On relating subjective and objective characteristics of push-button switches

Frank Rösler, Frank Schüttler, and Günther Battenberg

Keywords: push-button switches, haptics, scaling, semantic differential, consumer behavior

Zusammenfassung

In zwei Experimenten wurde der Zusammenhang zwischen objektiven Merkmalen von Drucktastern und subjektiven Empfindungen bei deren Betätigung untersucht. In Experiment I wurden via Paarvergleich und MDS multidimensionale Präferenzskalen für 10 kommerzielle Drucktaster bestimmt. Die varianzstärkste Dimension korrelierte bedeutsam mit Kraftänderungen der Taster. In Experiment II wurden 12 weitere Taster mit der Methode der kontrollierten Assoziation (semantisches Differential) bewertet. Eine PCA mit Varimax Rotation lieferte 4 idealisierte Skalen der konnotativen Bewertungen. Diese sind durch die Pole „hart – weich", „raue – glatte Bewegung", „zuverlässig – unzuverlässig" und „modern – konventionell" charakterisiert. Jede Dimension korrelierte signifikant mit objektiven Merkmalen, die die Bewegungstrajektorie beschreiben. Die Studie zeigt, dass sich subjektive Empfindungen bei der Betätigung mechanischer Elemente zuverlässig erfassen und mit objektiven Merkmalen in Beziehung setzen lassen. Der Ansatz kann genutzt werden, um bei der Konstruktion von Kontrollelementen subjektive Handhabungseigenschaften zu berücksichtigen.

Abstract

We investigated relationships between objective and subjective characteristics of switch handling. In experiment I multidimensional preference scales were constructed by means of pair comparisons and scaling methods for 10 commercially available push button switches used in automobiles. Most variance of the preference judgments were captured by one scaling dimension related to an objective characteristic of load-change differences during the switch operation. In experiment II 12 distinct push button switches were evaluated by means of controlled associations (semantic differential). PCA-Varimax revealed four dimensions. These idealized scales reflect the connotative associations during switch actuations. The poles of the dimensions were "tough vs. soft", "rough vs. smooth", "unreliable vs. reliable", and "fancy vs. conventional". Each of the four evaluative, connotative dimensions correlated significantly with distinct objective criteria that describe the mechanical, dynamic features of the switch trajectories. The study demonstrates that highly subjective, internal feelings during operation of control elements can be reliably derived and related to objective measures. The approach could be of use for designing control elements that target for specific consumer groups.

Introduction

Mechanical and dynamic features of push-button or rotary selector switches indicate the necessary operation forces, force changes, movement displacements, and other characteristics (e.g. whether the movement trajectory is stepwise or continuous). Such physical features can be adjusted to optimize control elements in a specific ergonomic context. However, these objective parameters are not the only criteria that have to be taken into account. Another and increasingly important aspect is how control actions are subjectively evaluated. Control elements with equivalent functionality can, when designed differently, elicit highly distinct connotative evaluations, i.e. whether a control element has a sportive or a more conservative touch, whether it feels reliable or unreliable, or whether it has an aesthetic appeal or not, etc. The importance of such subjective evaluative features of control elements will increase with decreasing functional differences, i.e. a consumer decision for or against a product will depend more on such evaluative, connotative aspects if functional differences are minimal.

To date little is known how control elements in automobiles are subjectively experienced and evaluated. In particular, it is unknown whether objective criteria as load, displacement, audible feedback, etc. of a control element have predictive power for such more subjective features, as felt reliability, sportive touch, etc.. Since subjective, evaluative features are most likely determined by the feedback characteristics of a switch, it should be possible to find systematic relationships between objective physical-mechanical features and subjective evaluative features of a control element. Given such systematic relationships, it would be possible to design control elements that target for specific consumer groups.

In the present study we investigated with two sets of push-button switches whether such systematic relationships between objective and subjective characteristics of control elements can be established.

Experiment 1: One- and multidimensional scaling of push-button switches

In a first experiment, ten commercially available push-button switches were selected for a pair-wise comparison and scaling task. The results of the multidimensional scaling analysis were related to objective criteria of the switches derived from the load-displacement diagram. To this end, we calculated multiple regressions between objective characteristics (the predictors) and the subjective scale values (the criteria). In order to control for the effect of auditory feedback during switch actuations the scaling procedures were replicated in two independent groups, the participants of one group received normal auditory feedback when pushing a button, while those of the other wore headphones to prevent auditory feedback.

Methods

Thirty-six students (29 men) participated (mean age: 22.9 years, range: 19 – 46 years). They were allocated at random to the two conditions with and without auditory feedback. Ten commercially available push-button switches from automobile cockpits were inserted into a control panel such that only the surface of the button was visible and touchable Participants completed a full pair-wise comparison task and indicated which of two paired switches felt more acceptable (in German “angenehm”) when operated.

The physical features of the ten buttons were measured with a force measurement device ATI force/torque sensor FT-40-2 and the resulting force-travel diagrams were plotted (Fig. 1). From each diagram several displacement and force measures were taken and combined to second-order attributes that described force changes over displacements.

Results

We used the ALSCAL algorithm to estimate the number of dimensions and the respective coordinates from the dominance probabilities (s. Borg & Groenen, 1997). Number of dimensions was determined by the stress-criterion. This procedure provided two dimensions for the group *without* auditory feedback and three for the group *with* auditory feedback.

The first dimension estimated for each group correlate substantially (.92), i.e. they represent the same internal scale. The second dimension extracted in the group without auditory feedback and the third dimension extracted in the group with auditory feedback represent also highly similar internal scales (correlation -.60). The third scale in the group with auditory feedback reflect acoustic characteristics of switch operation.

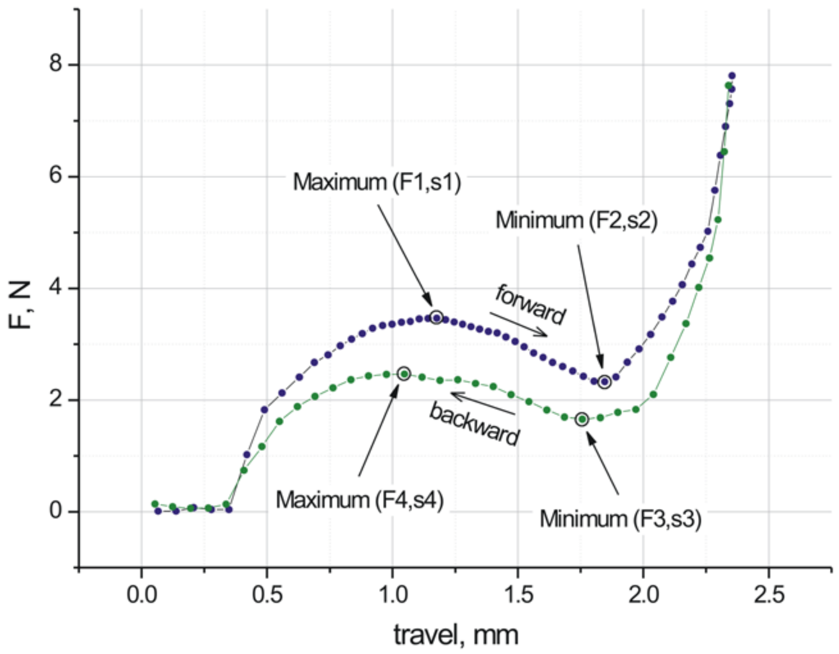

Fig. 1. Force displacement diagram of a push-button switch for the forward and backward movement trajectory

A multiple regression approach was used to estimate to what extent the objective measures derived from the force-displacement diagram can be used to predict the subjective scaling results. In both groups the scaling results of dimension 1 can be predicted significantly, in the group without auditory feedback with a multiple R of .932 ($F(2,7) = 22.97$, $p(F) < .0001$) and in the group with auditory feedback with $R = .908$ ($F(1,8) = 37.70$, $p(F) < .0001$). In both groups the most substantial predictor was the difference of the force-displacement change at the final part of the movement trajectory between forward and backward movement. The button operation is perceived as more preferable if this slope difference was large (significant beta-weights ($p < .01$) amount to -1.081 and -.908 in the groups without and with auditory feedback, respectively)

Experiment 2: Connotative dimensions of push button operations

Multidimensional scaling of pair-comparisons provides an elegant approach for estimating implicit judgment dimensions. However, if the number of items increases, the data acquisition method becomes quite cumbersome. An alternative approach to delineate implicit judgment dimensions is provided by controlled association methods as, e.g., the semantic differential (Hofstätter, 1955; Osgood, Suci, & Tannenbaum, 1957). As shown in previous studies the semantic differential is a useful tool to determine consumer preferences and the evaluation of technical systems (e.g. Karlsson, Aronsson, & Svensson, 2003; Mondragon, Company, & Vergara, 2005; Voss, Spangenberg, & Grohmann, 2003).

We used the semantic differential method to elicit controlled connotative associations by presenting the same list of adjectives while participants operated push button switches. The total set of associations was then reduced by the mathematical tool of PCA to a minimum number of idealized judgment scales that are sufficient to explain the variability in the associations. Previous work with the semantic differential has shown that usually 3 or 4 idealized dimensions are sufficient to capture the systematic variance of the data (Flade, 1978; Hofstätter, 1955; Osgood et al., 1957). The factor scores averaged across participants for each item describe how these control elements are implicitly evaluated. Moreover, objective physical measures of the switch characteristics can be used to predict these evaluations via multiple regression analysis.

Methods

Participants were 64 students of the Philipps-University of Marburg (34 women). Mean age was 21.4 years (range 21 – 31). Twelve push button switches were used. These had distinct a priori characteristics: Seven had a short movement path (S), three a long movement path (L), two had a double-switch characteristic (D) and one a double, but somewhat unusual switch characteristic. Force and displacement values were measured as described before. A representative sample of 25 adjective polarities was drawn from the set of adjectives of German (e.g. männlich – weiblich (male – female), stark – schwach (strong – weak), etc). The selection was based on previous studies of marketing and social science research in which representative sets of adjectives were used to estimate the "semantic space" (Flade, 1978). In addition, we included 5 adjective pairs that more specifically target at evaluations of control devices, these were "safe – unsafe", "sportive – clumsy", "reliable – unreliable", "worn out – firm", "durable – fragile". Each adjective polarity was presented with a six-point scale ranging from -3 to +3. The scale vale 0 was deleted in order to enforce decisions for the one or the other polarity. The 12 push button switches were inserted into a square-formed metal plate with a side length of 40 cm. Three switches were arranged in a row on each side of the square. Each switch was covered with the same button cap. Thus, there were only mechanical but no visual differences between the buttons. Each switch could be operated as often as wanted while a participant simultaneously filled in the semantic differential.

Results

PCA with VARIMAX rotation of the raw data matrix provided a four dimensional solution explaining 53,5 % of the total data variance. The number of extracted dimensions was determined according to the scree-test (Cattell & Vogelmann, 1977). After rotation the four dimensions are defined as follows:

Idealized dimension 1 explains 15% of the total variance and is characterized by high loadings of the positive adjective poles "tough" (loading: .81) , "tense" (.76), "firm" (.62), "loud" (.73), "male" (.65), "strong" (.68) vs. the negative poles "soft", "relaxed", "worn out", "quiet", "female" and "weak", i.e. high positive scores on this scale are given, if a switch provides the feeling of toughness and tenseness, and negative values, if the switch operation is felt as soft and waggly. In short, the idealized scale contrasts "toughness" (positive pole) with "softness" (negative pole).

Idealized dimension 2 explains also 15% of the total variance. The following adjectives pairs define this dimension by means of high loadings "thick – thin" (.74), "coarse- fine" (.68), "slow-fast" (.70), "long-short" (.58), "clumsy-sportive" (.64), "large-small" (.71), and "heavy – light" (.70). Switches receive a high value on this dimension if their actuation is felt as heavy and clumsy, and a small (negative) score if their operation is felt as easy, fast, and short, i.e. a short description of this dimension is given by the contrast "rough running" (positive pole) vs. "smooth running" (negative pole).

Idealized dimension 3 explains 13% of the total variance and contrasts the adjective poles „dangerous" (.70), „strange" (.67), "unpleasing" (.69), "unreliable" (.71), "fragile" (.58), "repellent" (.56), and "ugly" (.55) with their opposites "safe", "familiar", "pleasing", "reliable", "durable", "friendly", and "beautiful". Switches that are felt as unreliable and unsafe receive a positive score on this dimension, while those felt as reliable or safe receive a high negative score.

Idealized dimension 4 explains 11% of the total variance. It contrasts switches that are experienced as “fancy” (.66), “showy” (.61), “elegant” (.65), “expensive” (.56), “young” (.43), and “exciting” (.77) with those that are experienced as “conventional”, “modest”, “simple”, “cheap”, “old”, and “boring”. The positive pole characterizes “fancy” and “attractive”, the negative “conventional” and “unattractive” switches.

An ANOVA with the idealized judgment scores as dependent and the switches as levels of one independent variable provided highly significant main effects for factor “switch” of each idealized judgment scale (all p(F) < . 001).

Idealized dimension 1 (toughness(+) vs. softness(-)) can be reliably predicted by a slope variable (standardized regression weight .747 for the forward movement slope, and .775 for the backward movement slope). I.e. a switch operation is perceived as tough, if the force change is fast, and soft, if it is slow. The second idealized dimension (rough (+) vs. smooth (-) running) is best predicted by size of the movement displacement (regression weight .693 for the forward and .698 for the backward displacement). I.e. the perception of a roughly running switch goes together with a long displacement. With idealized dimension 3 (unreliability(+) vs. reliability(-) switches that have a very short displacement are perceived as more reliable than all other types, i.e., switches with a long displacement or a double switch characteristic (regression weight -.672). Dimension 4 (fancy (+) vs. conventional (-)) is predicted best by the load change (regression weight -.701 for the forward and -.640 for the backward movement). I.e. switches with a small load change are perceived as more fancy and exciting than those that have a very large load change. The latter are perceived as more conventional.

Discussion

Connotative evaluations of switch operations, as subjective preferences and feelings of handling, have not necessarily any functional implication. A push button switch that feels tough or rough when operated can be used as good as one that feels soft and smooth to initiate one and the same system action. Nevertheless, such connotative characteristics determine how comfortable an operator will feel in a certain technical environment and such feelings may have great influence on consumer decisions. Therefore, it seems worthwhile to understand which connotative evaluations are elicited when control devices are handled and, second, whether these subjective evaluations can be predicted from mechanical and dynamic characteristics of the device. These two goals were pursued in the present study. We used two methods to determine implicit judgment scales, first, standard psychophysical scaling methods, second, the controlled association method of the semantic differential. With both approaches, we were able to delineate significant relationships between the subjective evaluations and the objective features of the control devices.

Preference judgments as collected and scaled in experiment I can provide important information about how control elements are evaluated. The scaling results can be used to select those switches for a cockpit that are evaluated as most preferable. Moreover, the established relationship between preference scale and the objective switch characteristic of load change differences can be used to design switches that have a more desirable handling characteristic.

In Experiment II in which the semantic differential technique was used a limited number of idealized dimensions could be extracted that explain a substantial amount of the total variability of the association data. These dimensions reflect haptic-tactile feelings when the switches are actuated. They are orthogonal to each other, i.e. they reflect fully independent aspects of the evaluation, and, as each explains about the same amount of data variance (between 11 and 15%) they are of about equal importance. Each idealized judgment dimension could be related to one distinct objective switch characteristic. Toughness of the switch movement was found to be related to a slope change measure, a rough vs. soft running switch was found to be predictable by the overall movement displacement size, a reliable switch was found to be best predicted, if it had a typical short moving characteristic in contrast to those with a long displacement or a double switch characteristic, and switches were experienced as more fancy, if their snap rate (the load change between maximum and minimum force) was small.

Taken together the data prove that highly subjective, internal feelings during operation of control elements can be objectively and reliably derived from preference judgments and controlled association tests. Moreover, these psychological variables were found to be systematically related to objective measures of the load-displacement diagram, i.e. subjective, connotative evaluations of switch actuations can be predicted by means of physical measures. Therefore, this approach could be of use for designing control elements that target for specific consumer groups.

Reference List

Borg, I., & Groenen, P. (1997). Modern multidimensional scaling. Theory and applications. New York: Springer.

Cattell, R. B., & Vogelmann, S. (1977). A comprehensive trial of the scree and KG criteria for determining the number of factors. Multivariate-Behavioral-Research, 12(3), 289-325.

Cox, T. F., & Cox, M. A. (Eds.). (1994). Multidimensional scaling. London: Chapman & Hall.

Flade, A. (1978). The evaluation of psychological concepts concerning the environment through a concept-specific and a universal semantic differential. Zeitschrift-Fur-Experimentelle-Und-Angewandte-Psychologie, 25(3), 367-378.

Hofstätter, P. R. (1955). Über Ähnlichkeit. Psyche, IX, 54-80.

Karlsson, B. S., Aronsson, N., & Svensson, K. A. (2003). Using semantic environment description as a tool to evaluate car interiors. Ergonomics, 46 (13-14), 1408-1422.

Mondragon, S., Company, P., & Vergara, M. (2005). Semantic Differential applied to the evaluation of machine tool design. International-Journal-of-Industrial-Ergonomics, 35(11), 1021-1029.

Osgood, C. E., Suci, G. J., & Tannenbaum, P. H. (1957). The measurement of meaning. Urbana-Champeign, Il: University of Illinois Press.

Voss, K. E., Spangenberg, E. R., & Grohmann, B. (2003). Measuring the Hedonic and Utilitarian Dimensions of Consumer Attitude. Journal-of-Marketing-Research, 40 (3), 310-320.