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Designing low-complexity electrical consumer products for ecological use

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Abstract

This study examined the environmental impact of low-complexity electrical consumer products during their use in a domestic context. In the experimental scenario, 48 users were asked to use a kettle under different conditions. On-product information (OPI), task instruction, and kettle design were employed as independent variables in a mixed multi-factorial design to examine their effects on different parameters of ecological performance (e.g., water and electricity consumption). Measures of user variables (environmental concern, knowledge, domestic habits, environmental control beliefs) were also taken to examine their relationship with performance parameters. The results revealed main effects of ecological task instruction, OPI and (partly) kettle design on ecological user behaviour. Habits, environmental concern and control beliefs were found to be related to performance parameters whereas knowledge was not. The implications of the results for product design are discussed against the background of a strong prevalence of habits and low ecological user motivation.
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1. Introduction

This paper examines the environmental impact of electrical consumer products (ECP) during their use. While previous research on consumer products has had a strong focus on ergonomic issues such as usability (e.g., Green and Jordan, 1999) and safety (e.g., Wilson, 1983; Norris and Wilson, 1999), it is argued here that the environmental impact of ECP represents a further important dimension for consumer product design, warranting ergonomic research. There has been some research in the engineering disciplines about the significance of this particular product group for environmental conservation (Wenzel et al., 1997). That work revealed that the overall environmental impact of ECP was substantial. It also showed that the utilisation phase (i.e. when the user actually interacts with the product) had a stronger environmental impact than other phases of the product's life cycle, such as production and recycling. The utilisation phase accounted for about 80% of the environmental damage of the ECP, averaged across several model products (e.g., refrigerator, TV-set, high-pressure cleaner). The predominance of the utilisation phase illustrates the importance for ergonomic design to consider the environmental impact of product features (Sauer et al., 2001).

In the design of consumer products, there are a number of difficulties that arise from the personal use of products, in contrast to human–machine interaction in a work context. Achieving behaviour modifications in the use of ECP is not a trivial task since the possibilities of influencing user behaviour are much more limited in the domestic domain than in a work environment. This is due to a number of factors, such as little opportunity for formal training, no selection of users for competence, and user-defined tasks (see also Benedyk and Minister, 1998).

In addition to the general problems of ECP utilisation, particular problems are faced when dealing with low-complexity ECP. In the domestic domain, these are products such as kettle, food processor and coffee

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machine. They are different from more complex domestic appliances (such as dishwasher and washing machine) with regard to a number of factors, such as level of automation, number of functions, and ease of maintenance. The possibilities of modifying user behaviour are more limited for low-complexity than high-complexity ECP for at least two reasons. First, habitual behaviour patterns are developed more quickly. This is because the simpler operation of low-complexity products permits a more rapid change from a knowledge-based mode of system management to a skill-based mode (see Rasmussen, 1986). This skill-based mode is considerably more resistant to behavioural change than knowledge-based behaviour. Second, the use of instruction manuals (i.e. the main form of "training" in the domestic domain) decreases with diminishing product complexity (Wiese et al., 2002).

Against the background of the particularities of low-complexity ECP, there is a need to identify and to implement measures that modify user behaviour or, put differently, increase ecological performance of the user-product system. There are several types of measures that may help change user behaviour. First, user behaviour may be constrained by preventing users from showing undesired behaviours (Norman, 1988). For example, when setting up a PC, each plug matches only one socket, effectively preventing any wrong connection. Similar to the rationale behind constraints is the idea behind the automation of functions. It aims to reduce user errors, for example, by implementing an automatic switch-off into a kettle, which strongly minimises the danger of overheating. While this is primarily done for reasons of product safety, this measure also reduces energy consumption. Second, transparency (or visibility) of the product function may be increased (Norman, 1988). For a product with a high level of transparency, it is obvious what the relevant parts are and how they should be operated. Third, product information may be presented with specific instructions to encourage users to behave more ecologically. Traditional forms of product information, such as instruction manuals, may be very limited for this purpose since they are often not (or only partly) read by users (Sanders and McCormick, 1993; Wiese et al., 2002). Therefore, on-product information (OPI) is an important alternative. OPI is typically employed in the form of labels attached to the product itself rather than being enclosed with the product. Research shows that OPI may be efficacious in modifying user behaviour (Frantz, 1993, 1994; McCarthy et al., 1995). Their efficacy is influenced by a number of factors, such as location proximity, procedural explicitness, print design and amount of information presented.

Environmental behaviour during use of ECP is not only dependent on system features but may also be influenced by other factors. A causal model of resource-consumption behaviour contains several variables which are considered to be related to environmental behaviour: knowledge, attitudes and beliefs, external incentives and constraints, and socio-economic background (Stern and Oskamp, 1987; Gardner and Stern, 1996).

In social and environmental psychology, there has been extensive research on the relationship of proenvironmental *attitude* and ecological behaviour (e.g., Fransson and Gärling, 1999; Kaiser et al., 1999). The findings of a meta-analysis concluded that the correlation between environmental concern and ecological behaviour was at best moderate (Hines et al., 1986). This link becomes stronger if attitudes and behaviour are measured at a high level of specificity (Kaiser et al., 1999). On the basis of the causal model of Stern and Oskamp (1987), it may be argued that environmental concern alone is not sufficient to induce proenvironmental behaviour if it is not backed by appropriate *knowledge*. This refers to knowledge of appropriate strategies to achieve environmental goals as well as to knowledge of the environmental impact of behaviour patterns. Knowledge of strategies in the context of human–machine interaction may also be described by the concept of mental model. The quality of the mental model is an important performance-shaping factor (Norman, 1983; Wickens and Hollands, 2000).

While some users show high environmental concern, they may not necessarily be convinced that their proenvironmental behaviour will make much difference to environmental conservation. This is reflected in the concept of control beliefs, which refers to the degree to which individuals believe that they are the master of their own destiny (Rotter, 1971). In the context of environmental conservation, this means to what extent individuals perceive their own behaviour as having an impact on the state of environment (Hoff and Walter, 1998). The concept of *environmental control beliefs* encompasses several dimensions. While some individuals discount their personal influence on shaping the environment, they may believe that the collective of consumers and/or powerful agents (such as industry and government) exert some influence on the environment. It is argued here that environmental control beliefs represent a further important user variable affecting ecological behaviour.

Finally, proenvironmental behaviour may also be affected by the presence of *habits*. Behaviour patterns that are carried out without undergoing any reflective process are particular resistant to change. There has been empirical evidence of the difficulties associated with the modification of habitual behaviour in the domestic environment (Dahlstrand and Biel, 1997). This problem has also been coined "behavioural inertia" (Gardner and Stern, 1996). The adoption of habitual behaviour is facilitated when tasks are characterised by low complexity and are frequently completed.

2. Present study

The present study is concerned with the utilisation of low-complexity ECP and how ecological performance of this product group can be improved. The goals of the study were twofold: First, it examined ways of improving ecological user performance by modifying product design features. Second, it aimed to gain a better understanding of the influence of user variables on ecological performance.

The kettle was chosen as a model product of a low-complexity appliance for two reasons. First, it is a frequently and widely used appliance and is characterised by considerable electricity consumption during operation (up to 3 kW h). This indicates a sizeable environmental impact. Second, ecological performance is more transparent for this appliance because it is comparatively easily quantifiable (e.g., boil water for two cups of tea). For most other ECP (e.g., vacuum cleaner, hair dryer) task goals tend to be much less specific (e.g., clean the carpet thoroughly or dry the hair thoroughly), partly because the appliance does not support the determination of task goals at a high level of precision. Whereas the kettle may provide this support (e.g., to gauge 0.4 l of water), neither hair dryer nor vacuum cleaner provide any equivalent feedback (e.g., by assessing the number of dust particles per mm^2 left on the floor). Put differently, the user cannot show high ecological performance if he/she does not know when the floor is clean. Ecological performance becomes more evident to the user if the appliance supports a clearer definition of task goals. Therefore, a greater influence of user variables on performance is expected for kettle use.

Previous work has already addressed the specific problems of kettle use (Stanton and Baber, 1998). Based on a task analysis for error identification, Stanton and Baber have identified a considerable number of typical user errors, such as pouring water before it has boiled or not switching off a boiling kettle. Although their work was not explicitly related to ecological product usage, the consequences of these errors for ecological performance are obvious. Critical ecological parameters in kettle utilisation are water usage and energy consumption. Both are strongly interrelated and depend largely on the amount of water being boiled. If the kettle is filled with more water than actually needed, this will increase boiling time, water usage and electricity consumption.

There may be a number of factors of why ecological user performance may be non-optimal: poor mental model of user about what constitutes ecological performance, lack of motivation to behave ecologically, strong habits that result in largely unreflective behaviour, and poor product design that does not adequately support the user in completing task goals. The kind of ergonomic measures needed to improve ecological performance would clearly depend on the respective influence of each factor.

If non-optimal ecological performance was due to a poor mental model, specific advice in the form of OPI should be effective. This is because of the knowledge-conveying function of OPI, which informs the user about how the appliance is operated best. The user's mental model is measured by giving specific instructions to users to demonstrate their best ecological task performance. For the present study, OPI advises that the kettle is not to be filled with more water than required. First evidence for the use of OPI in the domestic domain suggested that it was moderately effective (Wiese et al., 2002; Sauer et al., in press, 2002).

If non-optimal ecological performance was due to habits or because of low motivation to perform the task in an environmentally friendly manner, the knowledge-conveying function of OPI would have little effect because users would not seek information in the same way as they would do if they wished to improve their mental model. Although OPI may also have the effect of instigating behavioural change (since users are asked to behave in a certain way), this effect would be expected to be smaller because the information was presented in written form and was well integrated into the design of the kettle (i.e. low level of explicitness). Furthermore, the information was not part of the experimental instruction. In contrast, if users are orally instructed by the experimenter to perform the task in an environmentally friendly manner (i.e. high level of explicitness), it is expected that this would (at least partly) break non-ecological habits and would "encourage" users to show improved ecological performance during the experiment.

Based on these considerations, it was predicted that ecological instructions would reduce resource consumption. Furthermore, it was hypothesised that OPI would also enhance ecological performance. This was based on the assumption that knowledge levels were moderate and would be enhanced via product information. A significant interaction of OPI and instruction was also predicted in that ecological performance would be highest under OPI and ecological instruction, compared to all other conditions. These predictions are illustrated in Table 1. Based on the pattern of results, the respective influence of knowledge and habits on ecological performance can be determined. For example, if, against

Table 1
Predicted pattern of effects for ecological performance as a function of on-product information and task instruction

	On-product information	No information
Ecological instruction	(Strongly) increased	Increased
Standard instruction	Increased	Baseline

our predictions, knowledge was low and habits were weak, a main effect OPI would be expected but no effect for task instructions. This is because OPI provides specific advice about how to perform the task ecologically.

The present study also examined two design features in which kettles may differ: transparency and scale label. Stanton and Baber (1998) have demanded that the kettle should be transparent or equipped with a floating ball to enable the user more easily to determine the amount of water in the appliance. The floating ball may be considered a (mechanical) display that informs the user about the current level of water in the appliance. Compared to a transparent kettle, there is however a delay of feedback since the floating ball usually rests in a small tube in which the water rises slightly slower than in the main body of the appliance. This is of little importance if the user requires static information (e.g., "Is there enough water left in the kettle to make another cup of tea?") but becomes more relevant if dynamic information is required (e.g., "How long would the tap need to be left on if the kettle was to be filled for exactly one cup of tea?"). A research question in this study was whether this slight feedback delay would lead to an overestimate of the water needed, compared to a transparent plastic kettle. It was hypothesised that users employing a highly transparent kettle would consume fewer resources than when using a low-transparency kettle.

Kettles also differ in the kind of labels used for scale markings. There are litre-scales, which provide a very precise unit of measurement but not all users may be able to mentally transform the size of a cup into a litre scale. Conversely, while cups labels represent a more symbolic unit of measurement, they have the problem that they may not match the cup in size on which the scale is based. There was no research hypothesis of what kind of scale labels would provide better support to the user.

3. Method

3.1. Participants

Forty-eight participants took part in the study (female: 37.5%), aged 19–38 years ($M = 21.5$). All participants were regular kettle users. They were recruited among the student population of Darmstadt University of Technology and were not paid for their participation.

3.2. Design

Three independent variables were examined in a mixed $3 \times 2 \times 3$ factorial design: task instruction, product information and type of kettle.

Task instruction was varied at three levels as a within-users variable. No task instruction (NTI): Users were asked to make tea without any further specification. Ecological task instruction (ETI): Users were instructed to make tea "in an environmentally friendly way". Standard task instruction (STI): Users were given the instruction to make tea "as they would do at home".

OPI as a between-users variable was manipulated at two levels: *product label* versus *no product label*. In the first condition two coloured labels were placed on the kettle, one positioned on the body of the kettle, the other on top. No labels were used in the other condition.

Type of kettle was varied between users at three levels. The appliances differed in two factors: level of transparency and scale label. The first model was highly transparent with the label representing litre scales (HiT-L). The second was also highly transparent but used cup labels for the scale markings (HiT-C). The third model was characterised by low transparency and had litre scales (LoT-L).

3.3. Measures and instruments

3.3.1. Performance measures

Water consumption: This refers to the amount of water (l) used to carry out the task. Separate measures were taken of total water consumption (i.e. water being boiled) and the remains left in the kettle (i.e. water not used for making tea).

Energy consumption: This parameter measures total energy consumption (kW h) during the experimental trial. This measure was a direct function of trial duration (i.e. time during which appliance was in operation) since power levels of the appliance were not adjustable. Therefore, a separate measure of trial duration was not taken.

Early switch-offs: This was a dichotomous variable measuring whether the participant had manually switched off the appliance before the automatic function did.

Discarded liquid: This measure was also taken as a dichotomous variable, indicating whether participants rinsed the kettle and poured water into the sink.

3.3.2. Environmental knowledge

A six-item test was developed that specifically measured the explicit mental model of ecological kettle use. The users had to indicate whether the statement was correct, incorrect or the response was not known. An example of an item was: "Descaling your kettle reduces energy consumption". Additionally, the user had to indicate for each response the confidence with which the judgement was made on a 7-point Likert scale (very confident—not at all confident).

The scoring method used was different from conventional scoring methods. It took into account incorrect responses and also the confidence level with which users made their judgement. The score for each item (1 for a correct response, −1 for an incorrect one) was multiplied by the confidence score (from *very confident=1* to *not at all confident=1/7*). This means if a response was incorrect, this lowered the total score. A maximum test score of 6 could be obtained if all items were correctly responded to and maximum confidence levels were expressed for each response. The distribution of test scores ranged from 0.4 to 6.0 ($M = 4.25$; SD = 1.38).

3.3.3. Environmental concern

This was measured by an 38-item version of the environmental concern questionnaire (ECQ) developed by Schahn and Holzer (1990). It comprises sub-scales of different aspects of ecological behaviour: water conservation, energy conservation, recycling, sport and leisure, community action, shopping and traffic. The last five concepts were measured by three items each (from the short version of ECQ) while the most relevant subscales for the present study (water conservation, energy conservation) were measured by 12 items each (from the long version of ECQ). The analysis revealed the following score for the ECQ and its subscales: ECQ (M= 181.3, SD = 22.4), "energy conservation" (M= 65.2, SD = 8.1) and "water conservation" (M= 57.2, SD = 8.4).

3.3.4. Environmental control beliefs

This was measured by a 12-item measure of environmental control beliefs (Wiese and Sauer, 2000), based on the theoretical work of Hoff and Walter (1998). A distinction was made between four different kinds of control beliefs.

Control of individual: This measures the degree to which each individual can make an impact on the state of environment (Example item: As an individual I can make an impact on environmental conservation).

Control of consumer collective: Not a single person but all consumers together can exert some influence (Example item: Unless all consumers behave ecologically, my own behaviour will not have much impact).

Control of powerful agents: Only powerful stakeholders (such as industry and government) can make an impact on environmental conservation (Example item: Environmental legislation represents the most effective measure for conservation).

Control of collective and powerful agents: Only consumers and powerful others together can exert some influence (example item: for successful environmental conservation, all stakeholders together (industry, government and consumers) have to pull their weight).

Responses needed to be indicated on a 7-point Likert scale (very confident—not at all confident).

3.3.5. Self-reported domestic behaviour

A six-item questionnaire was developed to capture users' employment of the kettle in their domestic environment. Its items covered the following specific behaviours: energy conservation, water conservation, exact filling, switching off manually, regular descaling, and general ecological behaviour during kettle usage. The items were presented in the form of a statement, such as "I generally try to save water when I use a kettle", using a 7-point Likert scale (strongly agree—strongly disagree).

3.4. Material and procedure

The experimental work took place in a laboratory that was equipped with all facilities needed to make tea. Users were assigned to one of six experimental conditions, where they were given one of the three kettle types, either with or without the information label. For the conditions HiT-L and HiT-C, a model from Kenwood (JK 723) was employed, which, due to its transparency, allowed a direct reading of the water level. Under HiT-L the kettle was equipped with a litre scale that indicated the amount of water in 0.2 l intervals. For the HiT-C condition, the indications in litres were replaced by cup labels. In the condition LoT-L, a Krups model (Aqua Control 858) was used. This model was not transparent but water levels were indicated by a floating ball. Scale indications were in litres.

The design of the product label took interindividual differences in user priorities into account by pointing out several benefits to filling the kettle only with as much water as actually needed (savings in time, energy and water). Fig. 1 shows the label used. One label was placed on the body of kettle, a second one on the lid.

Users were instructed to make three cups of tea with the material available: kettle, three cups (0.2 l each) and tea bags. In the first trial, users were simply instructed to

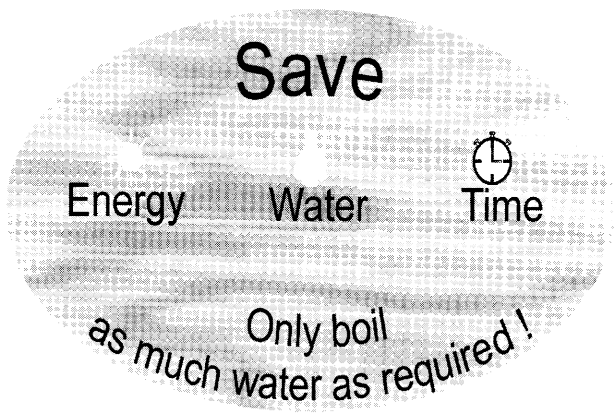

Fig. 1. OPI label.

make the tea without any further specification (NTI). This was considered a training trial that allowed users to familiarise themselves with the appliance. In the second trial, they were either given the instruction "to make the tea as they would do at home" (STI) or "to make the tea in an environmentally friendly way" (ETI). Half of the users received the trials in the order *NTI–STI—ETI*, the other half in the order *NTI—ETI–STI*.

The amount of water used to make the tea was determined by a measuring jug. A multi-purpose electricity meter was employed to measure electricity consumption and time needed to boil the water. After the third trial was finished, users were given the battery of instruments in the following order: knowledge test, short interview, ECQ, environmental control beliefs questionnaire, and domestic behaviour questionnaire.

4. Results

4.1. Performance measures

Water consumption: This was the primary variable of ecological performance, as it also influenced electricity consumption. The results showed an effect of kettle type, with the HiT-C group using less water than the two groups with litre scales (see Fig. 2). This was confirmed by a significant main effect ($F = 3.49; df = 2.42; p < 0.05$) and post-hoc LSD-tests showing that only HiT-C was different from the two others ($p < 0.05$). Fig. 2 also seems to suggest that the information label reduced water use but the difference failed to be significant ($F = 3.01; df = 1.42; p = 0.089$). As predicted, ETI resulted in improved ecological performance on this parameter compared to STI and NTI ($F = 24.6; df = 2.84; p < 0.001$). While ETI was different from the two (LSD-test: $p < 0.001$), no significant difference was found between STI and NTI (LSD-test: $p > 0.05$). In addition to total water consumption, the remaining water in kettle was also measured. As the pattern of results was found to be very similar, these data are not reported here.

Energy consumption: This refers to total energy consumption (kW h) during the trial. The results for this parameter showed a close relationship to water consumption because power levels were not adjustable. Electricity use was lowest for HiT-C, followed by HiT-L and LoT-L (see Fig. 3). However, the difference was not sufficiently large to be statistically significant ($F = 1.85; df = 2.42; p = 0.16$). A clear difference was found for information label, with the prompt significantly reducing energy consumption ($F = 6.74; df = 1.42; p < 0.05$). Fig. 3 also illustrates the significant decrease in electricity use under ETI, compared to STI and NTI ($F = 26.6; df = 2.84; p < 0.001$). The difference was significant between ETI and the two others (LSD-test: $p < 0.001$), but not between STI and NTI (LSD-test: $p > 0.05$).

Early switch-off and rinsing: Energy consumption is mainly a function of the technical efficiency of the appliance and the amount of water being boiled. Additionally, it can be influenced by energy-saving strategies, such as switching off the appliance immediately after boiling point (i.e. some seconds before the automatic switch-off). Under STI, 43.8% of users

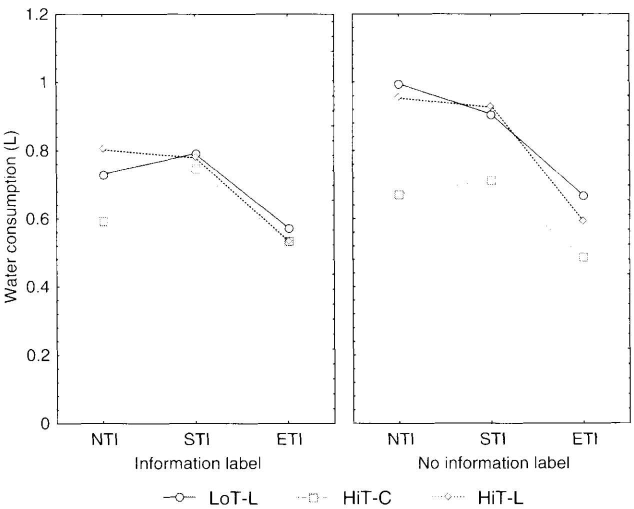

Fig. 2. Water consumption (l) as a function of OPI, task instructions and transparency (NTI: normal task instructions, STI: standard task instructions, ETI: ecological task instructions; LoT-L: low transparency-litre, HiT-C: high transparency-cups, HiT-L: high transparency-litre).

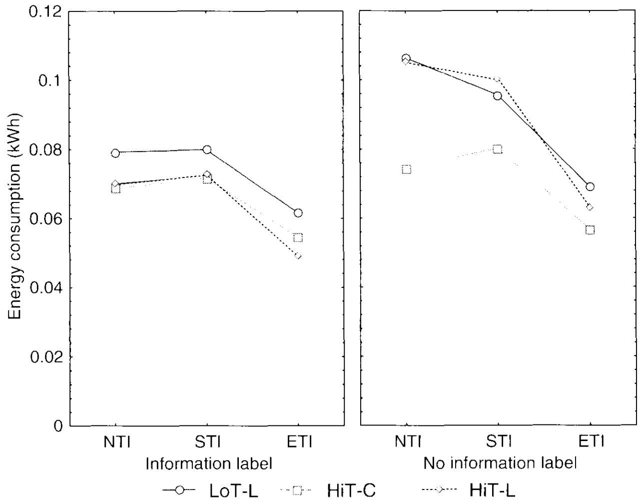

Fig. 3. Energy consumption (kW h) as a function of OPI, task instructions and transparency (NTI: normal task instructions, STI: standard task instructions, ETI: ecological task instructions; LoT-L: low transparency-litre, HiT-C: high transparency-cups, HiT-L: high transparency-litre).

switched off the appliance manually while this proportion significantly increased to 62.5% under ETI (sign-test: $p<0.05$). Under STI, there was a slightly larger number "early switch-offs" when the product label was present ($N = 13$) than when it was not ($N = 8$). However, this difference was not significant ($Chi^2 = 2.12; p > 0.05$). The difference was even smaller under ETI (16 vs. 14 users). For the amount of liquid discarded, the analysis revealed that only a minority of users (10.4%) showed this behaviour. There were no effects of independent variables.

4.2. User variables

Fig. 4 shows the correlation coefficients for different user variables and performance measures. They all refer to the condition STI since no significant relationships were found under ETI.

Environmental knowledge: The results showed no association with performance measures (all $r<0.01$). There was a positive relationship with the subscale "water conservation" of the ECQ ($r = 32; p<0.05$). No other significant correlations were found.

Environmental concern: Examining the relationship of environmental concern and performance showed that users with a high score on the subscale "water conservation" used less water in the experiment under STI ($r = -0.31; p<0.05$). Interestingly, the correlation between the subscale "energy conservation" and experimental energy consumption was not significant ($r = -0.06; p > 0.05$). There was also a correlation between the two subscales "water conservation" and "energy conservation" ($r = 57; p<0.001$). When examining correlations among user variables, it emerged that environmental concern was positively correlated with individual control beliefs ($r = 0.32; p<0.05$). No other significant associations were recorded.

Environmental control beliefs: The analysis showed that users with high individual control beliefs used up less water in the experiment under STI ($r = -0.30; p<0.05$) while those who scored high on the subscale "powerful agents" consumed more water under the same experimental condition ($r = 0.31$; $p<0.05$). There were no other significant associations with performance variables.

Self-reported domestic behaviour: There was evidence for some correspondence of behaviour shown in the experimental situation and in a domestic setting. Overall, there were significant associations between domestic behaviour and performance under STI but not under ETI and NTI. Users who reported ecological use of kettle in the domestic environment consumed less water ($r = -0.34; p<0.05$) and less electricity ($r = -0.35; p<0.05$) in the experiment under the STI condition. There was a significant correlation between self-reported manual switch-off (item 5) and actual switch-off under STI ($r = 0.49; p<0.001$) but not for ETI ($r = 0.24; p > 0.05$).

User variables and performance: A hierarchical multiple regression analysis was used to predict performance

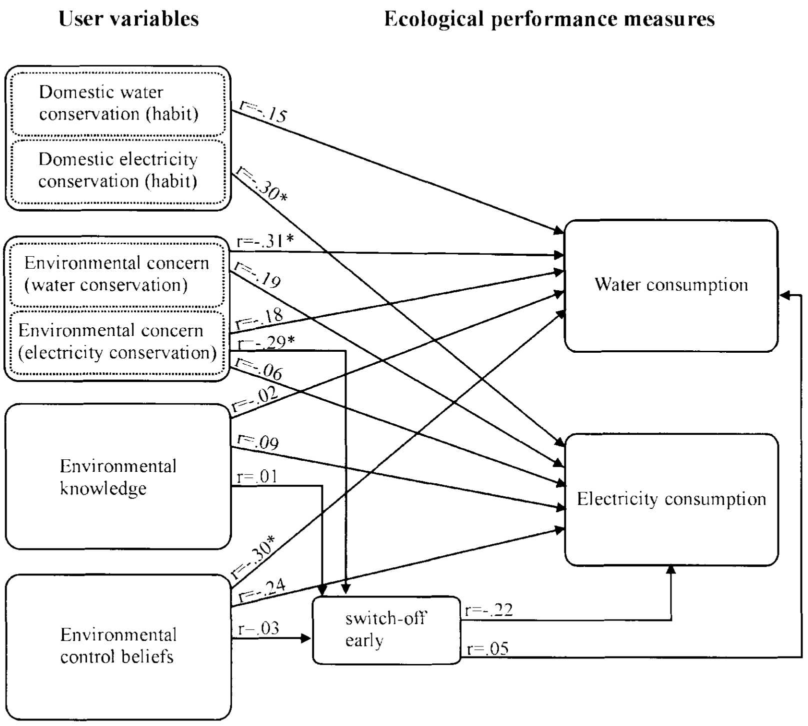

Fig. 4. Relationship between user variables and performance measures under experimental condition "standard task instruction" ($*p<0.05$).

from user variables. The following predictors were entered into the equation: environmental concern, domestic behaviour and environmental control beliefs. The analysis revealed that water consumption under STI could be significantly predicted ($R^2 = 0.22; p<0.05$) by the following variables: environmental concern ($\Delta R^2 = 0.08$), domestic behaviour ($\Delta R^2 = 0.02$), and environmental control beliefs ($\Delta R^2 = 0.02$). The ΔR^2-values represent the unique variance of each variable. The remaining variance ($\Delta R^2 = 0.10$) was shared by environmental concern, domestic behaviour and control beliefs. No such significant predictions could be made for water consumption under ETI ($R^2 = 0.09$). The analysis of energy consumption as a criterion did not reveal any significant results, neither for STI ($R^2 = 0.11$) nor for ETI ($R^2 = 0.08$).

Post-experimental interview: Some interesting findings also emerged from the interview data. 95.8% of users remembered that there was a product label and 87.5% could recall its content correctly. However, only 10.4% of users reported that they would change their behaviour in future when using a kettle (i.e. old behaviour patterns will prevail).

Table 2
Summary of main findings

Variable	Observed effects
Task instruction	Under ecological task instruction, best performance for all ecological performance indicators (water, energy, switch-off)
On-product Information	Led to reduced energy consumption (water consumption just failed to show a significant effect)
Kettle type	Cup scale resulted in lower water consumption than litre scale; no effect of transparency
Environmental concern	Users concerned about water consumption used less water in experiment
Environmental knowledge	No association with performance variables
Environmental control beliefs	Users with high individual control beliefs used less water in experiment
Self-reported domestic behaviour	Association between domestic behaviour and experimental performance under standard task instruction

5. Discussion

The results showed that all independent variables had an effect on ecological performance. Effect sizes were larger for task instruction than for OPI and kettle type. All user variables showed some form of relationship with performance, except for knowledge. The results are summarised in Table 2.

The first major finding of the study was that ecological performance increased under ETI compared to the other conditions. Confirming the research hypothesis, this finding suggests that lower ecological performance under STI (and NTI) was not primarily due to a knowledge problem (though it played a smaller role) but because of ecologically undesirable habits and/or low motivation to perform the task ecologically. Previous research in the domestic domain also found that ecological performance significantly increased when users were instructed accordingly, suggesting that the ecological performance potential was not taken advantage of under normal task conditions (Sauer et al., in press, 2002).

This finding has implications for the implementation of ergonomic design measures. It is generally much more difficult to implement measures that break habits or increase low user motivation than to improve the user's mental model. To achieve the latter, information-based measures (e.g., product transparency, user feedback, OPI) are useful since they support the achievement of the user's task goals by providing information about product state (e.g., kettle is filled) and optimal product management (e.g., average energy consumption). However, the effectiveness of these measures is clearly dependent upon the user's willingness to pursue ecological task goals.

If habits represent a barrier to high ecological performance, measures of another kind are needed. While breaking ecologically undesirable habits is generally a difficult task (Dahlstrand and Biel, 1997), this becomes even more challenging if interventions are limited to design measures. An important design option is to allocate to the machine those functions for which ecologically undesirable habits have been formed, hereby effectively removing the activity from the user. An example of an important automated function in kettle design is the automatic switch-off. It supports the user in reducing energy consumption by eliminating prospective memory failures of forgetting to switch off the appliance. While automation is generally considered a useful measure to improve overall human–machine-system performance (Wickens and Hollands, 2000), in the domestic domain particular attention needs to be paid to the kind of automation implemented. To achieve a sufficient level of user acceptance, the user should still have the possibility of overriding the machine. This would correspond to an intermediate level of automation, as proposed by automation models (Sheridan, 1997; Endsley and Kiris, 1995).

If the cause of poor ecological performance was due to low motivation, the conflict between ecological and personal task goals would have to be reduced. A personal goal may be to minimise physical effort (e.g., kettle is always filled to the top to reduce number of refills), which however leads to increased electricity consumption. To reduce this conflict, a design-based modification may be a double-reservoir kettle in which only one reservoir is boiled. Obviously, design modifications of this kind need to be evaluated with regard to user acceptance.

Interestingly, there was no change from NTI to STI, suggesting the absence of any practice effects. One could have expected these, as users improve in their ability to match cup size and scale. However, due to the low complexity of the appliance, it is quite conceivable that learning effects did not take place.

The second major finding was that knowledge was not a primary determinant of ecological performance. If it had been a knowledge problem, at least one of the following three observations should have been made. First, the knowledge test score should have been correlated with ecological performance, which was not the case. Second, ecological instructions should not have led to performance improvements as observed since users would have been lacking the knowledge to achieve them. Third, there should have been a stronger effect of OPI than actually found since the label provided users with the knowledge needed.

As indicated by the test results, the user's explicit mental model of ecological performance was generally quite good. This is likely to have resulted in the effect of OPI being less strong than expected. This is because of the effectiveness of OPI being related to the user's mental model. The higher knowledge levels are, the smaller the amount of new information is that can be acquired by the user. Nevertheless, a small effect was observed, which confirmed our research hypothesis. In addition to its knowledge-conveying function, OPI also encompasses a prompting function. Therefore, reminding users of the completion of certain actions may also have contributed to the effect of OPI even if no new information had been acquired by the user.

In the context of designing information labels, the problem of human limitations in information processing also needs to be considered. Previous research from the domestic domain indicated that the effectiveness of OPI can be increased by limiting the number of messages to one or two since more information is unlikely to be processed by the user (Wiese et al., 2002; Sauer et al., in press). This raises the question of what information is to be presented if there are limits to the amount of information being processed. The two primary criteria to be considered are (1) the potential impact of not following the instruction and (2) the likelihood that the instruction instigates behavioural change (McCarthy et al., 1995). One can also assume that OPI is more efficacious with consumer products for which no habits have yet been formed. Since most studies in the literature investigating OPI employed products that are not normally used very frequently (e.g., drain cleaner in Frantz, 1993), one might expect lower effectiveness of OPI for familiar consumer products.

The third important finding was that an association between environmental concern and performance was found. A similar association emerged for individual control beliefs and performance. In both cases, for environmental concern and control beliefs, the association applied to water conservation but not to electricity conservation. This raises the question of why was there an association between attitude and behaviour although many previous studies from the domestic domain regularly failed to demonstrate a relationship of this kind (Sauer et al., in press, 2002). Furthermore, the question needs to be asked why was there an association of attitude with water consumption but not with electricity consumption.

These unexpected results may be due to differences between the present study and previous research. Ecological performance in kettle use is much more clearly definable than in other appliances. The feedback provided by the appliance makes deviations from optimal ecological performance more evident, helping users show the behaviour that corresponds to their proenvironmental attitude. However, this only applies to water use but not to electricity consumption. There was direct feedback about water consumption whereas no such feedback was given to the user about energy use. Furthermore, water is a visible resource while electricity is not. Both factors, feedback and visibility, may have contributed to water consumption being more closely related to attitude than energy use. This suggests that the association between attitude and performance was resource-specific. However, the research literature (which has predominantly examined energy consumption rather than water consumption) has, hitherto, paid little attention to resource-specific effects. This may be inappropriate since the association of attitude and behaviour may not only depend on visibility and feedback but also on the perceived importance of the resource for environmental preservation.

Overall, the results of the regression analysis suggested that the influence of user variables was not negligible since a considerable amount of variance of water consumption (22%) could be predicted from user variables. This is noteworthy in the light of the fact that the present study measured actual behaviour rather than behaviour intentions or self-reported past behaviour, as it has been done in many previous studies exploring the relationship between attitude and behaviour. One would normally expect a lower R^2-coefficient for actual behaviour than for behaviour intentions since the former is influenced by more intervening variables (effectively reducing R^2) than the latter.

Based on the results discussed so far, the important question needs to be raised of what kind of ergonomic measures are best suited to improve ecological performance. There were small but clear benefits for the use of OPI, which should be provided in succinct form. If appropriate, one may also consider the use of pictograms since they have some advantages over text-based information labels (see Davies et al., 1998).

Cup scales appeared to be somewhat superior to litre scales. This may be because, unlike litre scales, cup scales require no transformation into physical units. While cup scales appeared to be the preferable option, a combination of both may be even better since for some purposes the litre scale may be more useful. Contrary to expectations, the level of transparency had no effect on user performance. This may be because the feedback delay of the low-transparency model was too small to show any significant effect. Nevertheless, it is difficult to see why high product transparency should not be aimed for, as there is a sound theoretical basis for this recommendation.

In future empirical studies, further product features of high relevance to ecological performance may be worth examining. First, an *acoustic feedback signal* may be helpful since it indicates the termination of the boiling process (as a whistling kettle does). This is because users often forget to attend to the kettle again because they have been busy with other domestic tasks in the meantime. This represents a prospective memory failure (e.g., Sauer, 2000), of which the consequence for ecological performance is an energy-wasting re-boiling. Second, there may be benefits to an *adjustable set point* for the automatic switch-off. Some beverages require temperature levels well below boiling point (e.g., instant coffee, green tea). If the kettle does not have this adjustable set point, users have to let the water cool down from boiling point rather than the kettle being switched off at a lower temperature. This of course impinges on ecological performance. Alternatively, a *temperature display* may support the user in deciding when the appliance needs to be switched off.

Finally, against the background of ecological design of consumer product, it is also important to take into consideration the additional environmental impact (and manufacturing cost) of implementing a design-based measure. It has to be demonstrated that the benefit of increasing ecological performance during product utilisation is not outweighed by undue increases in the product's environmental impact during other phases, such as manufacturing or product disposal. This weighing up of the environmental impact across different phases of the product's life cycle is a critical activity for ecological design of consumer products (Wiese et al., 2001). For example, in the case of OPI, the additional environmental impact of producing the label would be minimal, which adds to the utility of OPI.

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