handle contact. However, in terms of overall preference for handle cross section, creased features on handle surface affect handle preference. Therefore, a combination of circular cross section with creased profile offers a good geometrical design solution to the handle design problem.

The anatomically shaped handle developed for kitchen knife handle is also significantly bulkier than the other handles, and future work could address this issue. Specific re-work could be performed upon the surface so that the excessive and non-functional surface features may be removed, and some other functional and usable features may be included. Only a limited number of cross-sectional shapes were evaluated in this study. However, other geometrical primitives and their combinations could be evaluated in future work. Also, the handles could not be evaluated for specific tools, or for specific tasks in this body of work, but the same could be taken up in a later study. In terms of structure, investigations inquiring optimization in terms of hollow / honeycomb / other light weight ergonomic handles could also be undertaken. Focus on tactile and force exertion criteria during actual use of different shaped handles can add value in the future work.

References

1. Taylor, P., Kuijt-evers, L.F.M., Twisk, J., Groenesteijn, L., Looze, M.P.De.: Identifying predictors of comfort and discomfort in using hand tools. Ergonomics 48, 37–41 (2007)
2. Kuijt-evers, L.F.M., Vink, P., Looze, M.P.De.: Comfort predictors for different kinds of hand tools: Differences and similarities. Int. J. Ind. Ergon. 37, 73–84 (2007)
3. Vergara, M., Mondragón, S., Sancho-bru, J.L., Company, P., Agost, M.: Perception of products by progressive multisensory integration. A study on hammers. Appl. Ergon. 42, 652–664 (2011)
4. Lipscomb, H.J., Dement, J.M., Loomis, D.P., Silverstein, B., Kalat, J.: Surveillance of work-related musculoskeletal injuries among union carpenters. Am. J. Ind. Med. 32, 629–640 (1997)
5. Paivinen, M., Heinimaa, T.: The usability and ergonomics of axes. Appl. Ergo. 40, 790–796 (2009)
6. Young-Corbett, D.E., Nussbaum, M.A., Winchester, W.W.: Usability evaluation of drywall sanding tools. Int. J. Ind. Ergon. 40, 112–118 (2010)
7. Herring, S.R., Castillejos, P., Hallbeck, M.S.: User-centered evaluation of handle shape and size and input controls for a neutron detector. Appl. Ergon. 42, 919–928 (2011)
8. Huang, L., Li, M., He, C.: Innovation Design of Hand Tools Based on User Experience. Appl. Mech. Mater. 47, 1295–1299 (2011)
9. Eijk, D. Kuijk, J,, Hoolhorst, F., Kim, C., Harkema, C., Dorrestijn, S.: Design for Usability; practice-oriented research for user-centered product design. Work. 41, 1008–1015 (2012)
10. Mugisa, D.J., Katimbo, A., Sempiira, J.E., Kisaalita, W.S.: Anthropometric characteristics of female smallholder farmers of Uganda–Toward design of labor-saving tools. Appl. Ergon. 54, 177-185 (2016)
11. Meena, M.L., Dangayach, G.S.: An ergonomic approach to design hand tool for screen textile printing. Int. J. Recent advances in Mech. Eng. 4, 59-67 (2015)
12. Sun, C.Y., Wang, S.Y., Wang, B.C.: Ergonomic Design and Evaluation of Laparoscopic Instrument Handle Based on Anthropometry. In: Adv. Mat. Res. 950, pp. 109-113. Trans Tech Publications (2014)
13. Harih, G., Dol, B.: Comparison of subjective comfort ratings between anatomically shaped and cylindrical handles. Appl. Ergon. 45, 943–954 (2014)
14. Leamon, T.B., Dempsey, P.G.: The unusual congruence between subjective evaluations and losses associated with inadequate hand tool design. Int. J. Ind. Ergon. 16, 23–28 (1995)
15. Lin, J., McGorry, R.W.: Predicting subjective perceptions of powered tool torque reactions. Appl. Ergon. 40, 47–55 (2009)
16. Bisht, D.S., Khan M.R.: Ergonomic assessment methods for the evaluation of hand held industrial products: a review. In: Proceedings of the World Congress on Engineering 2013 Vol I, pp. 559-564. Online (2013)
17. Strasser, H., Wang, B., Hoffmann, A.: Electromyographic and subjective evaluation of hand tools: The example of masons' trowels. Int. J. Ergon. 18, 91–106 (1996)
18. Aldien, Y., Welcome, D., Rakheja, S., Dong, R., Boileau, P.: Contact pressure distribution at hand – handle interface: role of hand forces and handle size. Int. J. Ind. Ergon. 35, 267–286 (2005)
19. Kuijt-evers, L.F.M., Bosch, T., Huysmans, M.A., Looze, M.P. De., Vink, P.: Association between objective and subjective measurements of comfort and discomfort in hand tools. Appl. Ergon. 38, 643–654 (2007)

20. Groenesteijn, L., Eikhout, S.M., Vink, P.: One set of pliers for more tasks in installation work: the effects on (dis) comfort and productivity. Appl. Ergon. 35, 485–492 (2004)
21. Garneau, C.J., Matthew, B.P.: Optimization of product dimensions for discrete sizing applied to a tool handle. Int. J. of Ind. Ergon. 42, 56-64 (2012)
22. Seo, N.J., Armstrong, T.J.: Investigation of grip force, normal force, contact area, hand size, and handle size for cylindrical handles. Hum. Factors 5, 734–744 (2008)