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Automation and decision support in interactive consumer products

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This article presents two empirical studies (n = 30, n = 48) that are concerned with different forms of automation in interactive consumer products. The goal of the studies was to evaluate the effectiveness of two types of automation: perceptual augmentation (i.e. supporting users' information acquisition and analysis); and control integration (i.e. supporting users' action selection and implementation). Furthermore, the effectiveness of on-product information (i.e. labels attached to product) in supporting automation design was evaluated. The findings suggested greater benefits for automation in control integration than in perceptual augmentation alone, which may be partly due to the specific requirements of consumer product usage. If employed appropriately, on-product information can be a helpful means of information conveyance. The article discusses the implications of automation design in interactive consumer products while drawing on automation models from the work environment.

Keywords: Automation; Consumer product; Performance; On-product information; Environmental concern

1. Introduction

1.1. *Background and automation models*

This article is concerned with different forms of automation in interactive consumer products (ICP) and their impact on the effectiveness of product usage. More specifically, it examines to what extent automation can be used to shorten task completion times, increase accuracy of performance and reduce energy consumption. All three parameters may be considered efficiency measures of product operation (cf. Jordan 1998).

ICP are technical systems that are used by humans outside a work context, such as during domestic and recreational activities. While there is considerable research on automation in work environments (e.g. Parasuraman and Mouloua 1996), there is

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comparatively little work that has specifically addressed this issue for ICP. This article examines to what extent the advancements made in automation research in work environments can be used for ICP. For that purpose, two empirical studies are presented that examined different forms of automation design for ICP.

Automation research in a work context has developed a number of models that provide guidance in designing human-centred automatic systems (e.g. Sheridan and Verplank 1978, Parasuraman *et al.* 2000, Kaber and Endsley 2004, Wandke 2005). These models have been applied to a range of application areas such as continuous process control, discrete manufacturing and transportation. In the domestic domain, most technical processes are discontinuous (like the one examined in the current article) since they can be interrupted without any negative consequences ensuing from this suspension. Therefore, these automation models may also be useful when designing automated ICP. The model of Parasuraman *et al.* (2000) is presented here in more detail. Their model comprises two dimensions, with the vertical dimension representing different levels of automation. This ranges from low levels (e.g. full manual control) through intermediate levels of automation (e.g. machine makes suggestions to operator) through to full control by the automatic system with no human intervention possible. The horizontal dimension outlines the following four phases representing the human decision-making process: information acquisition; information analysis; action selection; action implementation.

1.2. *Perceptual augmentation and control integration*

The first two phases (information acquisition and analysis) refer to perceptual augmentation (PA) (Lee and Sanquist 1996). PA is concerned with the automation of functions that improve the human's perception of the system and its environment rather than supporting the actual control of the system. For example, using radar improves information acquisition because targets become visible to the human that would otherwise have remained invisible. An example for information analysis would be a plotting aid that helps determine the position of the target at a certain time in the future (e.g. speed vector of a vessel). This kind of support may also be provided in the domestic domain. For example, a sensor in a dishwasher detects that an insufficient amount of detergent has been added (information acquisition). The current level is compared against the required standard and the user is notified by a signal (information analysis). The critical question in system design is at what level of automation this decision support function should be implemented. In the context of work-related automation, it is argued that level of automation can be quite high for these phases because it will reduce operator workload and free mental resources (Wickens *et al.* 1998). It remains to be empirical tested whether this would also apply to the domestic domain.

The last two phases of the model are concerned with action selection and its implementation. This may be termed control integration (CI) (Lee and Sanquist 1996). CI enhances the ability of the human to control the system (e.g. autopilot on a ship's bridge). This includes action selection (e.g. deciding that the course of a vessel is to be altered) and subsequent implementation of the action (e.g. turning the steering wheel). In the context of ICP, this may be applicable to dishwasher design. After a dishwasher has detected highly polluted water (due to dirty dishes), the automation takes the decision to use more water (action selection), which is implemented by opening the water supply valve (action implementation). According to findings in automation research, automation levels should be lower for these phases if system tasks involve considerable uncertainty and risk (Wickens *et al.* 1998). The findings also suggest that automation levels may be higher for these phases if the system tasks involve relatively little uncertainty and risk. Since the latter situation would typically apply to the ICP domain, one might generally envisage higher automation levels in this domain. This would also meet user preferences because it will relieve the user of routine tasks, freeing time that may be spent on more interesting activities.

1.3. *On-product information*

The effectiveness of automation may be influenced by the availability of static information (e.g. display labelling or product labels) that supports the user in achieving task-related goals. Of particular relevance is static information for ICP usage, since, unlike in work environments, there is no formal training that instructs the user in how to operate the system. A widespread form of conveying information to domestic users is by means of instruction manuals. However, their major drawback is that they are rarely consulted by users (Sanders and McCormick 1993). This is usually only done if serious usability problems are encountered or users do not feel at all confident with using the appliance. Therefore, alternative means of static information conveyance are of importance in ICP design, such as product labels, display and control labelling. In contrast to instruction manuals, these are permanently visible to the user and may therefore have a stronger influence on behaviour. The term on-product information (OPI) is used here to refer to all static information that is being presented on the appliance. A number of studies in ICP design have already demonstrated the effectiveness of OPI in modifying user behaviour (e.g. Sauer *et al.* 2002, 2004, Sauer and Rüettinger 2004).

For effective information conveyance from the machine to the user, the content of the message needs to pass successfully through several stages of information processing. According to a four-stage model of information processing, information needs to be noticed, encoded, comprehended and complied with by the user (Rogers *et al.* 2000). At any stage, the information-processing sequence may break down so that the desired behaviour modification does not occur. Whereas the first three phases place particular emphasis on the presentation of information (e.g. gaining attention, comprehensibility), the fourth and last phase points out the important fact that the user needs to be sufficiently motivated to follow the advice.

1.4. *Influence of user variables*

While product design features undoubtedly have an impact on user behaviour, there are also person-related factors that are expected to have an influence on user behaviour. Since one of the efficiency measures examined in this work was electricity consumption (which represents an important aspect of environmentally friendly product usage), it was of interest to what extent pro-environmental user behaviour is influenced by user variables such as environmental concern and environmental knowledge. Both user variables have been considered as antecedents of pro-environmental user behaviour (Gardner and Stern 1996).

The research literature does not provide unequivocal findings with regard to the relationship of environmental concern and ecological behaviour (e.g. Hines *et al.* 1986, Fransson and Gärling 1999, Kaiser *et al.* 1999). However, there is evidence that the association becomes stronger when both factors are measured at a high level of specificity. A similar picture emerged with regard to the association between knowledge and behaviour (Kaiser and Fuhrer 2003). The evidence was mixed but the strength of the association increased when operational knowledge was examined (e.g. knowledge of procedure to achieve environmental goals) rather than factual knowledge (e.g. knowledge of strong environmental impact of car usage). Overall, the literature on the relationship of person-based factors and environmentally friendly behaviour seems to be characterized by considerable inconsistencies in their findings.

1.5. *The present studies*

The present work was were chiefly interested in the question to what extent automation can be used to improve the efficiency of ICP usage, as indicated by task completion time, task accuracy and energy consumption. A particular emphasis was placed on reducing energy consumption, which may also be referred to as improving ecological performance. The vacuum cleaner was selected as a model product since it is a widely used ICP, characterized by considerable energy consumption during operation.

There are several forms in which automation can be implemented in vacuum cleaner design. One may broadly distinguish between four types of automation design: type 1 (low levels of automation for PA or PA^-, high levels of automation for CI or CI^+), type 2 (PA^+, CI^-), type 3 (PA^+, CI^+) and type 4 (PA^-, CI^-). The four types are presented in figure 1.

First, automation levels may be low for PA but high for CI. A previous study examined the effectiveness of an automatic reset function, which meant that power control was reset to its most energy-efficient level (around 750 W) every time the appliance was switched off (Sauer *et al.* 2004). This function was effective in increasing energy-efficient usage of the appliance because most users did not override the automation to select higher power levels (i.e. less energy-efficient levels), although automation design offered this level of control to the user. This type of automation corresponds to type 1 in figure 1, with low levels of automation for PA but high levels for CI.

Second, automation levels may be high for PA and low for CI (see type 2 in figure 1). Automation in PA may support the user in gaining a precise picture of the environmental state (e.g. cleanness levels). The selection of the decision and its implementation, however, are not supported by automation and are taken by the user alone. This form of automation was examined in study I. Pilot work indicated that a dust sensor provided a much more precise assessment of cleanness levels (i.e. PA) than a typical human operator. It was hypothesized that PA would lead to increases in efficiency since it would support

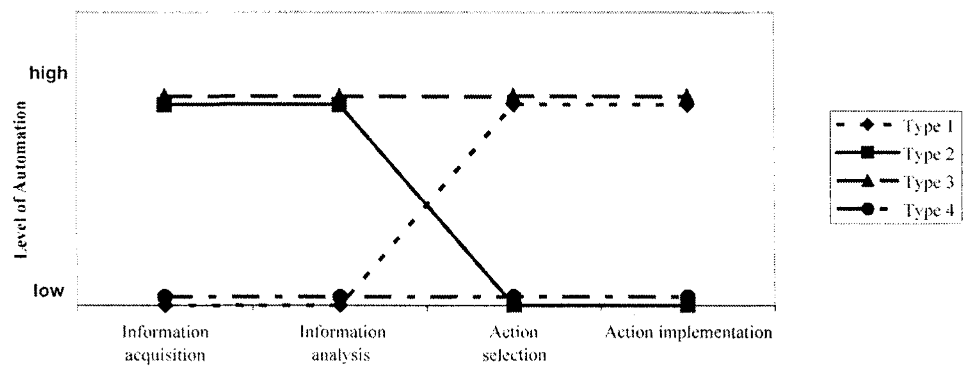

Figure 1. Model of automation (adapted from Parasuraman *et al.* 2000).

users in identifying dusty floor areas more effectively, avoiding the repeated treatment of already clean floor areas. Furthermore, it was expected that this effect was moderated by environmental concern, with individuals scoring high on that motivational factor showing better performance than those with lower scores.

Third, automation levels may be high for PA and high for CI (see type 3 in figure 1). This design option would provide support to the user with regard to PA and CI alike. This was examined in study II. It was hypothesized that CI would lead to efficiency gains but this effect should be stronger than for PA due to the additional support provided in controlling the system.

Finally, to complete the circumplex, the fourth quadrant is characterized by low levels of automation on both PA and CI (see type 4 in figure 1). This would correspond to the design of vacuum cleaners without any automatic support. In the present work, this condition was represented by the control group used in study I.

2. Study 1

2.1. *Aim*

The main goal of this study was to examine the effectiveness of PA by providing a signal that informed the user of the environmental state (e.g. quantity of dust on the floor). In addition to this main question, three other issues were addressed in this study. First, the study examined whether OPI in the form of display labelling would enhance user perception and improve efficiency of system operation. Second, the effectiveness of PA was tested under different environmental conditions (i.e. different amounts of dust to be removed). Third, to control for practice effects, users completed two identical trials. This made it possible to determine whether familiarity with the appliance would affect efficiency parameters.

It was hypothesized that PA would result in efficiency gains. Furthermore, it was expected that differences in performance as a function of PA would be more pronounced in a low-taskload condition (i.e. smaller amount of dust to be removed) than in a high-taskload condition (i.e. larger amount of dust to be removed). In the former, dust will be less visible and hence support through automation would be more effective. Finally, OPI would further enhance the positive effects of PA on operational efficiency because it would provide behavioural guidance to users.

2.2. *Method*

2.2.1. Participants. In this study, 30 participants (33.3% female) took part. Their ages ranged from 19 to 45 (mean 25.6) years. Half of the participants were recruited from the student population of Darmstadt University while the other half were members of the general public. Study participants received €5 for their participation. A sample with a larger age range was chosen to obtain a sample that may be more representative of the typical user population. However, this had no effect on user behaviour as there was no correlation between age and user behaviour ($r = 0.03$ to $r = 0.17$ for different parameters; all $p > 0.05$). Similarly, no differences in user behaviour between students and non-students were observed.

2.2.2. Design. A $3 \times 2 \times 2$ mixed design was used to examine the following three independent variables: level of PA; level of dirtiness (LoD); and familiarity with appliance.

PA was a between-subjects variable, being varied at three levels: none; naked; enriched. In the no-support condition, neither a display nor OPI was provided (i.e. OPI^-, PA^-, CI^-). In the condition 'naked PA', the appliance was equipped with a dust sensor indicating cleanness levels through a LED display (i.e. OPI^-, PA^+, CI^-). The display issued alternating signals in red (= still dusty) and green (= clean) colours as a function of cleanness levels. In the third condition 'enhanced PA' was provided, with the display being enhanced by OPI to give instructions about how to respond to the signals (i.e. OPI^+, PA^+, CI^+). The OPI is displayed in figure 2.

As a second between-subjects variable, environmental state was varied at two levels: 'high-dirtiness' environment (150 g sand) vs. 'low-dirtiness' environment (75 g sand). Familiarity with appliance as a within-subjects variable was manipulated at two levels. Participants had to complete two trials under exactly the same conditions, which allowed for a direct comparison between the first and the second trial.

2.2.3. Experimental measures. The following performance measures were taken in the study: energy consumption (kWh); duration of cleaning operation (s); and achieved cleanness (% of dust collected in dust bag).

Before and after the cleaning operation, participants rated the level of cleanness of the floor area on a 100 mm visual analogue scale (not dirty at all – very dirty). Moreover, participants were asked to indicate the thoroughness with which the cleaning operation was carried out (not thorough at all – very thorough). This made it possible to relate these two subjective user assessments to objective performance indicators.

Environmental knowledge was measured by a short knowledge test. It was specifically developed to measure explicit ecological knowledge in the context of vacuum cleaner usage. The test comprised seven statements, which the participant had to judge as true or false (e.g. 'Choosing a low setting of control slider leads to energy savings'). The participant then had to rate the confidence of their own judgement on a 7-point Likert scale (very confident – not at all confident).

Environmental concern was measured by the short version of the Environmental Concern Questionnaire comprising 21 items (Schahn *et al.* 2000). It contained seven subscales that covered the following facets of ecological behaviour: saving energy; saving water; recycling; sport and leisure; community action; shopping; traffic.

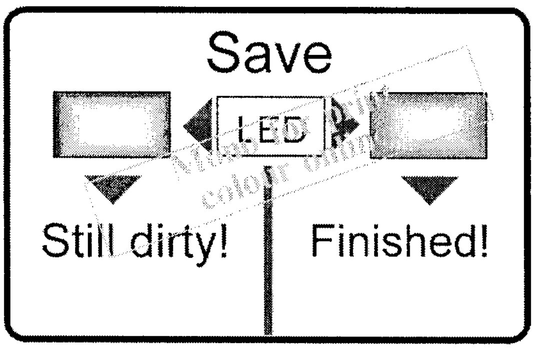

Figure 2. Display labelling (translated from German). The LED display in the centre switches between red and green colours depending on the environmental state determined by the dust sensor.

2.2.4. Material and procedure. The experiment took part in a laboratory, which was modelled after a typical private study, with a carpet and four pieces of furniture (two chairs, desk, computer desk) being placed in it. The size of carpet was 14 m^2 (5.0 m by 2.8 m). After the carpet was cleaned very thoroughly, very fine sand (75 g or 150 g according to the experimental condition) was distributed on the carpet. The type of sand was similar to the quality of sand employed for industrial testing of vacuum cleaners according to EN 60312.

Participants were informed that the general purpose of the study was to examine how people operate different domestic appliances with a view to improving their design. Before beginning the experiment, the participants were instructed in the operation of the vacuum cleaner (including the feedback facility if applicable) and given some time to familiarize themselves with the appliance by cleaning an especially prepared work surface. After this training phase, the participants were instructed to clean the prepared floor area. It was emphasized to the participants that they should be cleaning the floor in the same way as they would typically do at home. The instructions did not refer to speed or accuracy as task-related goals since the objective of the instructions was to make users show the cleaning behaviour they would normally adopt in their own domestic environment.

Before and after the trial, participants completed the visual analogue scales to assess thoroughness and cleanness. Participants were then presented two questionnaires to measure knowledge and environmental concern. A post-experimental interview was also carried out to determine to what extent the information label was noticed and complied with. After the participant left the laboratory, energy consumption was measured by taking the readings of an electricity meter while cleanness levels were measured by weighing the dust bag that had been filled during the experimental trial. This was followed by a second cleaning trial under exactly the same conditions (i.e. same level of automatic support and same environmental state).

For the purpose of this study, an off-the-shelf vacuum cleaner (Philips Mobilo 8539; Koninklijke Philips Electronics NV, Eindhoven, The Netherlands) was modified to provide automatic support to the user. This was in the form of an infrared sensor that was connected to an intermittent red light, indicating whether dust particles were still passing through the nozzle. If the amount of dust particles fell below a certain threshold value, the signal turned green. The signal light was fixed on top of the cleaning foot and was easily visible to the user. It provided information to the user about current levels of dirtiness.

2.3. *Results*

Apart from one exception (later referred to under subjective user assessment), there were no effects found for the variable 'familiarity' (in most cases $F < 1$). For reasons of simplicity, no further reference is therefore made to the statistical parameters of the variable 'familiarity' in the remaining results section.

2.3.1. Energy consumption. The data of this variable are presented in table 1. The data showed an effect of LoD, with a higher LoD resulting in higher energy consumption ($F = 7.29$; df = 1,24; $p < 0.05$). Energy consumption also rose with increasing level of automatic support but the effect failed to be significant ($F = 1.55$; df = 2,24; NS). While there was no significant difference in means, the variance was much higher for naked and enhanced support (SD 0.032 and 0.027) than for no support (SD 0.012). No interaction

Table 1. User performance as a function of perceptual augmentation (PA) and operational conditions, averaged across the two trials.

	PA			
	None (PA^-, OPI^-)	Naked (PA^+, OPI^-)	Enhanced (PA^+, OPI^+)	Overall
Energy consumption (kWh)	0.039	0.052	0.055	
High LoD	0.051	0.057	0.070	0.059
Low LoD	0.026	0.048	0.039	0.038
Task completion time (s)	126	178	202	
High LoD	164	179	257	200
Low LoD	88	178	147	137
Achieved cleanness (%)	95.0	96.3	97.2	
High LoD	97.6	96.2	99.0	97.6
Low LoD	92.4	96.4	95.5	94.8

LoD = level of dirtiness; OPI = on-product information; $^+$ present; $^-$ absent.

was observed. Similarly, a related parameter, power control setting, did not show any effect (most $F < 1$), with most users having chosen a setting of around 1.06 kW.

2.3.2. Task completion time. As the data in table 1 demonstrate, users needed more time to clean the room under high LoD than low LoD ($F = 7.17$; df = 1,24; $p < 0.05$). In contrast to expectations, increasing levels of decision support led to longer cleaning times. This effect was significant ($F = 3.64$; df = 2,24; $p < 0.05$), although post-hoc LSD-tests only confirmed the difference between enhanced and no support to be significant ($p < 0.05$). This effect was paralleled by considerable differences in within-cell variances, with standard deviations being again much higher for enhanced and naked support (both SD 74.5) than for no support (SD 38.3). No interaction occurred.

2.3.3. Achieved cleanness. The data showed slightly higher cleanness levels under high LoD than under low LoD (see table 1) but the difference just failed to be significant ($F = 3.40$; df = 2,24; $p = 0.07$). There was no main effect of PA ($F < 1$). However, variances were considerably smaller for enhanced PA (SD 4.2) than for the other two (naked: SD 8.2; none: SD 7.2), suggesting more standardized cleanness levels under high support. No interaction was observed.

2.3.4. Subjective user assessment. The data showed an effect of environmental state, with users under low LoD giving lower pre-experimental ratings than those under high LoD (49.3 vs. 67.1). This difference was significant ($F = 5.69$; df = 1,24; $p < 0.05$), suggesting that users can detect differences in dustiness levels providing that the differences are sufficiently large. With regard to perceived thoroughness of cleaning, the analysis showed that higher LoD led to users cleaning the floor area more thoroughly than under low LoD (67.4 vs. 79.8). This difference was significant ($F = 5.20$; df = 1,24; $p < 0.05$).

2.3.5. User variables and performance. Environmentally concerned users reported that they cleaned more thoroughly than users with lower environmental concern ($r = 0.56$; $p < 0.001$). This association was also found for objective performance data (albeit somewhat weaker), as a correlation coefficient of $r = 0.34$ ($p = 0.07$) between environmental concern and achieved cleanness demonstrated. A more fine-grained analysis revealed that the correlation coefficient was largest under enhanced support (r = 0.76), followed by naked support (r = 0.36) and no support (r = 0.18), suggesting the importance of support through PA for highly motivated users. In contrast to achieved cleanness, energy consumption was not associated with environmental concern (r = +0.17). A separate analysis of each experimental condition revealed no systematic pattern (none: r = +0.27; naked: r = +0.02; enhanced: r = +0.18). No correlation was found between achieved cleanness and user knowledge (r = −0.14; NS). The results also revealed that users with higher thoroughness scores consumed more energy (r = 0.38; $p < 0.05$) and showed longer cleaning times (r = 0.49; $p < 0.01$). These associations were found in the first trial as well as in the second. However, users' subjective assessment of the thoroughness with which they cleaned the floor did not correspond to the objective cleanliness measure (r = 0.24; NS).

2.4. *Discussion*

The main finding of this study was that PA did not lead to improved efficiency, with one of the measures (i.e. task completion time) even increasing under automatic support. The analysis further revealed that, as expected, higher task load (i.e. larger amount of dust) led to increased energy consumption and longer cleaning times but no effect of practice was observed.

The finding that PA did not improve efficiency was puzzling at first. It had been expected that PA would have supported users in identifying dirty floor areas more effectively and hence would lower energy consumption. However, the data showed no effect on resource consumption while task completion times significantly increased. The post-experimental interviews revealed some explanations for this unexpected finding. Users appeared to differ in the way they made use of PA. Some users reported, as hypothesized, that the automatic system had helped them identify dirty spots more efficiently. By contrast, a second group of users reported that the automatic system had encouraged them to clean the floor more thoroughly than they would have done otherwise, which essentially counteracted the original purpose of PA. There was further evidence for considerable interindividual differences between users with regard to their response to automatic support. This stemmed from the increased variance of user performance under the naked and enhanced PA, compared to the no-support condition (variance differed by factor 4!). The origins of this effect might be found in interindividual differences with regard to user conscientiousness. Highly conscientious users may have been tempted to clean more thoroughly under PA support than under no support while the reverse may have been the case for less conscientious users. In hindsight, it would have been useful to collect a trait measure of thoroughness and to use decision support as a within-subjects variable. This would have allowed testing the hypothesis that thoroughness (which is similar to the Big-5 factor 'conscientiousness') would moderate the effectiveness of automation. Overall, the bi-directional effects of PA represent another case of automation having an unanticipated impact. It is of particular importance that interindividual differences appear to be at the root of this effect; an issue that has largely been neglected in automation research (an exception to this is, for example, the study of Prinzel *et al.* 2005).

The findings may raise concerns about the utility of automation in the form of PA. In the domestic domain, the effectiveness of PA may be threatened by a number of factors (Sauer and Rüttinger 2007). First, users need to be suitably motivated to achieve energy savings or to pursue efficiency-oriented task goals. Second, PA is not good at breaking undesirable habits, which show a high prevalence in the domestic domain. Third, users may have insufficient knowledge of how to make optimal use of the automatic system. All three factors may have contributed to the low effectiveness of PA, with users making use of the information provided in a different way than anticipated by the designer. Considering the context of usage of ICP, in which task goals are usually self-defined, PA may be less effective than in a work context, where maintaining or improving performance levels represents a major aspect. This implies a need to focus more strongly on CI, as it provides stronger behavioural guidance to users than PA.

The absence of any practice effects on user performance has an important implication. From a methodological point of view, this may be seen as a positive indication since there were no effects of time-on-task due to learning or motivational changes. It therefore seems to be acceptable to use only one experimental trial because no change in behaviour occurred as users became more familiar with the appliance. This emphasizes the point that due to the high prevalence of low-demand routine tasks, practice effects are typically much weaker or even completely absent in most domestic activities.

Interestingly, higher environmental concern did not lead to reduced energy consumption, as one would normally predict. Instead, it resulted in increased cleanness levels, with the effect being even stronger under automatic support. This is because environmental concern may also be associated with environmental cleanliness as a specific facet of that construct. Similar findings have been observed in previous studies using the vacuum cleaner as a model product (e.g. Sauer *et al.* 2002), suggesting a product-specific effect. In contrast, when task activities were unrelated to environmental cleanliness (e.g. operating a kettle or a central heating system), the expected positive relationship between environmental concern and energy consumption was observed rather than a negative correlation (e.g. Sauer and Rüttinger 2004). This reiterates that the relationship between attitude and behaviour is complex and may be moderated by the technical system used and the tasks to be carried out. In contrast to environmental concern, no relationship was found between performance and knowledge. This suggests that differences in user performance were more likely to be due to motivational reasons (demonstrated by the influence of environmental concern) than due to lack of knowledge. The strongest and most consistent relationship between performance and user variables was observed for thoroughness, which may be considered a similar concept to conscientiousness, as one of the Big-5 personality factors (Costa and McCrae 1992). This corresponded to a number of studies in the research literature, which reported a positive relationship between conscientiousness and work performance (Barrick and Mount 1991). Overall, the analysis of the different user variables and their relationship with performance measures demonstrated that there are a number of moderating factors (e.g. task type, technical system features, motivation) that contribute to rather inconsistent findings across studies.

3. Study 2

3.1. *Aim*

The goal was to examine the effectiveness of PA with the simultaneous availability of automatic support in the form of CI. For that purpose, the appliance was equipped with an adaptive power control function, which turned down suction power if the sensor did not detect any dust particles. The automatic function could however be overridden by the user. This design option of automation corresponds to type 2 in figure 1. Furthermore, it was examined whether PA combined with CI would benefit from OPI.

It was hypothesized that efficiency gains would be made if users were aided by system automation. It was expected that this effect would be larger than in study 1 because, due to the availability of CI, there would be less dependence on user knowledge and motivation to achieve energy savings. This would also produce a weaker correlation between environmental concern and energy consumption in the present study than in the previous one. Finally, it was predicted that OPI would lead to improved operational efficiency.

3.2. *Method*

3.2.1. Participants. A total of 48 users (43.8% female) took part in the experiment, with their ages ranging from 18 to 54 (mean 26.0) years. Half of them were students of Darmstadt University; the remaining participants were recruited from the general public. They received a payment of €5 for their participation. The rationale for selecting a more heterogeneous sample was the same as in study 1 (see 2.2.1). Similar to that study, no correlation between age and user behaviour was found, ranging from $r = -0.10$ to $r = +0.16$ for different performance parameters (except for task completion time, which was positively correlated with age; $r = 0.32$; $p < 0.05$).

3.2.2. Design. A 2 × 2 between-subjects design was employed in the study. PA (i.e. combined with CI) was varied at two levels: available vs. unavailable. OPI was also varied at two levels (available vs. not available). The OPI was designed as shown in figure 3. For the condition in which no decision support was available (i.e. PA^-), the text needed to be modified and read as follows: 'Please save time and energy – If floor area is clean, move on quickly'.

3.2.3. Experimental measures. The measures taken in this study were identical to the ones taken for the previous one. In addition, the frequency with which participants manipulated suction control was measured. This was considered to be an important parameter because it indicated how frequently users overrode the automatic control settings.

3.2.4. Materials and procedure. In this experiment, a model of Panasonic (MC-E110; Panasonic, Osaka, Japan) was employed. This appliance was equipped with an automatic suction control that was operational in all experimental conditions (i.e. CI^+). Furthermore, the appliance had a dust sensor and a display that provided a dichotomous feedback signal (red = dirty, green = clean). As in study 1, one group of participants worked with an appliance equipped with a feedback signal (PA^+), while the other experimental group had no feedback signal available (PA^-). When the sensor detected

Please save time and energy Pay attention to the red signal If the red light is off, the floor is clean

Figure 3. On-product information attached to appliance for the condition PA^+, OPI^+.

decreasing levels of dirtiness, suction power was automatically reduced. Participants were informed about this feature of the appliance. Although the setting of suction control was fully automated, the appliance allowed the user to override the system manually by either selecting minimum or maximum suction control. In the condition OPI^{+} two labels were fixed to the appliance. One was positioned on the cleaning foot of the appliance, the other on the cylinder of the appliance (the labels were similar to the ones used in the study 1). No labels were used in the condition OPI^{-}.

The same laboratory was used as in study 1, with the same procedure being employed for instructing participants and for distributing the sand on the carpet (150 g in the present study). Further details may be found in section 2.2.4.

3.3. *Results*

3.3.1. Energy consumption. As the data in table 2 indicate, the lowest energy consumption was observed when PA was present and supplemented by OPI. Interestingly, the worst score was recorded under PA^{+} OPI^{-}. No difference between the two OPI conditions was observed when no decision support was available. The analysis confirmed the significant cross-over interaction between decision support and OPI ($F = 4.34$; $df = 1,40$; $p < 0.05$). Post-hoc LSD-tests showed that only the two extreme values were statistically different from each other ($p < 0.05$). No main effect of decision support ($F < 1$) and none of OPI ($F = 2.36$; $df = 1,40$; NS) was found. No interaction was recorded. A related parameter, power control setting, showed essentially the same pattern. This indicated that reductions in energy consumption were due to lower control settings chosen by the user or the automatic system.

3.3.2. Task completion time. The data for trial duration are presented in table 2. As visual inspection of the data suggests, there was little difference between the experimental conditions. This was confirmed by the results of the ANOVA (all $F < 1$).

3.3.3. Achieved cleanness. As the data in table 2 show, the decision support function was effective in achieving higher cleanness levels. This difference was significant ($F = 4.65$; $df = 1,40$; $p < 0.05$). Interestingly, the presence of OPI resulted in users removing less dust because labels encouraged users to move on quickly to save energy ($F = 12.2$; $df = 1,40$;

Table 2. Performance variables as a function of perceptual augmentation (PA) and on-product information (OPI).

	PA^{-} (CI^{+})	PA^{+} (CI^{+})	Overall
Energy consumption (kWh)	0.032	0.033	
OPI^{+}	0.033	0.027	0.034
OPI^{-}	0.031	0.038	0.031
Task completion time (s)	147.3	145.3	
OPI^{+}	151.3	140.4	145.9
OPI^{-}	143.2	150.2	146.7
Achieved cleanness (%)	67.1	73.0	
OPI^{+}	64.2	66.3	65.3
OPI^{-}	70.0	79.7	74.9

CI = control integration; $^{+}$present; $^{-}$absent.

$p < 0.005$). The data seem to suggest that the best cleaning performance (i.e. 79.7%) was achieved when no OPI discouraged the user from thorough cleaning and automatic support was provided. However, this interaction could not be confirmed as a statistically significant effect ($F = 1.9$; $df = 1,40$; NS).

3.3.4. Subjective user assessment. A significant interaction between decision support and OPI was found ($F = 5.2$; $df = 1,40$; $p < 0.05$). Users with decision support reported that they cleaned the carpet more thoroughly if there was OPI available (mean 76.7) than if there was not (mean 57.2; LSD-test: $p < 0.05$). No significant difference was found when no decision support was available. No other differences between experimental conditions were found.

3.3.5. User variables and performance. A negative correlation between knowledge and performance was found ($r = -0.30$; $p < 0.05$). This suggests that users with higher knowledge consumed less electricity. No significant association was found between environmental concern and energy consumption ($r = -0.04$; NS). When computing correlation coefficients for the different experimental conditions, the analysis revealed considerable differences between them. A positive correlation was found for the condition PA^-, OPI^+ ($r = 0.50$) while the other conditions showed negative correlations, such as for PA^+, OPI^+ ($r = -0.10$), PA^-, OPI^- ($r = -0.28$), PA^+, OPI^- ($r = -0.42$; none of these coefficients was significant, with each of them being based on $n = 12$). This indicated that the presence of OPI resulted in more positive associations between environmental concern and energy consumption. Furthermore, there was evidence that subjective ratings of dirtiness of operational environment influenced user behaviour, that is, achieved cleanness was positively correlated with pre-experimental assessment of LoD ($r = 0.30$; $p < 0.05$). However, users' subjective assessment of the thoroughness with which they cleaned the floor did not correspond to the objective cleanliness measure ($r = 0.15$; NS). Similar to the findings of study 1, the results also showed that users with higher thoroughness scores tended to use up more energy ($r = 0.24$; NS) and to show longer cleaning times ($r = 0.24$; NS), although both correlations failed to be significant.

3.3.6. Use of automatic suction control. The data provided some evidence that users generally accepted automation in the form of CI. The vast majority of users (83.3%) were in automatic control mode for most of the experimental trial, with only a minority of users preferring a non-automatic setting of suction control (seven users opted for the maximum setting while one user chose the minimum setting). A considerable number of users (47.9%) did not even once override the automatic control during the experimental setting.

3.4. *Discussion*

The main finding of the study was that there were benefits of automation for reducing energy consumption but only when support through OPI was available. While higher cleanness levels were also achieved through automation, no effect was observed for task completion time. Finally, the data provided evidence for good user acceptance of CI.

A reduction in energy consumption was only observed when there was simultaneous support from automation and OPI. It is an interesting finding that effectiveness of automation was dependent on the presence of OPI, which provided instructions of how to make use of automatic support. This suggests that an automatic function of this kind may not be sufficiently self-explanatory to users.

In the present study, there were much smaller differences in user behaviour across the different experimental conditions than in study 1. Furthermore, there was much less evidence of interindividually different reactions to automation than in study 1, where intra-group variances were found to be increased under higher automation. This suggests a stabilizing influence of CI on user behaviour due to the constraints placed on the users' degrees of freedom. Power control settings were optimized with regard to energy consumption by automation so that inefficient power settings were less likely to occur unless the user overrode the automatic function selecting inappropriate power settings. This was, however, rarely observed. More than 80% of users were happy to operate the appliance with the auto control function being switched on. This finding suggested that automation in the form of CI enjoyed high user acceptance. User reliance on automation is an important outcome variable in automation design (Riley 1996) since there is little need to provide automatic support if it is not made use of.

The findings showed that in the design of automation for ICP, an important role is played by OPI because of the non-availability of training in this specific domain. The pivotal role of OPI to support automation was notably demonstrated by the fact that in the least advantageous condition for making energy savings, the automatic system was available but deprived of any support through OPI. Operating a 'naked' automatic system may have confused users rather than helped them. The observation of an effect of OPI in the domestic domain is a positive indication since there have been concerns that, due to the high familiarity of that particular environment, there is an elevated risk of OPI not being paid attention to (cf. Cushman and Rosenberg 1991). For example, Frantz and Rhoades (1993) have argued that in the context of on-product warnings, it would be advisable to provide information such that it temporarily interferes with task performance. This is to ensure that important information is not simply overlooked. Although the strong impact of habits may generally suggest limitations of the effectiveness of OPI for ICP design, in the present case the integration of an automatic suction control system represents a novelty factor. This unfamiliar situation may have led to increased information search activities, reducing the influence of habitual behaviour patterns.

In the present study, no overall association between environmental concern and energy usage was found. This may be due to the moderating effects of automation and OPI. When users had a full manual system (with OPI), a positive correlation of $r = 0.50$ was found. Conversely, the correlation turned negative ($r = -0.42$) under automation (without OPI). Compared to study 1, the correlation between user knowledge and energy consumption was stronger (and became significant) in the expected direction, that is, more knowledgeable users consumed less energy. Overall, the patterns found reiterate the point made in the discussion of study 1 in that moderating factors contribute to rather inconsistent findings in the relationship between user variables and behaviour.

4. General discussion

A major goal of this article was to explore the role of automation in the design of ICP. Based on the automation model of Parasuraman *et al.* (2000), two types of automation were empirically tested. Although the data of the two studies are not exactly comparable (due to different appliances being used), a simple comparison was still considered to be useful. For that purpose, the main findings from these two studies are summarized in table 3. To facilitate comparisons between the two studies, the quantitative results were transformed into qualitative evaluations (e.g. low, medium, high) based on the statistical test results. The findings of the studies pointed at considerable differences in the effects of automation between $PA^{+}CI^{+}$ and $PA^{+}CI^{-}$. With regard to energy consumption as the most critical performance parameter, it emerged that higher automation levels in PA alone may not be sufficient in achieving performance improvements. They need to be supplemented by high automation levels for CI because this form of automation level is better at breaking habits and compensating for low user motivation. This suggests that CI may compensate some of the negative effects of PA (e.g. PA encouraged some users to clean more thoroughly than they would have done otherwise). The overall pattern of the data indicated that the recommendation given by Wickens *et al.* (1998) may apply to the domestic domain, too. They argued that high automation levels should be used for decision-making and action implementation involving little uncertainty and risk. This corresponds to typical domestic routine activities (e.g. vacuum cleaning), which are also characterized by low levels of uncertainty and risk. On the basis of the theoretical considerations in automation design, it is recommended that in ICP design automatic support should not only be provided for PA but also for CI. Alternatively, very low levels of automation (i.e. PA^{-} CI^{-}) also showed benefits for energy consumption. This was however achieved by a less sophisticated cleaning strategy in that users simply shortened task completion times (resulting in reduced energy use) because PA was unavailable to point out unclean areas that were not easily visible to humans. The more efficient cleaning strategy of selecting a more optimal power control setting was only used under automatic support through CI.

An important benefit of high automation on both factors (i.e. $PA^{+}CI^{+}$) might also lie in reducing the negative effects of interindividual differences, such as over-conscientious users cleaning the floor. Despite these benefits for higher levels of automation, it also needs to be pointed out that exceedingly high automation levels (e.g. providing no possibility for the user to correct the decision of the machine) are not appropriate either, since a smaller number of users preferred to override the power levels chosen by the machine. This decision latitude should clearly be given to users, in particular, as user satisfaction is of higher importance in the domestic domain than at work (Shneidermann 1998).

There is clearly an important role to be played by OPI in the domestic domain in conveying critical information to the user, in particular, as training as a form of knowledge conveyance is unavailable. In the present work, the benefits of OPI could not

Table 3. Overview of results of two studies for main parameters based on a three-star rating (the more stars, the better).

	Study 1				Study 2			
	$PA^{-}CI^{-}$		$PA^{+}CI^{-}$		$PA^{-}CI^{+}$		$PA^{+}CI^{+}$	
	OPI^{-}	OPI^{+}	OPI^{-}	OPI^{+}	OPI^{-}	OPI^{+}	OPI^{-}	OPI^{+}
Energy consumption	*** (lower)	N/A	* (higher)	* (higher)	** (medium)	** (medium)	* (higher)	*** (lower)
Task completion time	*** (shorter)	N/A	** (medium)	* (longer)	** (medium)	** (medium)	** (medium)	** (medium)
Achieved cleanness	** (medium)	N/A	** (medium)	** (medium)	** (medium)	** (medium)	*** (higher)	** (medium)

PA = perceptual augmentation; CI = control integration; OPI = on-product information; $^{+}$present; $^{-}$absent; N/A = not available.

be consistently demonstrated across studies. This may be due to slight variations in the design and content of OPI between studies. In the present work, OPI also referred to efficiency-related aspects rather than safety as most previous research. One would generally expect a higher compliance rate for safety-related information than for non-safety aspects conveyed by OPI (e.g. information about how to increase user convenience, improve environmental friendliness of usage or reduce task completion times). Even for safety-related OPI (or so-called on-product warnings) a number of factors have been identified that may threaten the effectiveness of the measure (Cushman and Rosenberg 1991). For example, the effectiveness of on-product warnings was negatively influenced by increased product familiarity, decreased spatial proximity and increased information quantity. This suggests that there are even higher demands for effective OPI design than for on-product warnings if satisfactory compliance rates are to be achieved.

The main variables examined (i.e. PA, CI and OPI) were operationalized by specific design elements (i.e. certain label or signal). These were chosen on the basis of a number of selection criteria. First, they should refer to the primary function of the appliance (i.e. effective cleaning). Some design elements were chosen because they represent current market technology (e.g. CI in one of the appliances), with commercial availability representing an obvious constraint to the selection of design elements. Other design elements were chosen on the basis of theoretical considerations (e.g. OPI was designed according to the model of Rogers *et al.* 2000 outlined in the introduction) as well as the findings of empirical work (e.g. OPI design also took into account the findings of previous research into the conveyance of environmental information by labels). Based on these selection criteria, one would expect that the design elements chosen were sufficiently representative of the entire class of possible design elements.

A central issue in this work has referred to the question to what extent the general theoretical framework of automation design originating from a work context can be transferred to the ICP domain. On the basis of the data, first evidence hints at the transferability of the automation model to the ICP domain. While this points to some common features between automation requirements for work and the ICP domain, one would expect to find typical automation problems encountered at work to the same extent as in the ICP domain. Most work-related automation problems (e.g. skill decrement, out-of-the-loop situation, overtrust, complacency, mode errors and excessive mental workload during automation failure; Wickens and Hollands 2000) appear to be less critical in the ICP domain for various reasons. For example, skill decrements are unlikely to represent a major problem since required skill levels are generally rather low for these simple routine tasks typically found in the ICP domain. Furthermore, most technical systems in the ICP domain are not safety-critical so that, in the event of a serious problem, they will safely return to a stable system state. These factors reduce (or even eliminate) many problems associated with automation. The age of users can also exert an influence on automation effectiveness, with older users showing generally poorer performance under automation than younger ones (Mouloua *et al.* 2002). Although no such effects were found in the present work, the issue is still considered relevant to the ICP domain, in particular, as the age range of users in the domestic domain is generally considerably larger than at work.

It is expected that automation issues in ICP will gain in importance in the future because more functions currently allocated to the human will be taken over by the machine, paralleled by an increasing prevalence of automated products. Against this background, there is a need for increased research activities to address the particularities of automation requirements for ICP.

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