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Ecological performance of electrical consumer products: the influence of automation and information-based measures

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Abstract

Being concerned with the environmental impact of electrical consumer products, this article examines possibilities of influencing ecological user performance through design features. Furthermore, it looks at the relationship of user characteristics and ecological performance. The impact of level of automation and type of control labelling on ecological user performance was examined in a lab-based experimental scenario with 36 users. In addition to performance indicators, a range of user variables (e.g., self-reported domestic behaviour, environmental knowledge and attitude) was measured to assess their influence on user behaviour. The results showed that low-level automation improved ecological performance whereas no such positive effect was observed for enhanced display-control labelling. Furthermore, the results suggested that the user's mental model of ecological performance was rather limited. No relationship was found between environmental knowledge, attitude and performance. The findings pointed at the strong prevalence of habits in the domestic domain. The implications of the results for designers of consumer products are discussed.

Keywords: Consumer products; Performance; Design; Environmental concern; Habit

1. Introduction

1.1. Consumer products and ecological performance

Within the field of ergonomics, interest in the design of consumer products has been growing over recent years (Green and Jordan, 1999; Stanton, 1998). There are a number of reasons why the importance of consumer ergonomics is likely to increase further in the future. First, the complexity of domestic appliances is clearly rising (e.g., intelligent refrigerators automatically order foods that are about to run out). Second, there will be a stronger integration of separate appliances (e.g., heating may be remotely controlled by a mobile phone). Third, there is a strong proliferation of consumer products, with the number of household appliances increasing steadily.

There are a number of aspects that need to be considered in ergonomic design of consumer products, such as usability (e.g., Green and Jordan, 1999) and safety (e.g., Norris and Wilson, 1999). A further important aspect refers to the *environmental impact* of consumer products, which may be described as the aggregated environmental damage that a product causes during different phases of its life cycle (e.g., toxic emissions during production, energy consumption during utilisation, toxic waste during disposal). The environmental impact of electrical consumer products is not negligible (Wenzel et al., 1997). Due to the proliferation of these products, the problem is likely to increase in the future. Despite the growing importance of this issue, there is little ergonomic research that has addressed the environmental impact of consumer goods. This article focuses on this neglected research area by exploring possibilities of how user–product interaction can be influenced with a view to reduce the environmental impact of electrical consumer products.

Analyses have shown that the product utilisation phase is generally most relevant for a consumer product's environmental impact during its life cycle (Wenzel et al., 1997). Therefore, the environmental impact during product utilisation becomes a central

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concern in ecological product design. The term *ecological performance* refers to those criteria of human–machine-system performance that have an environmental impact during product utilisation. Ecological performance may be considered a multi-facetted concept, including parameters such as resource consumption (e.g., energy, water) as well as emissions (e.g., dioxins). Although there has been no explicit reference to the concept of ecological performance in the literature so far, the concept has been employed implicitly since some aspects of performance may also refer to ecological facets of performance (e.g., an aircraft's fuel consumption). The advantage of using ecological performance as a distinct term is that it provides the possibility to focus research efforts more strongly on environmental issues in system design. In the context of consumer product use, the main aspects of ecological performance are water and energy consumption. The latter will be the focus of the present study.

1.2. Design features and ecological performance

To improve ecological performance of electrical consumer products during use, a number of design-based measures may be implemented, such as automation, on-product information, redesign of controls, enhancement of display-control labelling and enhancement of system feedback (Sauer et al., 2001). Among these, automation and display-control labelling are discussed in more detail since they are relevant to the present study.

1.2.1. Automation

There are several reasons for automation (Wickens and Hollands, 2000). In the domestic domain, the following two seem to be most relevant. (1) A function is allocated to the machine because the human is unable to perform the function because of inherent limitations. (2) A function is allocated to the machine because the human performs the function only very poorly. There are a number of possible reasons for poor human performance. It could be due to poor user knowledge. It could also be due to disadvantageous habits, which are likely to develop rapidly in the domestic domain since it involves the completion of a large proportion of routine activities (see Dahlstrand and Biel, 1997). These well-established behaviour patterns are normally not subject to conscious planning and are generally difficult to break. Therefore, if the task concerned is assigned to the machine, the habit may no longer impinge on performance.

1.2.2. Display-control labelling

While automation removes the responsibility for certain functions from the user, the effectiveness of product information is contingent upon the user's willingness to take advantage of the information provided. Product information is of particular importance if user knowledge is limited. There are several types of product information, such as instruction manuals (e.g., Young and Wogalter, 1990) and on-product information (e.g., McCarthy et al., 1995). Since each type has specific strengths and weaknesses, the implementation needs to be carefully considered. Instruction manuals provide detailed information but are often not read by users. The compliance rate may be higher for on-product information (because of its permanent visibility to the user) but space for information presentation is very limited. Display-control labelling may also be considered an information-based measure since it provides important user information. Compared to on-product information and instruction manuals, an advantage of information conveyance via display-control labels is that the information provides more action-specific support because it is clearly linked to the setting of controls. Therefore, the user receives direct behavioural guidance on how the controls are best set under specific operational circumstances. While there is generally little doubt about the utility of display-control labels (Bullinger et al., 1997), their effectiveness in the domestic domain still needs to be examined.

1.3. User variables

While design features are generally strong determinants of human behaviour, a causal model of resource-consumption behaviour presents a number of further factors that are related to ecological behaviour, such as external incentives, attitudes, knowledge, attention and commitment (Stern and Oskamp, 1987; Gardner and Stern, 1996). Gardner and Stern argue that a major barrier to acting on a proenvironmental attitude is lack of knowledge (e.g., not knowing that blunt blades on a lawn mower increases energy consumption). Furthermore, there are external barriers that lie outside the control of the individual, which may also prevent proenvironmental action in various ways (e.g., no recycling containers nearby, charges for recycling refrigerators containing CFC). Since there are few external barriers in the context of our study, attitude (or environmental concern) and knowledge are considered as the two main factors that modify ecological performance.

1.3.1. Environmental concern

The literature has not been unequivocal about the correlation between environmental concern and ecological behaviour. Overall, the association between proenvironmental attitude and behaviour has been found to be rather weak (Alwitt and Pitts, 1996). Spada (1996) has identified several reasons for the lack of consistency between attitude and behaviour: comparatively low degree of priority despite pro-environmental attitude (e.g., using a car to return more quickly to family after work), well-established habits, lack of positive reinforcement, and lack of competence to carry out pro-environmental activity (e.g., being unable to ride a bike). Others have argued that the weak relationship between attitude and behaviour is due to measurement problems and the fact that non-ecological factors (e.g., different costs associated with environmental behaviour) were not sufficiently considered (Kaiser et al., 1999).

1.3.2. Environmental knowledge

A number of studies have indicated that environmental knowledge is rather poor while general environmental concern is high (e.g., Arcury and Johnson, 1987). This suggests that lack of knowledge of the relationship between the many elements of the user–product system may result in a low prevalence of proenvironmental behaviour. Stern and Gardner (1981) have argued that it is insufficient to encourage people to conserve resources, they also need knowledge of how to operate the system. A meta-analysis indicated that the correlation between behaviour and knowledge is moderate at best (Hines et al., 1986). However, most of the studies investigated environmental knowledge at a very general level, similar to attitude research that did not sufficiently distinguish between different facets of environmental concern.

1.4. The present study

The work reported in this article has two principal goals. First, it carries out an evaluation of design modifications to measure their effects on ecological performance. Second, it aims to examine the relationship of user variables and ecological performance. In this study, a distinction was made between knowledge-related user variables (e.g., ecological knowledge of user) and non-knowledge user variables (e.g., habits, low motivation to show environmentally friendly behaviour). This distinction was made because of the implications for design-based measures. If poor ecological performance was due to insufficient knowledge, different design-based measures would be needed than if poor ecological performance was due to habits or poor motivation. A further distinction between habits and motivation was not made in this study because it was not considered a primary research question.

For the purpose of this study, the vacuum cleaner was selected as a model product. It was chosen because of its wide-spread use in the domestic domain, coupled with considerable energy consumption during operation. For a vacuum cleaner, the main environmental impact is energy consumption. A technical analysis of vacuum cleaners revealed that at a level of approximately 750 W motor power, the ratio of energy consumption to suction power is optimal (Dannheim, 1999). However, virtually all models available permit considerably higher settings, which often results in energy-inefficient settings being chosen by the user. Nevertheless, it would not be a good design option to remove the function "power control" from the user by building an energy-efficient 750-W model with no adjustable power control; a model with such a feature proved to be unsuccessful in the market. This raises the central question of how users can be encouraged to select energy-efficient power settings without limiting their control over central functions of the appliance.

The implementation of automation may be a solution to poor human management of the power control function, which may be caused by habits and/or low ecological motivation. In the present study, automation was implemented in the form of an automatic reset device, which returned power control to a default setting when switching off the appliance. An energy-efficient default setting at approximately 800 W (i.e. medium power level) was compared to default settings of higher and lower levels. This allowed us to determine whether a machine-driven setting of power control would lead to energy savings. Energy savings would be achieved if an energy-efficient default setting was not overridden by users. If users increased power control from an energy-efficient default setting to a higher setting, this would suggest that they considered high settings as most effective for task performance. If users decreased power control from a higher default setting to a medium setting, this would suggest that they considered medium settings to be most energy efficient. If users did not manipulate power control during any of the experimental conditions (i.e. different default settings), this would suggest that they considered the power control function to be insignificant for task performance. The automatic device examined here is to be considered an example of low-level automation (see automation models of Endsley and Kiris, 1995; Sheridan, 1997), as it still allows the user to override the automatic function. In addition to providing high user control, a further advantage of low-level automation (compared to high-level automation) is that it would keep manufacturing costs down, which is important for achieving a strong proliferation of ecological consumer products.

If lack of knowledge was at the root of poor ecological performance, a design-based measure would be required that effectively conveys critical information to the user. Most display-control labels presently found on vacuum cleaners do not convey much environmental knowledge to the user. On the contrary, labels often provide a positive association with maximum power control settings (e.g., max, plus-sign, figure in Watt), which is likely to even encourage users to choose higher and hence less energy-efficient settings. For the purpose of this study, an enhanced display-control label has been designed that gives users information about the most energy-efficient setting of controls. In addition to the knowledge-conveying function, the label also has a prompting function, reminding the user of the most energy-efficient setting.

Since environmental knowledge may be an important factor for ecological performance, it would be important to determine the level of knowledge users have about ecological use of ECP. While an enhanced display-control label would provide users with important operational knowledge to use the appliance in an environmentally friendly manner, this would be largely ineffective if strong habits or low motivation were prevalent.

By means of using different task instructions, it was intended to identify the relationship of user habits/motivation and ecological performance. Under one task instruction, users were asked to complete the task in an environmentally friendly manner, under the other instruction users should behave as they would normally do in their domestic environment. If there was an improvement in ecological performance under the ecological instruction, this would suggest that habits and/or motivation have an impact on user performance because users only show better ecological performance when specifically instructed to do so. If there was no improvement, this would suggest that users were lacking sufficient operational knowledge to show better ecological performance (the alternative explanation that they could not improve because they already showed optimal performance level can be controlled for by an overall assessment of performance patterns).

For the automatic reset function, it was hypothesised that low and medium levels of power reset default would result in better ecological performance than a high level. Furthermore, it was predicted that enhanced display-control labelling would lead to better ecological performance because it provides users with information about the most ecological control setting. It was also expected that ecological task instructions (ETIs) would lead to better ecological performance, in particular, under the presence of enhanced display-control labelling. This was because the enhanced display-control label provided users with operative knowledge about how to improve ecological performance.

2. Method

2.1. Participants

Thirty-six participants took part in the experiment (female: 63.9%). Their ages ranged from 19 to 49 years (mean age: 27.9). The vast majority of participants (80.5%) may be considered experienced users of vacuum cleaners, with more than 5 years of practice. The living conditions of the sample were as follows: Single in own flat (41.7%), single in shared house (16.7%), living with partner and no children (16.7%), living with partner and children (22.2%), and other (2.8%).

2.2. Design

The design employed was a mixed 3 × 2 × 2 factorial design, with *automatic reset function*, *display-control labelling* and *task instruction* as independent variables. Automatic reset function and display-control labelling were between-subjects factors whereas task instruction was a within-subjects factor.

Automatic reset function was varied at three levels of motor power: low (400 W), medium (800 W) and high (1400 W). On the basis of empirical tests that were carried out on 45 vacuum cleaners to determine the relationship between motor power and suction power (Dannheim, 1999), it can be derived that the 800 and 1400 W settings have similar suction power. Since energy consumption on the high setting is about 75% higher than on the medium setting while suction performance is largely identical, ecological performance of the appliance will be lower on the high setting. As a fully operational reset function was not available, it was simulated by manually setting power control to one of the three conditions at the beginning of the experimental trial. This is considered an adequate experimental simulation of an auto reset device since the appliance was normally not switched off before the end of the experimental scenario. Only if the appliance had been switched off more than once by a user during the experimental scenario would the simulation of the automatic reset device be inappropriate (the data confirmed that users did not switch off the appliance before the end of the trial).

Display-control labelling was manipulated at two levels: *enhanced* vs. *standard*. The standard version was a typical label found on a considerable number of vacuum cleaners (see Fig. 1a). It was in black and white. The design of the standard label can be considered *motor power*-centred, i.e. the user associates a high setting (i.e. max) with high suction performance since no other information is provided on the label. The idea behind the enhanced version (see Fig. 1b) was to encourage users to choose a low or medium setting of the controls by using an *environmental state*-centred label. The verbal descriptor of the enhanced label suggests that the environmental state (i.e. how dirty is the floor?) should be identified first and then the controls setting should be chosen accordingly. It removes the positive connotation of high suction power by linking the optimal level of motor power to the environmental state. To support the verbal message, the three sections of the control device had a different colour coding. Based on generally accepted meanings of colours (Morgan et al., 1963), red (meaning: danger, stop) was

(a) (b)

Fig. 1. Display-control labels for: (a) standard and (b) enhanced condition (labels were translated from German).

chosen for the high setting as the undesirable section of control device and different shades of green (meaning: safety) for the desirable sections.

Task instruction had two levels: *ecological* vs. *standard*. In the condition of ETI, participants were asked to clean a room in an environmentally friendly manner. In the other condition, standard task instruction (STI), participants were asked to clean the room as they would do at home. To control for order effects, half of the participants completed the experimental session with ETI followed by STI while the other half were given instructions in the reverse order (STI–ETI).

2.3. Experimental measures

2.3.1. Performance parameters

The following measures to collect performance data were used: frequency of manipulating power control, setting of power control (kW), trial duration (s) and achieved cleanness (%). Of these measures, setting of power control and trial duration are particularly important since they are directly associated with energy consumption.

2.3.2. Environmental attitude

A German-language environmental concern questionnaire was used to measure environmental attitude (Schahn and Holzer, 1990). The 21-item questionnaire consists of seven sub-scales referring to different aspects of environment-relevant behaviour (e.g., shopping, traffic, leisure activities). One of the sub-scales ("saving energy") is particularly relevant to our work, allowing a separate analysis of the sub-scale score.

2.3.3. Environmental knowledge

Since there was no appropriate test available that measured environmental knowledge, a five-item scale was developed that specifically measured relevant knowledge. These were multiple-choice items with six possible responses (correct response, four distractors and "don't know"). An example of an item was: "Which one of the following vacuum cleaners is most energy-efficient?" The response categories were: (a) appliance with 800 W; (b) appliance with 1100 W; (c) appliance with 1500 W; (d) appliance with 1800 W; (e) all appliances are equally effective; and (f) don't know. The test items were derived from a technical analysis of the model product (Dannheim, 1999). Since the instrument was purpose-built for this particular research study, there is, as in many other cases, the general problem of determining the psychometric properties of scales that are in a developmental stage (see Annett, 2002). To ensure satisfactory levels of content validity, experts in the application area were used to check whether the items were representative and the response alternatives were unambiguous. The same approach was also employed for the two instruments that are subsequently presented.

2.3.4. Subjective user assessment

Visual analogue scales of 100 mm were used to capture user assessment of two variables. First, users were asked to assess the *cleanness* of floor area (*not dirty at all–very dirty*). This measure was taken before and after the cleaning operation. Second, users were asked to indicate the *thoroughness* with which they carried out the cleaning operation (*not thoroughly at all–very thoroughly*). The measurement of these variables allowed us to relate objective user performance to perceived environmental state (i.e. cleanness of floor area) and perceived cleaning performance.

2.3.5. User behaviour questionnaire

In addition to the observed behaviour in a laboratory, we wished to complement the database by collecting information about relevant user behaviour in their domestic environment. This enabled us to examine possible influences of domestic user behaviour on lab-based performance. For that purpose, a questionnaire was designed that measured different aspects of domestic cleaning behaviour. The areas covered were: cleaning strategies, cleanness standards, work preparation, system maintenance, manipulation of power control, ecological cleaning, frequency and duration of cleaning operations. An example of an item was: *I check the dust bag before switching on the vacuum cleaner (never–always)*. A five-point Likert scale was used for each item.

2.4. Procedure

The experiment took place in a laboratory, in which a $3 \times 5\,m^2$ carpet was fitted. After the carpet was thoroughly cleaned with a vacuum cleaner, 250 g dirt was distributed on the carpet. Four pieces of furniture (desk, computer desk, 2 chairs) were placed on the carpet to model a typical private study (see Fig. 2).

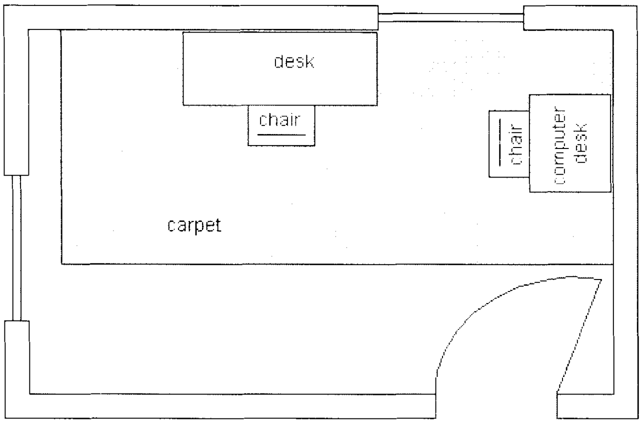

Fig. 2. Drawing of laboratory layout.

All participants were tested for colour blindness by using Ishihara plates (none of the participants had to be rejected). This was because colour blind users might have had difficulties distinguishing the different colours of the enhanced display-control label in the experiment. While it is acknowledged that appliances also need to be usable for users with deficiencies in colour perception, the test was carried out to control for the intervening variable 'colour blindness'.

Participants were randomly assigned to one of the experimental conditions, where they had to use a vacuum cleaner that was pre-experimentally set to 400, 800 or 1400 W motor power. It either had standard or enhanced display-control labelling. Upon entering the lab, participants were asked to complete the visual analogue scale, assessing cleanness of floor area. Participants then received instructions about how the appliance worked (e.g., power switch, power control). After this familiarisation phase, the instructions of the first trial (ecological or standard) were given. The participant's task was to clean the prepared floor area. After having finished the task, participants completed two more visual analogue scales (thoroughness and cleanness). The experimenter then prepared the cleaning surface for the second trial, in which participants received the other type of instruction. Apart from the difference in instruction the procedure was the same for the second trial. At the end of the experimental session, participants were administered three questionnaires: knowledge test, environmental concern questionnaire, user behaviour questionnaire.

3. Results

3.1. Experimental user performance

A three-way analysis of variance was carried out on all dependent variables. The results showed effects for auto reset and instruction while display-control labelling consistently showed no effect on any of the dependent measures (all $F<1$). Therefore, the data for display-control labelling are not presented here in detail.

3.1.1. Frequency of manipulating control

The data showed an overall propensity of users not to interact much with power control. 41.6% of users carried out no control action at all during the two experimental trials. Another 27.8% made one or two control actions. Only a very small number (11.1%) were observed to interact five or more times with the control device. Analysing the frequency revealed an average of 0.90 control actions per working session (see Table 1). The results of the analysis of variance showed no effect of task instructions ($F = 2.62$; df $= 1.30$; $p > 0.05$) and none of auto reset ($F = 1.39$; df $= 2, 30$; $p > 0.05$).

3.1.2. Setting of power control

This measure refers to the motor power (kW), which is determined by the setting of the power control. The data showed that lower control settings were observed when auto reset default was on low or medium than when on high (see Table 1). This difference was highly significant ($F = 14.2$; df $= 2.30$; $p<0.001$), with post-hoc LSD tests confirming that only the high default setting was different from the other two ($p<0.001$). Interestingly, ETI did not lead to users choosing lower settings ($F = 2.57$; df $= 1.30$; $p = 0.11$). No interaction was observed.

3.1.3. Trial duration

The data for trial duration (s) are presented in Table 1. No effect of auto reset was recorded

Table 1
Effects of auto reset and instructions on task performance (ETI = ecological task instruction, STI = standard task instruction)

	Default setting of auto reset			Overall
	Low	Medium	High	
Use of power control (No/trial)	1.17	0.50	1.04	0.90
STI	0.83	0.58	0.58	0.67
ETI	1.5	0.42	1.5	1.14
Setting of power control (kW)	0.77	0.86	1.10	0.91
STI	0.80	0.96	1.10	0.95
ETI	0.73	0.77	1.10	0.87
Trial duration (s)	280	238	219	246
STI	288	283	242	271
ETI	273	193	195	220
Achieved cleanness (%)	87.4	90.5	89.7	89.2
STI	88.4	92.7	91.1	90.7
ETI	86.6	88.4	88.3	87.7

($F = 1.78$; df = 2.30; $p > 0.05$). Shorter experimental trials were observed when users were given ETI than under STI ($F = 6.80$; df = 1.30; $p < 0.05$). This is an important result since trial duration is directly associated with energy consumption. No significant interaction was found.

3.1.4. Achieved cleanness

This measured the percentage of dirt that was removed from the designated cleaning surface during the experimental session. As Table 1 shows, there was no effect of auto reset for this variable ($F < 1$). A significant effect was however observed for task instruction. Users cleaned the work area more thoroughly in the STI condition than in the ETI condition ($F = 4.42$; df = 1.30; $p < 0.05$). Again, no interaction was found.

3.1.5. User ratings

The ratings of the visual analogue scales showed that users perceived the level of dirtiness of floor area above average (65.9 on the 100 mm scale). Naturally, in the post-experimental assessment, this was considerably reduced (23.9). None of the independent variables showed any effect for this measure (all $F < 1$). The thoroughness scale showed a mean score of 59.7. Users reported that they had cleaned the floor area less thoroughly under ETI (53.7) than under STI (65.7). This difference was statistically significant ($F = 10.1$; df = 1.30; $p < 0.005$).

3.2. User variables and performance

In order to examine the relationship among user variables and in relation to performance measures, correlation coefficients were calculated. Overall, only few significant correlation coefficients were found.

3.2.1. Environmental attitude

Examining the relationship between environmental concern and performance revealed no significant association, neither for the general scale nor for the sub-scale "saving energy". However, the sub-scale "saving energy" showed a significant inverse relationship with the thoroughness scale ($r = -0.38$; $p < 0.05$). This indicated that users with a high motivation to save energy cleaned the designated floor area less thoroughly.

3.2.2. Environmental knowledge

The results of the test showed that overall ecological knowledge of vacuum cleaners was rather poor. The mean test score was $M = 1.62$, compared to a possible maximum score of 5. Correlation coefficients indicated no significant relationship between environmental knowledge and any of the performance measures. Similarly, the analysis did not reveal any association between knowledge and attitude ($r = 0.04$; $p > 0.05$).

3.2.3. Self-reported user behaviour

The data from the user questionnaire indicated how users went about cleaning their home with a vacuum cleaner. Two variables were found to be associated with performance during the sessions under STI but not under ETI: frequency of cleaning and cumulative cleaning time. Participants who reported more frequent vacuum cleaning of their home showed longer trial duration ($r = 0.48$; $p < 0.01$), achieved higher cleanness standards ($r = 0.54$; $p < 0.001$), and chose higher settings of power control ($r = 0.51$; $p < 0.005$) in the experimental trials. Similar results were found for cumulative cleaning time (i.e. total cleaning time in hours per month). The occurrence of positive correlations for STI but not for ETI was not unexpected since the former reflects domestic behaviour more closely. No other correlations were found.

3.2.4. User ratings

Neither self-ratings of thoroughness nor of cleanness levels showed any significant correlation with performance measures.

3.3. Predicting performance from user variables and design measures

Since the correlation tables only showed some limited evidence for the influence of user variables on performance, regression analyses were carried out to examine whether experimental performance could be predicted by a set of variables. The analyses were carried out separately for ETI and STI. Five predictors were entered into the equation: Past user behaviour (frequency of use), system features (auto reset function), environmental user knowledge, environmental concern (attitude towards energy saving), and assessment of operational environment (pre-experimental assessment of cleanness of floor area).

The results of the regression analyses are summarised in Table 2. It reports the predictive variance of each factor (R^2) together with F-value, β-weight and squared semipartial correlation (ΔR^2). For STI, it emerged that *frequency of use* was a good predictor for ecological performance parameters. Frequent users tended to clean for longer and to achieve a higher cleanness standard during the STI trial. For ETI, *setting of power control* emerged as the best predictable criterion with an accountable variance of 51%. This was due to the auto reset feature, which very strongly determined the control setting of the appliance. Auto reset was also a significant predictor of setting of power control under STI, though the accountable variance was considerably lower. A significant effect of auto reset was also observed for trial

Table 2
Summary of multiple regression analysis

Criterion variable	Predictors	STI R^2	STI F	STI β	STI ΔR^2	Predictors	ETI R^2	ETI F	ETI β	ETI ΔR^2
Trial duration (s)										
	Frequency of use	0.23**	9.8	0.46	0.20**	Auto reset	0.14*	5.1	−0.35	0.09
	SCA	0.04	1.1	0.15	0.03	Knowledge	0.08	3.1	0.25	0.08
	Knowledge	0.03	1.3	0.16	0.03	SCA	0.08	1.1	0.18	0.03
	Auto reset	0.03	0.53	−0.08	0.01	Attitude "ES"	0.01	1.2	0.17	0.03
	Attitude "ES"	0.00	0.68	−0.06	0.00	Frequency of use	0.00	0.01	−0.01	0.00
	Total R^2	0.30*				Total R^2	0.28			
Achieved cleanness (%)										
	Frequency of use	0.29***	13.4	0.57	0.29***	SCA	0.20**	8.2	0.44	0.18**
	Auto reset	0.02	2.1	0.23	0.05	Frequency of use	0.08	2.5	0.28	0.06
	SCA	0.04	1.6	0.16	0.03	Auto reset	0.00	1.7	0.21	0.04
	Knowledge	0.02	1.4	0.16	0.03	Knowledge	0.02	0.25	0.07	0.01
	Attitude "ES"	0.00	0.17	−0.06	0.00	Attitude "ES"	0.00	0.15	−0.06	0.00
	Total R^2	0.40**				Total R^2	0.31*			
Mean energy consumption (kW)										
	Auto reset	0.19**	8.1	0.48	0.21	Auto reset	0.49***	31.4	0.72	0.46***
	Frequency of use	0.02	2.7	0.27	0.06	Knowledge	0.01	0.50	−0.08	0.01
	Knowledge	0.02	1.2	0.17	0.03	SCA	0.01	0.56	0.11	0.01
	SCA	0.02	1.1	−0.15	0.02	Attitude "ES"	0.02	0.04	0.03	0.00
	Attitude "ES"	0.01	0.00	0.01	0.00	Frequency of use	0.00	0.21	0.06	0.00
	Total R^2	0.30*				Total R^2	0.51***			

$*p<0.05$; $**p<0.01$; $***p<0.001$ (ETI = ecological task instruction; STI = standard task instruction; SCA = subjective cleanness assessment; ΔR^2 = squared semipartial correlation).

duration under ETI, though the relationship was inverse (as indicated by a negative β-weight), with higher settings of auto reset leading to shorter trial duration. The regression analysis also confirmed the significant association of cleanness assessment and achieved cleanness, with the first being a significant predictor of the latter. If users perceived the floor area as highly dirty, it was cleaned more thoroughly than when users rated the floor area as less dirty. However, this only applied to ETI while no such association was observed for STI. The user variables *environmental knowledge* and *attitude "saving energy"* did not come out as significant predictors for any of the criterion variables.

Overall, the regression analysis indicated that experimental performance was quite well predictable by past behaviour under STI while the auto reset function was generally the best predictor for different ecological performance parameters under ETI.

4. Discussion

The goal of the study was to evaluate the impact of product design on ecological user performance and to examine the relationship between user variables and ecological performance. While the results showed a positive effect of the auto reset function on ecological performance, enhanced display-control labelling failed to show any benefits. Since ecological instructions led to an increase in ecological performance, this suggests that the mental model of ecological performance was not fully taken advantage of during appliance operation. While there was evidence for the influence of domestic habits on experimental behaviour, other user variables (such as environmental concern and knowledge) did not show any relationship with performance variables. These main findings are now discussed in more detail.

The auto reset function emerged as a rather effective means for reducing energy consumption while the opposite was observed for enhanced display-control labelling. Low and medium default settings of auto reset function resulted in lower energy consumption than high default settings without compromising cleanness standards. The auto reset function was effective because users generally did not override the preset setting. There are three possible explanations for the propensity of users not to override the setting: peripheral position of power control, perceived insignificance of power control and high user familiarity.

First, the peripheral position of the control device is likely to have reduced the frequency of power control manipulations. This may be because the device was out of sight during normal system operation (hence no prompting function) and interventions required some physical effort (user had to bend down). Both factors may have contributed to the observed reduction in user interventions. While peripheral position of the power control was of benefit to the effectiveness of the auto reset function (i.e. decreased probability of automatic default setting being overridden), it proved to be disadvantageous for enhanced display-control labelling (i.e. sampling rate of display-control label decreased so that the information presented was not acquired by users). There is some supporting evidence for the "spatial proximity" explanation (see Wickens and Hollands, 2000) since in another study a centrally positioned power control in a vacuum cleaner (i.e. handgrip-based) encouraged users to more frequent changes of control settings compared to peripherally positioned power control (Sauer et al., 2002).

Second, there were indications that users have considered power control to be insignificant for achieving task goals. Under ETI, shorter trial durations were observed than under STI but no change in power control settings was recorded. While reducing trial duration is obviously one way of decreasing energy consumption, the more effective strategy of lowering power control settings was not employed by users. This suggests that users had only limited knowledge of how best to reduce energy consumption during appliance operation.

Third, since users were generally highly familiar with the kind of appliance used in the study, this is likely to have facilitated the occurrence of habitual behaviour patterns. The auto reset function may have benefited from the prevalence of habits (i.e. no overriding of default setting) while this has had the opposite effect for display-control labels (i.e. it reduced the propensity of users to acquire new information). There is ample evidence for this effect from other research areas. For example, in the context of travel mode choices, individuals with strong habits were less active in acquiring new information (Verplanken et al., 1997). Research on the perception of warning signals has demonstrated that the more familiar users were with an appliance, the less likely they were (a) to notice a warning and (b) to comply with it (Laughery and Wogalter, 1997).

There is further support for the influence of habits from the regression analysis, which showed that behaviour under STI could be well predicted by domestic user behaviour. This suggests that established behaviour patterns are also displayed in novel situations, such as the present lab-based setting. In contrast, proenvironmental attitude and ecological knowledge were not associated with ecological performance. When habits are present, individuals may not reflect on their behaviour so that attitude and knowledge have little influence. This is supported by other research that examined the relationship of attitude, knowledge and habits. It suggests that if environmental knowledge and attitude show no association with performance, this will be evidence for the prevalence of habits (Verplanken et al., 1994). Generally, the issue of habitual behaviour is of high relevance in the domestic domain since this environment provides very favourable conditions for the development of habits (see Dahlstrand and Biel, 1997). This is because most domestic tasks are of a rather simple cognitive nature and are characterised by frequent repetitions. Furthermore, the establishment of habits is facilitated in a non-work context due to the absence of control by supervisors and co-workers.

Since ecological instructions have been rather effective in improving ecological user behaviour, this suggests that users did not take full advantage of their mental model of ecological task performance. The fact that ETI primarily reduced trial duration but did not lower settings of power control suggests that most users associated enhanced ecological performance with shorter cleaning times (due to the obvious link with energy consumption) rather than with lower control settings (which would directly reduce energy consumption). The results of the knowledge tests showed that users had little knowledge of the utility of turning down power, which suggests some consistencies between the explicit mental model (i.e. results of knowledge test) and the users' implicit mental model (i.e. demonstrated task performance).

Finally, some recommendations are given to designers who wish to develop more environmentally friendly consumer products. Generally, the designer needs to be aware of the limitations of information-based measures (e.g., instruction manual, on-product information, display-control labelling) since these are contingent upon user motivation and are vulnerable to strong habits. However, despite their limitations, there is no need to reject them completely. First, the implementation of most information-based measures is not very costly and little additional environmental damage ensues from it. This is an important point in ecological design since the potential benefits of a newly implemented device (e.g., a complex feedback device that indicates electricity consumption) during product utilisation must not be offset by problems to manufacture or recycle the device (e.g., substantial increase in electronic waste). Second, work has shown that effectiveness of information-based measures can be increased if implementation is carefully considered. For example, it is important to strive for high spatial proximity between label location and user position (Sauer et al., 2002). Furthermore, it appears that information conveyance through on-product information is more effective than in the form of instruction manuals (Wiese et al., 2002). The utility of on-product information has been confirmed by other work, in which on-product information was presented in written form (e.g., Frantz, 1994) or as pictograms (Davies et al., 1998; Sauer et al., 2003). However, compared to information-based measures, automation appears to be a much more promising route to enhancing ecological performance.

5. Conclusion

The findings of this study are not solely relevant to ecological questions but also extend to the issues of usability and safety in the domestic domain. For example, safe use of consumer products (e.g., Wilson, 1983) may be hampered by habits or low user motivation to follow safe action sequences. Similarly, automation is often useful to reduce safety risks (e.g., an automatic switch-off of a kettle prevents overheating). In addition to usability and safety, the marketability of consumer products is a further aspect that designers have to consider during product development. Market requirements sometimes necessitate difficult trade-offs during product development, for example, if there is a conflict with ecological design criteria (Sauer et al., 2001). Against the background of the interdependence of usability, safety, marketability and ecological performance issues, it is necessary that future work on consumer product design strives for a stronger integration of these issues.

As an example of such an integration, one may refer to the Dyson range of vacuum cleaners. The highly innovative design of the Dyson, based on the cyclone principle, has partly removed the stigma associated with vacuum cleaning and has contributed to its great commercial success in a number of countries, notably the UK. This original design also provides a number of benefits for product utilisation since it meets general product design criteria, such as high transparency of system state (i.e. a clear bin) and ease of system maintenance (i.e. dust bin can be emptied easily).

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References

Alwitt, L.F., Pitts, R.E., 1996. Predicting purchase intentions for an environmentally sensitive product. J. Consumer Psychol. 5 (1), 49–64.

Annett, J., 2002. Subjective rating scales: science or art? Ergonomics 45, 966–987.

Arcury, T.A., Johnson, T.P., 1987. Public environmental knowledge: a statewide survey. J. Environ. Educ. 18, 31–37.

Bullinger, H.-J., Kern, P., Braun, M., 1997. Controls. In: Salvendy, G. (Ed.), Handbook of Human Factors. Wiley, New York, pp. 697–728.

Dahlstrand, U., Biel, A., 1997. Pro-environmental habits: propensity levels in behavioral change. J. Appl. Social Psychol. 27 (7), 588–601.

Dannheim, F., 1999. Die Entwicklung umweltgerechter Produkte im Spannungsfeld von Ökologie und Ökonomie. VDI, Düsseldorf.

Davies, S., Haines, H., Norris, B., Wilson, J.R., 1998. Safety pictograms: are they getting the message across? Appl. Ergon. 29 (1), 15–23.

Endsley, M.R., Kiris, E.O., 1995. The out-of-the-loop performance problem and level of control in automation. Human Factors 37 (2), 381–394.

Frantz, J.P., 1994. Effect of location and procedural explicitness on user processing of and compliance with product warnings. Human Factors 36 (3), 532–546.

Gardner, G.T., Stern, P.C., 1996. Environmental Problems and Human Behavior. Allyn & Bacon, Boston.

Green, W.S., Jordan, P.W., 1999. Human Factors in Product Design. Taylor & Francis, London.

Hines, J.M., Hungerford, H.R., Tomera, A.N., 1986. Analysis and synthesis of research on responsible environmental behavior: a meta-analysis. J. Environ. Educ. 18 (2), 1–8.

Kaiser, F.G., Wölfing, S., Fuhrer, U., 1999. Environmental attitude and ecological behaviour. J. Environ. Psychol. 19 (1), 1–19.

Laughery, K.R., Wogalter, M.S., 1997. Warnings and Risk Perception. In: Salvendy, G. (Ed.), Handbook of Human Factors. Wiley, New York, pp. 1174–1197.

McCarthy, R.L., Ayres, T.J., Wood, C.T., Robinson, J.N., 1995. Risk and effectiveness criteria for using on-product warnings. Ergonomics 38 (11), 2164–2175.

Morgan, C.T., Cook, J.S., Chapanis, A., Lund, M., 1963. Human Engineering Guide to Equipment Design. McGraw-Hill, New York.

Norris, B., Wilson, J.R., 1999. Ergonomics and Safety Consumer Product Design. In: Green, W.S., Jordan, P.W. (Eds.), Human Factors in Product Design. Taylor & Francis, London, pp. 73–84.

Sauer, J., Wiese, B.S., Rüttinger, B., 2001. Utilization phase as a critical element in ecological design. In: Hundal, M.S. (Ed.), Mechanical Life Cycle Handbook: Good Environmental Design and Manufacturing. Marcel Dekker, New York, pp. 257–284.

Sauer, J., Wiese, B.S., Rüttinger, B., 2002. Improving ecological performance of electrical consumer products: the role of design-based measures and user variables. Appl. Ergon. 33 (4), 297–307.

Sauer, J., Wiese, B.S., Rüttinger, B., 2003. Designing low-complexity electrical consumer products for ecological use. Appl. Ergon. 34 (6), 521–531.

Schahn, J., Holzer, E., 1990. Konstruktion, validierung und anwendung von skalen zur erfassung des individuellen umweltbewusstseins. Z. Differentielle Diagnostische Psychol. 11 (3), 185–204.

Sheridan, T.B., 1997. Supervisory control. In: Salvendy, G. (Ed.), Handbook of Human Factors. Wiley, New York, pp. 1295–1327.

Spada, H., 1996. Umweltbewußtsein: einstellung und verhalten. In: Kruse, L., Graumann, C.F., Lantermann, E.D. (Eds.), Ökologische Psychologie: ein Handbuch in Schlüsselbegriffen. Psychologie Verlags Union, Weinheim, pp. 623–631.

Stanton, N., 1998. Human Factors in Consumer Products. Taylor & Francis, London.

Stern, P.C., Gardner, G.T., 1981. Psychology research and energy policy. Am. Psychol. 36 (4), 329–342.

Stern, P., Oskamp, S., 1987. Managing scarce environmental resources. In: Stokols, D., Altman, I. (Eds.), Handbook of Environmental Psychology. Wiley, New York.

Verplanken, B., Aarts, H., van Knippenberg, A., van Knippenberg, C., 1994. Attitude versus general habit: antecedents of travel mode choice. J. Appl. Social Psychol. 24 (4), 285–300.

Verplanken, B., Aarts, H., van Knippenberg, A., 1997. Habit, information acquisition, and the process of making travel mode choices. Eur. J. Social Psychol. 27 (5), 539–560.

Wenzel, H., Hauschild, M., Alting, L., 1997. Environmental Assessment of Products, Vol. 1. Chapman & Hall, London.

Wickens, C.D., Hollands, J.G., 2000. Engineering Psychology and Human Performance. Prentice-Hall, New Jersey.

Wiese, B.S., Sauer, J., Rüttinger, B., 2002. Consumers' use of written product information, submitted for publication.

Wilson, J.R., 1983. Pressures and procedures for the design of safer consumer products. Appl. Ergon. 14 (2), 109–116.

Young, S.L., Wogalter, M.S., 1990. Comprehension and memory of instruction manual warnings: conspicuous print and pictorial icons. Human Factors 32 (6), 637–649.