Development of a Comprehensive Usability Testing and Analysis Protocol for Ergonomic Product Design

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The development of a user-centered product design is important to satisfy customers who want to use the product with ease of use and to keep the manufacturer competitive in the market. The present study developed a protocol to analyze and evaluate the usability of a product in a systematic and comprehensive manner. The proposed protocol consists of three phases (product-user interface analysis, usability evaluation, and usability analysis and synthesis) including various analysis topics in each phase. The usability testing and analysis protocol was effectively applied to canister-type vacuum cleaner to identify designs preferred and/or requiring improvement. The proposed protocol would contribute to developing user-centered designs by providing comprehensive information on the usability analysis and evaluation results of a product. A software program which incorporates the proposed protocol is necessary for efficient analysis on usability evaluations.

INTRODUCTION

Usability testing is important in the development process of a user-centered product design. The usability of a product refers to the effectiveness, efficiency, and satisfaction that users experience when interacting with the product (ISO, 1991). An effort to develop a product design with better usability helps not only users operate the product more easily but also the company remain more competitive in the market. Therefore, in the product development process concerns and efforts have been escalated on usability evaluation and design improvement based on usability testing results.

In usability testing, a comprehensive, systematic analysis on tasks, product components, and usability measures is often necessary. However, most published research introduces methodologies which are of use to identify the effect of a specific design characteristic on selected usability aspects. For example, Lee (2006) reported use of a motion analysis method to examine the effects of the size, shape, and alphanumeric input method on the usability of cell phone in alphanumeric input task; Drury and Hoffmann (1992), Brand & Hollister (1999), and Colle & Hiszem (2004) examined the size of button acceptable from the usability aspect. These studies are mainly intended to identify the optimal design values of selected components based on in-depth testing and analysis. However, research is lacking which introduces a methodology to provide usability testing results on a product in a comprehensive manner by considering various tasks, use environments, and usability aspects.

The present study developed a systematic protocol for comprehensive testing and analysis on product usability. The proposed protocol consists of three phases (product-user interface analysis, usability evaluation, and usability analysis and synthesis) including different analysis topics at each phase. The usability testing and analysis protocol was applied to canister-type vacuum cleaner to examine its effectiveness.

PROTOCL DEVELOPMENT AND APPLICATION

The present study developed a three-phase protocol as shown in Figure 1 for comprehensive usability testing and analysis on a product. The proposed protocol encompasses analyzing the characteristics of product design from the usability aspect, planning and conducting a usability study, and developing design recommendations based on usability testing results. The detailed analyses and activities involved in each phase are described below along with a case study on vacuum cleaner.

Phase 1. Product User Interface (PUI) Analysis

In the first phase, a set of fundamental information on a product under study is collected by the analysis of PUI characteristics and benchmarking of competitive products. This PUI fundamental information is utilized in the subsequent phases to plan a usability testing, analyze the results of usability testing, and provide design recommendations based on the testing results.

PUI characteristic analysis. The fundamental characteristics of PUI such as tasks (T), use environments, product components (C), usability measures (M) are analyzed. These PUI characteristics can be surveyed from various sources including operating manuals, hands-on operations, and

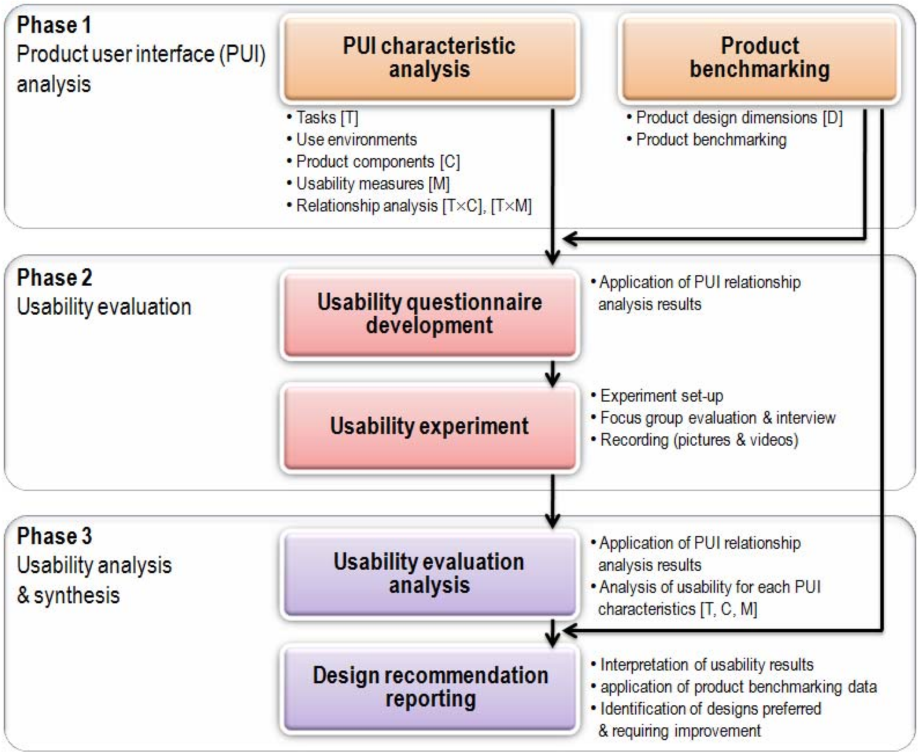


Figure 1. Comprehensive usability testing and analysis protocol

Table 1. Analysis of product-user interface characteristics (illustrated for canister vacuum cleaner)

a. Hierarchy of tasks [T]

Category	Task	Subtask	
Infrequent task	Preparation	Power supply	
		Brush installation	
Iterative task	Operation	Movement	Use of carriage handle
			Use of wheels
		Button Control	Power on/off
			Suction power control

b. Hierarchy of product components [C]

Category	Component
Body	Case
	Carriage handle
	Buttons
	Wheels
	Display
	Dust bin

c. Usability measures [M]

Measure	Definition
Comfortable posture	The extent to which comfortable postures are maintained while operating the product
Efficient motion	The extent to which motions are efficiently used to operate the product
Natural motion	The extent to which natural motions are used to operate the product
Effective use of force	The extent to which forces used to operate the product are acceptable
Fit to the hand	The extent to which the handle or grip fits to the size and shape of the hand
Ease of use	The extent to which a user easily operates the product

d. Relationship analysis of between tasks and components [T × C]

Task [T]				Component [C]					
				Case	Handle	Buttons	Wheels	Display	Dust bin
Iterative task	Preparation	Power supply		O		O			
		Brush installation							
	Use	Movement	Use of carriage handle	O	O				
			Use of wheels	O			O		
		Button Control	Power on/off			O		O	
			Suction power control			O		O	

field observations. As illustrated in Table 1, the collected PUI characteristic information is organized into a hierarchy and the relationships between PUI characteristics such as $T \times C$ and $T \times M$ are analyzed. Table 1.a indicates that tasks for the cleaner are divided largely into two categories according to iterativeness during product operation. Table 1.b shows that the components of cleaner are arranged by major product parts such as body, hose, tube, and brush. Next, Table 1.c defines measures that would be considered to evaluate the usability of the product. Lastly, Table 1.d displays components of the product that are involved to conduct each task.

Product benchmarking. The design characteristics of competitive product models are compared with each other to identify the design trend of product and interpret usability testing results from the product design aspect in the usability analysis and synthesis phase. For product benchmarking, the design dimensions (e.g., size, weight, shape, location, and texture) of each product component are defined and then measured for selected product models as illustrated in Table 2. By analyzing the product design benchmarking data, the design trend of product such as variability, similarity, and difference can be identified in depth for each product component.

Phase 2. Usability Evaluation

In the second phase, based on the understanding on the PUI characteristics a usability questionnaire is prepared and a usability study is planned and conducted accordingly.

Usability questionnaire development. A usability questionnaire is developed based on the relationship analysis results of $T \times C$ and $T \times M$. Usability questions are constructed for each component in a systematic manner by considering related tasks and usability measures that are identified in the $T \times C$ and $T \times M$ analyses. For example, Table 3 displays usability questions on brush that are prepared for three tasks (connection, disconnection, and storage/retrieval) by considering their related measures (ease of use and efficient use of force).

Table 2. Benchmarking of product designs (illustrated for canister vacuum cleaner)

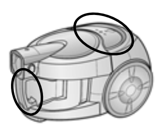
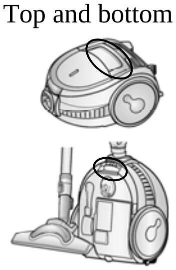
Component	Dimension	Model A	Model B	Model C	Design trend
Carriage handle	Size W × L × T (unit: cm)	18.5 × 8.5 × 2.0	20.5 × 12 × 1.5	18.0 × 7.0 × 1.5	- Width: 18.0 ~ 20.5 cm - Length: 7.0 ~ 12.0 cm - Thickness: 1.5 ~ 2.0 cm
	The number of handles	1	2	2	- The number of handles: 1 or 2
	Location (at the body)	Top 	Top and front 	Top and bottom 	- Primary handle: top - Secondary handle: front or bottom

Table 3. Usability evaluation questionnaire (illustrated)

Category	Task	Usability questions	Product Model		
			Model A	Model B	Model C
Brush	Connection of brush to tube	The extent to which brush is connected to tube at a single trial WITHOUT ERROR	Low High ① ② ③ ④ ⑤	Low High ① ② ③ ④ ⑤	Low High ① ② ③ ④ ⑤
		The extent to which brush is EASILY connected to tube	① ② ③ ④ ⑤	① ② ③ ④ ⑤	① ② ③ ④ ⑤
	Disconnection of brush from tube	The extent to which release button on brush is pressed by applying PROPER FORCE	① ② ③ ④ ⑤	① ② ③ ④ ⑤	① ② ③ ④ ⑤
		The extent to which brush can be EASILY disconnected from tube	① ② ③ ④ ⑤	① ② ③ ④ ⑤	① ② ③ ④ ⑤
	Storage & retrieval of brush	The extent to which disconnected brush is stored IN ORDER	① ② ③ ④ ⑤	① ② ③ ④ ⑤	① ② ③ ④ ⑤
		The extent to which brush is EASILY retrieved when necessary	① ② ③ ④ ⑤	① ② ③ ④ ⑤	① ② ③ ④ ⑤

Usability experiment. A usability testing on selected product models is conducted with participants at a testing site by using the usability questionnaire. A usability plan is established which describes procedures of participant recruitment, orientation, test administration, and debriefing. For example, the present study recruited 30 users in 30s to 40s to evaluate 5 different vacuum cleaner models. The test was run for about 3 hours in group of 2 or 3 users in a lab environment configured to simulate tasks in various use environments. The participants were asked to provide their evaluations on each product component after simulating tasks indicated in the questionnaire. Two monitors administered the usability test and recorded comments from the participants. After completion on testing the product models, debriefing was conducted in a conference room to obtain opinions and ideas for design improvement.

Phase 3. Usability Analysis and Synthesis

In the last phase, the usability evaluations are analyzed for the components, tasks, and usability measures defined and then design recommendations are reported based on the usability analysis results.

Usability evaluation analysis. The usability evaluations are summarized according to the PUI characteristics (components, tasks, and usability measures) by applying their relationship analysis results. Table 4 illustrates how the evaluations related to a certain task were combined, i.e., the connection and disconnection tasks with different types of brush (multi-purpose, wet-mop, and corner brushes) were combined into a grand average for each task. Likewise, the usability evaluations were combined according to product components and usability measures.

Design recommendation reporting. Design recommendations are documented regarding product designs preferred and requiring improvements (see Figure 2). The usability evaluation results for product components are interpreted in relation to corresponding benchmarking data of product models. The design characteristics which receive a high usability evaluation are classified as ones preferred and the opposite as ones requiring improvement.

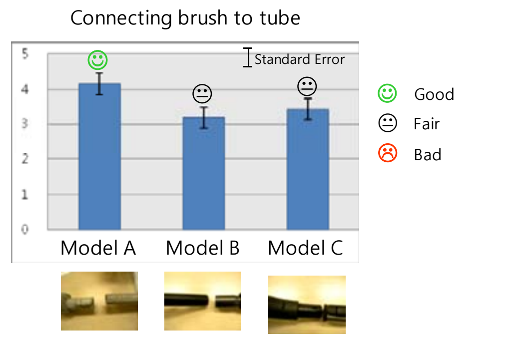
Table 4. Usability evaluation results by tasks (illustrated)

Task	Components related	Model A	
		Average	Grand average
Connection of brush to tube	Multi-purpose brush	4.0	4.0
	Wet-mop brush	3.8	
	Corner brush	4.1	
Disconnection of brush from tube	Multi-purpose brush	4.3	4.3
	Wet-mop brush	4.1	
	Corner brush	4.4	

DISCUSSION

The proposed testing and analysis protocol requires a comprehensive and systematic analysis on the characteristics of PUI (tasks, components, use environments, and usability measures). By using this comprehensive PUI information, the usability issues of a product under study can be comprehensively examined and analyzed.

In the present study the relationships between the PUI characteristics were analyzed and then applied to development of a usability questionnaire and analysis of usability evaluations. The PUI relationship information is useful for the usability analyst to prepare question items in a systematic manner and to integrate usability evaluations according to each PUI characteristic.



Category	Design criteria	Design characteristics	Image
Preferred	Weight	Model A (290 g) is lighter than Models B (513 g) and C (545 g)	-
	Visual information	Arrows to indicate connecting location and direction	
	Auditory feedback	Sound feedback when pipes are connected properly	
Requiring improvement	Use of force	Models B and C require larger force to connect pipe with brush	-

Figure 2. Design recommendations based on usability evaluation results (illustrated)

The present study asked the participants to provide their usability evaluations right after simulating tasks with each product model. Since the usability questionnaire was designed to evaluate each product component in terms of related usability measures immediately after conducting designated tasks, the participants could conduct the usability testing in order and provide more valid evaluations based on their use experiences.

Since the present study compared the usability evaluations on selected product models, preferred or improvement required designs, not optimal designs, could be identified on a relative basis. To explore an optimal design characteristic for a selected product component, techniques of design of experiment should be employed to focused prototypes. Ulrich and Eppinger (2003) discuss the trade-offs of comprehensive and focused prototypes in terms of analysis information type—more comprehensive and synthetic information can be obtained from use of comprehensive prototypes. Since the present study was intended to obtain comprehensive usability information on a product, competitive product models were tested.

A software program incorporating the proposed analysis protocol would be of use to obtain usability analysis results with time efficiency. Since usability evaluations are summarized for each PUI characteristic by using the relationship analysis results between PUI characteristics, the analysis time by manual would increase drastically as the number of elements in each PUI characteristic increases. Thus, it is necessary to develop a software program which reports usability results according to PUI characteristics if a data file of usability evaluations is fed to the program.

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