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Meaningful Prediction Parameters for Evaluating the Suitability of Power Tools for Usage

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Abstract

During the usage of power tools, user and power tool are interacting strongly with each other, which is why the working result depends heavily on the usability of a power tool depending on the application (Suitability of Usage (SoU)). The optimization of power tools, in terms of the user-centered design, therefore aims at an increase of the SoU. So far, the acquisition of the SoU is done within broad application tests, with several users and different application situations. Hereby, problems occur because it is often difficult to find an adequate mix of professional trained participants, which are able to evaluate the SoU objectively. To investigate the differences between professional power tool users and trained non-professional users, a study has been performed. In this study, 20 professional and 19 non-professional users tested power tools (cordless screwdrivers and impact wrenches, three different manufacturer each) and evaluated the handles of these systems according to fourteen test items, divided into an observation and a usage phase. By the use of statistical variance analysis, the captured data has been analyzed to investigate the influence on the evaluation through the usage experience of the users. Results indicates a strong influence within the evaluation categories where evaluations are done which rely on long term experiences, like the evaluation of the distributed force on the fingers. To produce further increase in efficiency and objectivity, a categorical regression by the use of Lasso models has been performed to identify the most meaningful influencing predictors for the SoU level. The investigation is carried out using the example of the evaluation of discomfort on the handle. Results indicates that the most meaningful predictor for the evaluation of the handle is the circumference of the handle at the position of the middle finger.

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Keywords: Power Tools; Suitability of Usage, Usability, Professional / Non-professional Users, User-Centered Design

1. Introduction

No matter which innovative, modern product is developed, the user centered design approach becomes increasingly more important for the product development [1]. Special focus is set on systems that interact strongly with the user, which directly affects the efficiency and effectiveness of the product [2] Power Tools are handheld devices (battery drill driver, hammer drill, circular saw, etc.) which are used by professional users to perform (partly) long-lasting applications in their daily work. During the usage, power tool and operator are connected by a constant flow of information and power [2]. This leads on the one hand to a working result, that depends on the skills of the operator and on the other hand, to an impression of the power tool to the operator, which is called application quality [3]. This application quality hereby can be separated into the objective part of the technical functionality (Does the power tool do what it was made for?) and within the subjective rated impression (Does the power tool fit to my needs?) [4, 5], which is called the Suitability of Usage (SoU) [3]. Based on the E. N. ISO 9241-11 [6] the Suitability of Usage is defined as the subjectively perceived extent to which a technical system can be used effectively, efficiently and satisfactorily by a defined user in its relevant applications. Hereby, the purpose is that a high level of the SoU leads to a high user acceptance of the product [7]. As stated by Aptel et al. [8] and Berekoven, et al. [9], an objective measurement of the subjective product impression is always influenced by several side effects coming

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out of the environment (e.g. workplace, equipment, use-case, scent), the operator (e.g. body shape, skill, experiences) and the system itself (e.g. vibration, haptic, noise, usability). Therefore, an objective detection of the SoU has to be done under observable, reproducible conditions, in which the side effects can be controlled [10]. This can be achieved through separating the long lasting, complex usage patterns into use-cases of single applications or a set of applications [11]. In dependence to the development goal, use-cases can be rated according to their relevance and transferred into test-cases [12]. By performing these test-cases under constant, reproducible conditions, with several test subjects (often non-professional due to better availability) using the specimen as well as additional reference systems [13, 14], the SoU can be measured by the use of questionnaires or interviews [3]. Hereby, the SoU has to be separated into several main clusters like ergonomics or performance and further subcategories (e.g. handle design, vibration, weight) [3], which enables the designer to conclude on potential improvement. As it is obvious, this approach is very time and cost intensive [15, p. 118], which is why it is an objective to identify new measurement methods for gathering and predict the SoU with higher efficiency [16, 17]. For this purpose, Nagamachi developed the approach of Kansei affective engineering. Kansei affective engineering is defined as the technology of translating the consumer's emotional product experience into the product design domain [18]. The approach enables product designers to analyze their system under consideration of the emotional influences from the user and to identify the design elements, which are relevant to these specific emotions [19]. Using Kansei Engineering in several product development projects proved high usability for improving whole systems like refrigerators, camera systems [13] or even the trigger of power tools [20]. Hereby, the dependent variables are chosen from the product design parameter itself without considering anthropometrical parameters of the users. While this might play a minor role, when evaluating systems with less interaction with the user or single part systems (e.g. trigger), it becomes increasingly important when evaluating system, which are in direct exchange of information and power with the operator. Lin et al investigated power tool users to predict on the subjective perception according to torque reactions of pneumatic nut runners [21]. Lin found out that the grip force, before and during the torque reaction phase, does have a significant influence on the subjective rating of the power tools. Therefore, from the investigation it can be assumed, that in the area of the main user interface anthropometrical parameters have to be considered when evaluating systems with strong user interaction [22–24]. This thesis leads to two main issues:

- Is there a significant difference between the evaluations of professional power tool users in comparison to trained non-professionals?
- Which are the most meaningful predictor parameters within a prediction model for the discomfort evaluation of the power tool handle?

Hence, the aim of this contribution is to analyze and predict the user's evaluation of the SoU of the handle on the example of battery-operated screwdrivers and impact wrenches under consideration of several anthropometrical hand and handle design parameters. For this purpose, an experimental setup has been established in which thirty-nine subjects performed several use-cases with the power tools and rated different aspects of the handle according to the SoU level. Professional and trained non-professional users have executed the experiment. Through variance analysis the influence of the experience level has been analyzed. To produce further increase in efficiently and objectivity the evaluation data has been analyzed with the objective to identify the most meaningful predictor variables for the discomfort evaluation of the power tool's handle. For this purpose categorical regression by the use of the Lasso model has been performed.

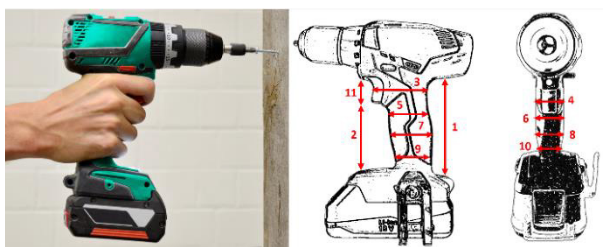
2. Method and Materials

2.1. Apparatus

To carry out the experiment, cordless screwdrivers (in the following simplified as screwdriver) and impact wrenches, each from three different manufacturers, were used. *18V* battery-operated screwdrivers from Bosch Professionals (B_S), Hilti (H_S) and Makita (M_S) were chosen. All systems are made for professional users, which means that they are designed for high demands on customer satisfaction.

Table 1. Handle design parameters for screwdrivers and impact wrenches

Design parameter handle [mm]	Screwdriver			Impact wrenches		
	B_S	H_S	M_S	M_I	D_I	H_I
height (at the back) (1)	95	102	95	95	93	100
height (in the front) (2)	73	75	75	66	71	72
circumference index finger (3)	151	147	156	158	172	149
length at index finger (3)	60	58	62	63	69	58
width at index finger (4)	34	33	34	34	35	31
circumference middle finger (5)	123	132	128	131	134	138
length at middle finger (5)	45	46	48	47	47	49
width at middle finger (6)	34	36	34	33	35	36
circumference ring finger (7)	123	125	128	127	134	134
length at ring finger (7)	45	44	48	46	49	48
width at ring finger (8)	35	35	34	33	35	35
circumference little finger (9)	113	113	116	119	125	119
length at little finger (9)	37	39	42	40	44	42
width at little finger (10)	34	32	30	33	35	31
Trigger length (11)	25	24	23	24	23	27
Trigger path	8	8	6	8	9	8



Screwdrivers are mainly used for screwing (*Ø5x50mm – Ø8x100mm*) into wood in horizontal and up-/downwards position and drilling flat steel (up to Ø *12mm*) in downwards position as well as drilling in wood (up to Ø 28mm) in horizontal and downwards position. All three screwdriver do have a pistol handle with an additional attached battery pack on the bottom. Table 1 presents the design parameter of the handle of the three screwdrivers. The selected impact wrenches are from the three manufacturers Milwaukee (M_I), Dewalt (D_I) and Hilti (H_I). All systems are made for professional users with high demands on the application quality. Heavy impact wrenches are manly used for bolting applications on construction sides (steel constructions, bridge building) [25]. The impact wrench driver from Milwaukee offers a maximum torque moment of *1.016 Nm*. The three power tools are powered by a *18V* battery pack which can be mounted at the bottom of a pistol handle. Table 1 (right side) presents the handle design parameter, which were collected from the impact wrenches.

2.2. Participants

Thirty-seven males and two women participated in the experiment. They were all free of health restrictions or muscular disorders. Their mean age was 27.3 years (min. = 21, max. = 56 / s.d. = 7.9 years), 38 of the participants were right handed. The subjective perceived experience level in the usage of power tools was ranked by the participants on a 5 point Likert scale (none – little – middle – much – very much) on a mean level of 2.86 (s.d. = 1.13). Twenty participants were professional test users, which do use screwdrivers (mean exp. = 3.3 / s.d. = 0.82) and impact wrenches (mean exp. = 2.56 / s.d. = 0.88) as part of their professional testing activities. The other nineteen of the participants do use power tools in general more than once a week outside of a professional activity but within their evaluation activities within the IPEK – Power Tool test center (screwdriver: mean exp. = 3.7 / s.d. = 0.94 ; impact wrenches: mean exp. = 1.63 / s.d. = 0.74). Before the experiment was started, there was an additional instruction for the non-professional users in the professional use of screwdrivers and impact wrenches. Based on Lindqvist et. al the design of a power tool handle depends significantly on the diameter and the length of the handle [25]. Therefore, the anthropometric hand data of the participants, which are in direct connection to these requirements, has been measured according to DIN33402-2 [26].

Table 2. Frequency distribution of anthropometrical hand data of the participants

	thumb length		hand width		hand length	
Percentile	*Freq.*	*%.*	*Freq.*	*%*	*Freq.*	*%*
≤ 5	3	7,7	2	5,1	2	5,1
< 5 ≤ 50	17	43,6	7	20,5	11	28,2
> 50 ≤ 95	16	41,0	25	61,5	23	59,0
> 95	3	7,7	5	12,8	3	7,7
Total	39	100,0	39	100,0	39	100,0

The measured data were separated into their percentiles according to DIN33402-2. The results can be seen in Table 2.

2.3. Experimental design and procedures

The experiment was divided within a part without active application of the power tool and part with active performing applications. In the pre-use phase each participant was provided with three power tools (screwdrivers or impact wrenches) and a questionnaire. By the questionnaire, six questions as presented in Table 3 were asked.

Table 3. Variance evaluation of professional and non-professional users

Q1	The handle length (from top to bottom is…	*5 pt. SD*
Q2	The diameter of the handle for the finger each is…	*5 pt. SD*
Q3	The softness of the 2C-Component is…	*5 pt. SD*
Q4	The reachability of the ideal hand position is…	*5 pt. SD*
Q5	The trigger position is…	*5 pt. SD*
Q6	The geometry of the trigger is…	*5 pt. SD*

For the rating, a 5 point semantic differential scale was used from *much too small – much too tall*. The general setup for the pre-use phase for the screwdrivers and the impact wrenches is shown in Figure 1.

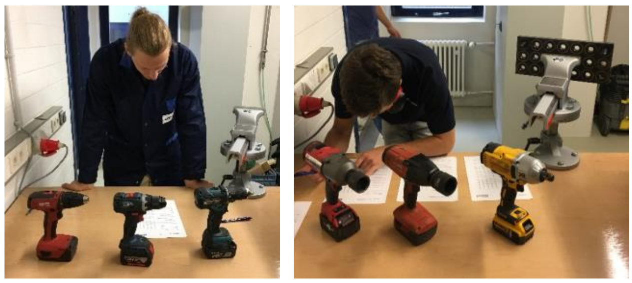


Fig. 1. Experimental setup for the pre-use phase at IPEK – Power-Tool Test center at KIT – Karlsruhe Institute of Technology

For the evaluation of the Suitability of Usage (SoU) level, each participant had to perform several test cases. Out of a use-case analysis different test-cases were defined which were introduced to the participants after the pre-use phase. For the 18V cordless screwdriver, there were five test-cases defined, which are considered as relevant for the experiment:

- 5 times screw in and unscrew of *Ø 6 x 80mm* wood screws into spruce cross frame *(80x100x1000mm*) in upright posture in the second gear stage.
- 5 times screw in and unscrew of *Ø 6 x 80mm* wood screws into spruce cross frame (*80x100x1000mm*) in bent down posture in the second gear stage.
- 5 times screw in and unscrew of *Ø 8 x 80mm* wood screws into spruce cross frame (*80x100x1000mm*) in upright posture in the first gear stage.
- 2 times drilling flat steel *t =5mm* (S235) with *Ø 6mm* HSS drill bit in second gear stage in bent down posture

Fig. 2. Performing of different test-cases for screwdrivers (left, middle) and impact wrenches (right) at IPEK – Power-Tool Test center

For the impact wrenches, there is only one test-case which is considered as relevant for the experiment:

- 15 times bolting (screw in and unscrew) of *M24* steel screw into a bolting plate in upright posture.

Each participant had to perform all the test-cases in the presented order. The professional user had to perform the experiment at their company within a separate test area. The trained non-professional users performed the experiment within the IPEK – Power-Tool Test center at KIT – Karlsruhe Institute of Technology. Care has been taken to ensure that in both experimental environments the presentation of the power tools and the setup of the test-cases have been presented in an equivalent manner. Figure 2 presents the different test-cases for the screwdrivers and the impact wrenches. After performing the test-cases each participant had to evaluate the handle of the power tools again by the use of a second questionnaire. In Table 4 the seven questions, which the participants evaluated on a 5-point semantic differential scale (SD), are presented. With an eighth question, the general discomfort of the handle was rated on a 7-point Likert scale (LS), which ranges from *no discomfort* to *very severe discomfort*.

Table 4. Questions to the participants after the usage of the power tools

Q7	The pressure distribution on the palm is…	*5 pt. SD*
Q8	The pressure distribution on the finger is…	*5 pt. SD*
Q9	The slip resistance of the handle is…	*5 pt. SD*
Q10	The handling of the power tool is…	*5 pt. SD*
Q11	The trigger path is…	*5 pt. SD*
Q12	The trigger force is…	*5 pt. SD*
Q13	The application of the required screwing force is…	*5 pt. SD*
Q14	How high is the discomfort during the usage of the power tool in general?	*7 pt. LS*

2.4. Data analysis

All statistical analyses were performed using SPSS v. 24.

2.4.1. Influences through the experience level

For the distinct evaluation of the influence through the experience level, the two groups of professional (p-user) and non-professional users (np-user) has been analyzed. In a first step the evaluation is done with all question. To analyze the variances on the mean value in evaluation, variance analysis (ANOVA) is executed. Through this, questions in which the variances in rating of the handles depends significantly on the experience level can be separated. Furthermore, the separated questions can be analyzed by the Pearson Chi Square test to evaluate whether professionals and non-professionals do rate the same evaluation levels. Eventually, the difference of the mean evaluation between the p-user and the np-user can be an examined by the Kruskal-Wallis test.

2.4.2. Evaluation of influencing variables on the SoU rating

As presented in section *2.1* and *2.2* the dimensions of the handles of the power tools and the anthropometric characteristics differ according to their dimensions. By the use of regression analysis, using the Lasso method, the variables from the handle and the anthropometric user data can be analyzed according to their influence on evaluation. The analysis is carried out on the item *Q14*. Analyzing the Lasso Paths shrinking model, the most meaningful prediction parameters for the SoU level according to the discomfort when using a power tool handle can be found.

3. Results

3.1. Difference between the evaluations of professionals in comparison to trained non-professionals

Variance analysis indicated differences between the professional and non-professional users within the five evaluations *Q1*, $Q2_{index\_finger}$, *Q7*, *Q8* and *Q13* ($p<0.05$). Table 5 presents the evaluation results of the variance analysis.

Table 5. Variance evaluation of professional and non-professional users

ANOVA			
Item	F	p-value	Partial Eta-Squared
Q1	8.644	**.004**	.070
$Q2_{index\_finger}$	4.155	**.044**	.035
$Q2_{middle\_finger}$	.630	.429	-
$Q2_{ring\_finger}$	.156	.694	-
$Q2_{little\_finger}$	2.454	.120	-
Q3	.145	.704	-
Q4	1.005	.318	-
Q5	.208	.649	-
Q6	.399	.529	-
Q7	5.256	**.023**	.044
Q8	11.242	**.001**	.089
Q9	.018	.893	-
Q10	1.954	.165	-
Q11	2.112	.149	-
Q12	.211	.647	-
Q13	8.145	**.005**	.066
Q14	3.319	.070	-

By the use of a frequency analysis of the evaluation of the p-users, the expected categories has been defined for the Chi-Square test to analyze the distribution of evaluation. For all presented evaluations except $Q2_{index\_finger}$ *(p=0.065)*, the thesis that p- and np-users do rate the same evaluation levels can be rejected (*p=0.000*). Furthermore, the Kruskal-Wallis test was calculated to analyze the rank distribution. Significance could be detected (*p<0.041)* for all evaluations, which confirms the differences in the mean evaluation between the professionals and the non-professional users. For the other twelve items, significant differences in evaluations due to the experience level cannot be confirmed.

3.2. Most meaningful predictors for the evaluation of the SoU of power tool handles

Evaluation results of the categorical regression analysis can be seen in Figure 3 in the Lasso shrinking Paths of the final model. The Lasso Paths shows the order in which the less influencing variables shrink to zero. The optimal model for predicting *Q14* can be implemented by five variables (*R-Square = 0.256, Std. Error = 0.117*). Meaningful predictors of the handle sizes are the *circumference_middle_finger (β = 0.339)* and the parameter *length_little_finger (β = 0.008)*. All of the anthropometric hand sizes, *Percentile_thumb_length (β = -0.089)*, *Percentile_hand_length (β = -0.136)* and the parameter *Percentile_hand_width (β = 0.100)*, are predicted as meaningful.

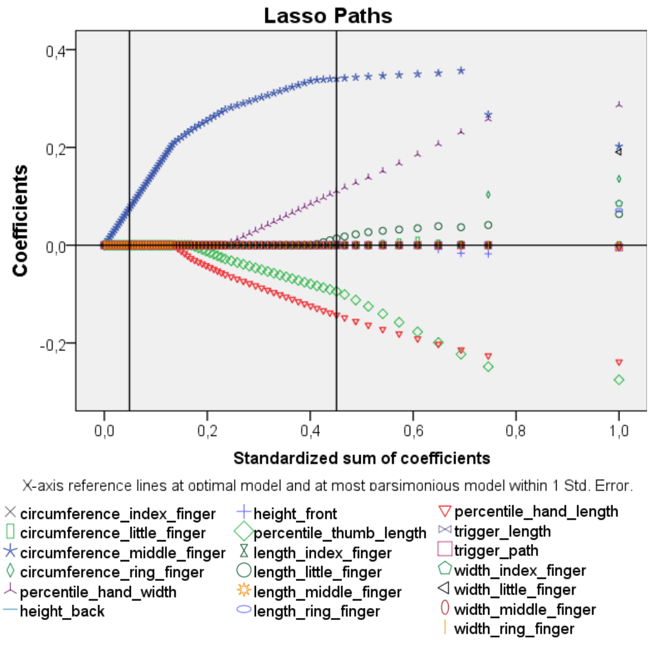


Fig. 3 Lasso shrinking path model of categorical regression

4. Discussion

Results indicates that there is a significant influence through the level of experience on the evaluation of power tools. Hereby, it seems that especially items, which do address issues, which rely on long term experience, like the evaluation of the distribution of pressure on the palm / finger during the screwing (*Q7* / *Q8*) or the required screwing force (*Q13*), produced differences in evaluation. Considering the partial Eta-Squared value, the influence is with 4.4 – 8.9% not that high as it was expected from the authors. Hereby it would be interesting to investigate other power tools, where applications have to be done by the user, which are more complex. Furthermore, evaluation results indicates a significant influence of the evaluation according to the handle length (*Q1, Partial Eta-Squared: 7%*) and the circumference of the handle at the index finger ($Q2_{index\_finger}$*, Partial Eta-Squared: 3.5%*). During our investigation, we could observe that there is often an obvious difference in holding the power tool between the professionals und the non-professional users, which might influence the evaluation. Therefore, this finding should be considered when implementing training setups for non-professional users in further studies. On the other hand, items, which rely more on haptic values like the softness of the grip *(Q3)* or the slip resistance *(Q9)*, can be evaluated equally from professional and non-professional users. The same applies for items, which focus on a more general evaluation like the reachability of the optimal hand position *(Q4)*, the trigger geometry/position (*Q5/Q6)*, the handling of the tool *(Q10)* or the general discomfort of the handle *(Q14)*. Results indicates, that through the training of non-professional users in the usage of power tools within the relevant use-cases, general evaluations can be evaluated in an equivalent manner to professional users. To use non-professional users for the evaluation of power tool specific items, a general instruction in the usage is not sufficient. Therefore, further experiments should focus on the implementation of new training methods, which enables non-professional users to rate power tool specific evaluation items. Although, due to the problem of multiple comparisons, these experiments should explicitly focus on items, which are relevant for this investigation to prove significance even under consideration of Bonferroni correction. Through this, a reliable, objective rating of the Suitability of Usage can be done under constant, observable conditions.

Within the scope of the implementation of the prediction model, the influence through the anthropometric user characteristics have been analyzed. As already stated by several researches [23, 24] it can be shown that there is a significant correlation between the evaluation of the power tool handle and the user's hand sizes. Depending on the evaluation item, this influence differs in its intensity. Significant correlation (partly only for professional or non-professional users) can be found on $Q2_{ring\_finger}$, *Q11* (all participants), *Q3, Q8* and *Q13* (np-users) *and* $Q2_{index\_finger}$ (p-users). Strongest correlation was between item $Q2_{index\_finger}$ and *Percentile_thumb_length* (*Pearson corr. = -0.357, p = 0.005*) respectively with *Percentile_hand_length* (*Pearson corr. = -0.345, p = 0.007*). Through the Lasso model evaluation, several prediction parameters, which significantly influence the evaluation of the handle, can be found. The circumference of the handle at the position of the middle finger (circumference_middle_finger) was identified as the most meaningful predictor *(β = 0.339)*. This fits very good to the findings from Sancho-Bru et al. who found out, that the greatest contributor to grasp is the middle finger when using power tools [23]. Under this consideration, it seems adequate that the circumference of the handle under the finger with the highest grasping forces also influences the subjective impression of the Suitability of Usage the most. As already seen within the correlation analysis, categorical regression supports the assumption, that anthropometric characteristics of the users hand sizes should be considered as meaningful parameters for the evaluation of power tool handles, too.

5. Conclusion

Based on the study carried out, the following findings were obtained:

- The professional experience in the use of power tools plays an important role in the evaluation of the Suitability of Usage, especially when very specific questions are asked.
- A general training to the use of power tools is not sufficient for an objective assessment of the usability of power tool specific test tasks.
- Training approaches should focus on the imparting of assessment criteria, which are normally learned only through many years of experience.
- The evaluation of the Suitability of Usage depends significantly on the anthropometric hand sizes of the users.
- The most meaningful prediction parameter on the evaluation of the subjective discomfort during the usage of a cordless screwdriver or impact wrench is the circumference of the handle at the height of the middle finger.

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