INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED15
27-30 JULY 2015, POLITECNICO DI MILANO, ITALY

THE USE OF MULTISENSORY FEEDBACK TO MAKE USERS BEHAVE IN A SUSTAINABLE WAY

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Abstract

The paper proposes an alternative approach to well-known feedback solutions, such as visual displays or warning sound messages, to make users perceptually aware of the energy consumption occurring when using a product. The approach is grounded on the use of multisensory feedback interfaces that are designed to make the user experience the consumption process directly during the interaction with the product. Such multisensory feedback should be intended as indications, rather then alarms, so as to naturally guide users towards a more sustainable behaviour. The daily task of opening the fridge door has been used as case study. All the steps followed to ideate and test the effectiveness of the designed multisensory interfaces are discussed. The results demonstrate how even simple stimuli, such as a gradual colour change of the fridge cavity from a cold to a warm one, may be able to reduce the time users keep the fridge door open.

Keywords: Sustainability, Human behaviour in design, User centred design, Multisensory design, Design for behaviour change

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Please cite this paper as:
Surnames, Initials: *Title of paper*. In: Proceedings of the 20th International Conference on Engineering Design (ICED15), Vol. nn: Title of Volume, Milan, Italy, 27.-30.07.2015

1 INTRODUCTION

As underlined in the work of Mühlhäuser (2008), one of they key features of a *smart product* is its ability of establishing an autonomous interaction with the user. Such autonomy of the smart product relies on its capability of continuously providing and suggesting new knowledge to users during the interaction (Mühlhäuser, 2008). Thanks to this capability (of building an enhanced interaction with the user as well as of enabling this information flow), smart products are now starting to play a leading role in helping us monitoring our energy consumptions. Indeed, they are conceived and designed not only to autonomously control their performance so as to deliver their functionalities in the most effective and efficient way (both as a single device and as part of a more complex environment) but also to keep users updated about their energy consumptions in relation to the use of the product.

All these considerations introduce a further interesting aspect, underlined by Strengers (2014) in his work: *smart products/technologies* are designed for a *smart user* (identified by Strengers as the "*Resource Man*"). A *smart user* is anyone strongly interested in knowing and analysing his energy behaviour through real-time data so as to improve his environmental impact on the world. A *smart user* is thus, conscious of both how his energy behaviour affects the external world and of the possibilities offered by the smart technologies in helping him reducing his energy consumptions (Strengers, 2014). Looking at this description of *smart users*, we are narrowing the context of the analysis to a specific cluster of people. That could be due to the fact that such rational "*vision*" may not fit with the dynamics and practices of our everyday life, which, on the contrary, should be carefully taken into account when designing these products/technologies (Strengers, 2014). As a matter of fact, for example, the work of Paetz et al. (2012) highlights that the willingness of using smart home technologies, among the various factors identified, is also related to the efforts required to users in adapting/changing their daily routines.

Considering the strong potential that smart products/technologies have in driving ourselves towards a more energy efficient and clean future, government institutions, researchers and industry associations are investing a lot of efforts in transforming the *smart product* from an unknown black box to a helpful and friendly "household object". Several streams of research have been run over towards this target: from reaching a better understanding of consumers' like/dislike about these technologies until making the interaction between the user and the smart technologies as easier and enjoyable as possible. For example, an interesting area of research is focused on improving the way the energy data are displayed to users thanks to dedicated visual display (e.g. Fitzpatrick and Smith, 2009; Hargreaves et al., 2010; Spagnolli et al., 2011; Hargreaves et al., 2013). Such studies are grounded on the consciousness that if we want to stimulate people in behaving in a sustainable way, we have to provide them with clear and direct feedback messages about their behaviours (Darby, 2006; Grønhøj and Thøgersen, 2011) so as to involve them in a more conscious *learn by doing* (and "seeing") approach. In addition, related with this issue, a further relevant stream of research is focused on exploring what are the psychology and social related aspects that influence our attitude in acting as environmentally conscious people (e.g. see the work of Kollmuss and Agyeman (2002)).

Likewise, also this study is grounded on the importance of providing clear feedback to users so as to make them more conscious about their behaviour when using a product. However, we focus on the possibility to somehow instruct them towards this target. Specifically, we have shifted the focus of the research moving it from a data visualization problem to a "more perceptual" one: is the data visualization the only strategy to make users more conscious about the energy consequences of their actions when using the product? Could the product provide to users a more sophisticated set of stimuli during the interaction so as to influence their behaviour? On the market, products with embedded feedback systems are already available (e.g. a sound alarm). However, the point here is to understand whether the stimuli generated by those systems are effective, which means whether they are able to provide the right message to the user and to get the right answer from them in terms of behaviour change. Additionally, it is not only a matter of the kind of information to deliver, but also how to do this: what kind of interfaces to use and how to design it so as not to make the user live a frustrating experience when interacting with the product. To address these issues we discuss the results of an ongoing study focused on identifying what feedback a domestic refrigerator should provide so as to improve our way of using it, from the consumption reduction perspective. Specifically, starting from the analysis of existing works driven by similar or complementary targets (see Section 2) we have identified a fridge as case study (see Section 3): we have applied a user-centred design approach for coming up with alternative feedback solutions based on multisensory stimuli. The product interfaces enabling these stimuli have been prototyped and finally tested with 10 subjects.

2 ENERGY CONSUMPTION RELATED TO USER HABITS

The behaviour of individuals in using products/energy is a factor that needs to be taken into account when designing strategies and approaches aimed at decreasing our energy consumptions (e.g. see Abrahamse et al., 2005; Steg, 2008; Wever et al., 2008; Tang and Bhamra, 2008). Focusing the attention on the use of domestic refrigerators, which is the context analysed in this paper, the study carried out by Geppert and Stamminger (2010) has lead to the following consideration: despite the attempts made by appliance manufacturers and consumer associations in providing recommendations about the proper installation and use of the appliance, in some cases, they are not always followed (e.g. the food is placed within the fridge when it is still hot or the fridge is installed close to heat sources). This way of using the product is not due to a low commitment of people in following a sustainable conduct. Most of the time it could be due to the lack of awareness about the side effects of their practices when using the product, which is also a consequence of the lack of effective communication modalities to make them more aware. Indeed, as suggested by Geppert and Stamminger (2010), it is important to improve the way usage guidelines and recommendations are provided. Additionally, we have also to consider the daily routine which forces us respecting specific time and space constraints. These constraints do not always match with people's desire of acting as environmentally conscious users. As underlined in (Ganglbauer et al., 2013), researchers have to design technical solutions able to fill the gap between individuals' intentions and their daily practices. To reach this target it is fundamental to carefully consider the boundary conditions and the users' needs behind the product usage, extending the context of the analysis outside the domestic area.

The intent of reducing this gap is what is driving several works of *design for sustainable behaviour*. For example, the works of (Tang and Bhamra, 2008; Lilley, 2009) discuss the role of design in driving users towards a more sustainable use of the product. A further work of Tang and Bhamra (2009) describes an interesting and in-depth usage patterns study through which the behaviour of fridge users is observed and analysed so as to derive a bunch of design interventions to apply to the product. Moving within the same stream of research we have the work of Lockton et al. (2008) where *design with intent* approaches are reviewed so as to point out the importance of clearly focusing the design activity on the kind of strategy to apply when looking for a change in the user behaviour. In line with this perspective, Wever et al. (2008) propose a typology of strategies designers can follow for inducing a sustainable use of a product. Such strategies, whose common denominator is the central role played by the final user in the design process, represent different modalities through which a product can be conceived so as to reach the objective of reducing the environmental impacts occurring during the use phase.

Starting from this overview, we have concentrated our research on the feedback strategy. However, instead of providing users with a quantitative graphical representation of their behaviour, we have tried to make them physically involved in the energy waste process. To reach this target we concentrated our efforts, interpreting the suggestion provided by Strengers (2014), on analysing how the consumption process (i.e. the use of the energy) is experienced during the interaction with the product. For example, if we image ourselves using the fridge two are the stimuli through which we realize we are interacting with it: 1) the light switches on (visual stimulus); 2) we feel the cold air within the cavity (a sort of tactile stimulus) by means of our skin (e.g. the face and the hands). Could we "augment"/"modify" them on purpose so as to make the user more conscious about the energy consumption process? In addition, the physical interaction with the fridge occurs by means of the tactile feedback given by the touch/grasping of the door handle and of the internal shelves/drawers. Focusing our attention only on the door, since its opening is one of the energy waste causes for a fridge (e.g. see (Saidur et al., 2002 and Liu et al., 2004) for a technical analysis on this topic), we come up with the following consideration: what if the door would be able to inform the user about the change of its status? Could such message influence the user's behaviour?

To put it in another way, we have tried to find out complementary or alternative strategies to the data visualization to instruct users behave in a more sustainable way. Making them perceptually aware of the consumption process is the target we pursuit in this study. Furthermore, an important requirement when choosing and optimizing the feedback, is that the user should not perceive it as noisy and frustrating, so as not to create a “fighting” relation with the product. On the contrary, such feedback should be intended as a suggestion, even as a hidden indication, so as not to be too invasive.

3 CASE STUDY

For testing the considerations introduced in Sections 1 and 2, as case study we selected a common daily task: the opening and closing of the fridge door. We have investigated how to reduce the time users keep the door open. To reach this target we designed and installed within the appliance different multisensory feedback devices. The aim of these devices is to make them perceptually aware of the following consequences due to the door opening: the temperature inside the fridge cavity is increasing while keeping the door open; an inlet flow of air at room temperature occurs; the door is no more in its 0° position. To ideate and evaluate the effectiveness of the multisensory feedback we carried out the following steps: 1) we run an online survey to collect people’s habits in the use of domestic refrigerators; 2) we used the results for inspiring the ideation of the sensorial stimuli during the concept design phase; 3) we prototyped the product interfaces enabling the generation of such stimuli; 4) we tested the effects of these stimuli with 10 subjects. In the following sections each step is described.

3.1 Background survey: how people use and what they think of their fridge

We have designed a questionnaire, taking as reference the literature analysed in Section 2, whose purposes were the following: 1) to understand the attitude and consciousness of the subjects in relation to the fridge opening/closing task; 2) to get an overall picture of their habits in relation to the use of their fridge; 3) to test subjects’ knowledge about the main energy efficiency aspects of the appliance; 4) to retrieve insights about their desires and convictions with regard to the possibility of having a fridge with embedded feedback functionalities; 5) to get their viewpoint about two well known feedback (the belt alarm of the car and the vibration/ringtone of mobile phones). It is worth to point out that the questionnaire has been conceived not as a consumers’ study, but as a tool to clarify us the context of our research and, to set a starting point for our design activity. 79 subjects aged between 18 and 59 (mean 30 STD 9.4, 38 male and 41 female) participated to an online survey. 87% of them were studying at university or were already graduated. The main results are clustered and discussed in the following.

3.1.1 The fridge opening/closing task

52% of the respondents declared that they usually open the fridge door at least six/ten times a day (more than 10 times 22%). The main motivation behind the door opening is to take the food for cooking something (48%). On the contrary, 5% open it to check if something is finished while 6% for storing grocery shopping. In terms of opening time, 39% feel to keep the door open the due time while 18% quite a lot or a lot: 57% of respondents are aware of the fact that they are maintaining the door open for a while. For what concerns how much they open it, 49% answered “enough, to easily take what I need” while, 18%, declared that they “completely open it so as to have a better view of the whole cavity”.

3.1.2 Users’ habits in relation to the fridge use

86% of respondents declared to usually have dinner at home with other people (8% for breakfast and 5% for lunch). That result suggests that, the highest frequency of door opening, may occur during breakfast (due to a different time schedule of the people living together, see also (Tang and Bhamra, 2009)) or, during dinner, when they need to cook something (see Section 3.1.1). The products that are the most difficult to find within the fridge are the following (a multiple choice was allowed): fruits/vegetables (42%); cured meats/cheese (34%) and sauces (29%). Among the list of issues proposed, related with this difficulty, respondents indicated the following (these are the most frequent answers): “the food is packaged so that it is difficult to distinguish it”; “these products are usually set behind or under others so they are hidden (especially the smallest ones)”; “the drawers/shelves are usually too filled and the vegetables/fruits are mixed so that it is difficult to distinguish them”; “the food is placed in the bottom/higher shelves so I find it difficult to reach them”. This list of issues provided us an overview of the main difficulties encountered by the subjects when searching and storing the food. Going into more depth about subjects’ habits, for what concern frozen food, 15% of them let it defrost within the fridge (24% use the microwave and 41% let the food defrost at room temperature) while, for what concern the selection of the fridge location, 39% of the respondents declared that the fridge is placed in the kitchen close to the oven (to further deepen these two aspects, see also the work of Geppert and Stamminger (2010)). Finally, 42% of the respondents think that their energy habits in using the fridge are enough correct while 34% fill to use it in a proper way.

3.1.3 Users' knowledge about energy efficiency topics

We investigated different energy efficiency topics, such as for example, users' awareness of the energy class of their fridge. However, since our aim was not to carry out a consumers' study, we summarise here the two results that we have considered as the most relevant. The first is that, 68% of the respondents declared to be interested in their fridge energy consumptions. The second one is about their knowledge of the factors determining such consumption. 38% of the respondents provided us with the following list: the door opening; the thermal insulation effectiveness; the difference between the inner/outer temperature (fridge cavity/room); the temperature of the foods; the technological solutions implemented in the product.

3.1.4 People's willingness to have a fridge with embedded feedback functionalities

63% of the respondents think that it could be useful or essential to have a fridge able to give them a feedback about their energy habits. Regarding the type of feedback that the product should be able to deliver, we got the following results (a multiple choice was allowed): the information about the fridge energy consumption according to its real use (67%); how long the fridge door remains open (30%); fridge instantaneous internal temperature (22%); how many times, during the day, the fridge door has been opened (19%). Hence, feedback functionalities are of interests for users. For this reason, exploring a wide range of alternative solutions/modalities (from "easy to implement" to more advanced applications), to integrate such feedback functionalities into products, could be useful to manufacturers in order to enrich their product portfolio and spread a more sustainable behaviour in the use of products/energy.

3.1.5 People's perspective about two well-known feedback: the belt alarm and the mobile phone calling system

We decided to inquire respondents about two well-known feedback messages. The first is the belt alarm (i.e. the sound feedback) of the car, which is a warning about the safeness of people and, it depends on the user's action. The second is the ring/vibrate mode of mobile phones, which is set by the user and it is mainly related to daily and/or working situations. Therefore, those feedbacks are built for providing two completely different "messages" to users. Regarding the belt alarm 65% of the respondents declared that it is useful and even essential, even if 54% consider it as annoying. That is also the reason why, even if annoying, 61% still prefer the sound alarm instead of only a visual feedback: in this way they are sure that they will remember to fasten the belt so as to guarantee their safeness and the one of the people travelling with them. Regarding the mobile phone example, taking into account all the possible feedback modalities (vibrate/ring/visual alarm), it comes out that, at work, the vibrate mode is selected by 84% of the respondents, while the ring mode is appreciated by 16%. 41% make use of a combination of different feedback. In this way they are sure not to miss the call. At home the ring mode is selected by 73% of the respondents. However, as at work, the interesting aspect is that 43% would need a combination of two/three kinds of feedback (vibrate-ring, vibrate-ring-visual alarm, vibrate-visual alarm).

3.2 Concept Design of the multisensory feedback stimuli

On the basis of the background knowledge (see Section 2) acquired for designing the online survey and of the gathered results, we elaborated some ideas using the following three sensory modalities: vision, touch and hearing. The decision to have more than one sensorial feedback was made so as to compare the effectiveness and the contribution of each stimulus as well as of their combination (as in the mobile phone, see Section 3.1.5). The choice of the stimuli to implement is a consequence of the following considerations. First, since people would like to visualize their energy consumption according to their real use (see Section 3.1.4) we decided to make evident to them what happens when the fridge door is open: the temperature of the cavity increases, and a flow of warm air is going inside. The first effect has been translated into a visual stimulus: the colour of the internal cavity changes from a cold colour to a warm one, i.e. from white to red. The second effect would have not been powerful if rendered solely visually, since, as humans, we feel the air mainly as a tactile stimulus. That objection could be also true for the first stimulus, even if in this case we have based this choice on the mental association that our brain makes: warm colours generate warm sensations. However, in this second case, to simplify the feedback we turned it upside-down: we decided to render the outlet of the internal air that exits due to the door opening. That is also what makes us closing quickly the freezer since we feel the cold air flowing out. To inform the user that the door is open we have decided to replicate the same stimuli available in the mobile phone. Actually, for the sound stimulus there are on the market fridges that already embed such kind of feedback. The idea in the study was to replicate such feedback so as to use it as a reference for the new ones. The source of this stimulus is placed, in the door because it is the product component that should deliver the message (specifically its internal side). The vibration mode of the mobile phones has been applied to the door handle and it could be perceived as a tactile stimulus when the user grasps the handle. The vibration becomes a sound feedback when the user stops touching it. In Table 1 all these stimuli are summarised while Figure 1 illustrates the position of the source of each stimulus, as well as, the technical solutions implemented for prototyping them.

Table 1. The multisensory feedback stimuli we ideated

Sense involved	Stimulus	Message to the user
Vision	A gradual change from a cold to a warm colour	The internal temperature is increasing
Haptic	Sudden air flow	"The cold air has started to exit" (even if it is the warm air going inside this feedback reproduces the same feeling of opening a freezer)
Haptic (+ Hearing)	Vibration	The door informs the user that it is open
Hearing	Sound	The door informs the user that it is open

3.3 Prototyping strategy: requirements and tools

Before starting building the prototypes we have defined a bunch of requirements so as to select the most appropriate prototyping strategy and the proper location of the devices. Firstly, we found it important to have prototypes working similarly to plug-and-play solutions since we did not want to alter the normal functioning of the fridge used for running the experiments. Second, according to this need, we have tried to take advantage of the technical features already available in this kind of products (e.g. the internal lighting system). Third, the prototype should not obstacle the searching of the food neither waste space so as not to alter the main functionalities of the product. That aspect has been considered both when selecting the dimensions of the devices used and, when defining the set-up for the testing. Fourth, such prototypes should be intended as concept solutions. For this reason, in building them, we tried to find a compromise between having low or hi-fidelity representations: we needed something working properly so as to create the desired stimulus but we did not go into much detail so as to have quickly something ready for testing the ideas.

For building the prototypes we have used the Arduino electronics platform (www.arduino.cc) and specifically, the Arduino UNO board. For each stimulus a dedicated Arduino UNO board has been used so as to reduce the encumbrance given by the number of cables necessary to let an external PC control the boards. Furthermore, an additional board has been used to automatically acquire the opening times during the testing activity.

The circuit designed for the airflow feedback consists in the following components: a PC fan (i.e. a 12V load); a transistor (which applies an ON/OFF control on the fan motor); a photoresistor (to read the light variation within the fridge cavity); a diode; a 9V battery. The photoresistor acts as a trigger since it informs the board when someone opens the door and the fridge lighting system turns on. Immediately, the opening time is acquired while after 3 seconds from the opening the fan starts working. The fan has been supplied with a 9V battery rather then 12V so as not to create a too strong tactile effect on the user's face. The fan has been placed on the internal side of the door, on one of the middle-height shelves. Obviously, its position should be correlated to the user's height. However, for carrying out the first tests we have considered a user having an average height of 1.65 m.

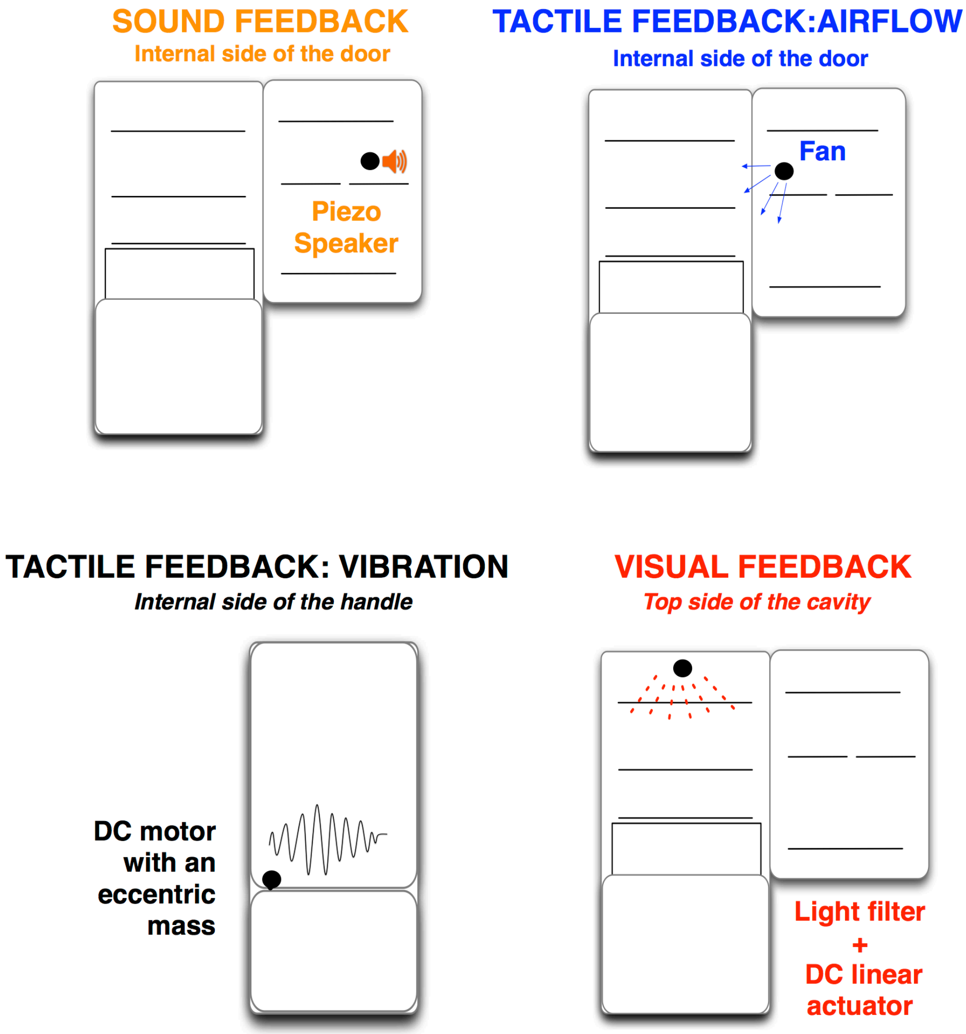

Figure 1. The position of the source of each stimulus and the technical solution adopted for prototyping the four multisensory feedback: sound; tactile (airflow); tactile (vibration); visual

The circuit built for creating the second tactile feedback (i.e. the door vibration) makes use of the same components as before even if, in this case, we have used a 9V DC motor with an eccentric mass to generate the vibration. Again, the photoresistor acts as a trigger for the Arduino board. The DC motor has been supplied with 5V instead of 9V so as not to have a too noisy effect. The intent has been to replicate the same effect we have in our mobile phone.

The prototype of the sound feedback has been made with a piezo speaker, which continuously pulses on/off. Also in this case the activation of the piezo is controlled through the photoresistor. Finally, to change the colour of the fridge cavity from white to red we have used a DC liner actuator to progressively cover with a red filter the light bulbs of the fridge lighting system. The activation of the linear actuator is controlled through the photoresistor. The actuator can work backward and forward, i.e. it can return in its initial position when the user closes the door. The actuator starts working after 3s from the door opening. This value has been chosen so as to have the time necessary to make the user perceive a gradual change of the colour of the internal cavity of the fridge.

3.4 Testing: results and subjects' responses

Before running the experiments we have invested effort in order to analyse what were the aspects to take into account so as to get reliable data. To try recreating what occurs in reality, we filled the fridge with objects (mainly boxes) paying attention not to use real foods or branded packages so as to avoid any influences on the subject. In addition, such objects have been stored in a random order. The prototypes of the stimuli have been placed within the fridge trying to hide them as much as possible.

Figure 2. Two examples of tasks performed by the subject and a focus of the zones selected for placing the feedback devices (both the pictures have been made with the visual stimulus in the active mode – to make the devices visible for the picture we have removed the solutions used for hiding them).

10 subjects participated to the tests (5 males and 5 females, 8 right handed and 2 left handed, aged between 23 and 35, mean 27, STD 4). Each of them has been asked to perform a list of tasks that consisted in taking out from the fridge one of the geometric shapes we had hidden within the fridge (see Figure 2) in one of the following place: top shelve; central shelve; bottom shelve; door. Before performing any task, the arrangement of the food inside the cavity was changed so as to avoid any "memory" effect in terms of objects positioning. We have used geometric shapes instead of food so as to avoid any influence in relation to the food shape and the subject's eating habits. A specific feedback stimulus has been related with each geometric shape, but the subjects were not aware of that correlation. In addition, we tested also the effects on the subject when more than one feedback was active. This decision was taken as a consequence of the results given by the questionnaire where a strong appraisal of a double feedback was observed in case of the mobile phone example (see Section 3.1.5). The order followed to test the stimuli has been counterbalanced between subjects to avoid any learning effects. At the end of the test we asked subjects to fill out a post-test questionnaire so as to compare the quantitative data retrieved from the experiments (the time needed for taking out the required shape) with the perception felt by the subjects about the feedback effectiveness. The main results are summarised in Figure 3.

An interesting aspect that comes up from the results is that the combined feedback, considered by the subjects as the most effective (i.e. the *sound + vibration,* see Figure 3 bottom chart), is not the one always associated with the highest reduction time. Indeed, looking at the top chart of Figure 3 we see that the combination of the airflow feedback plus the light change has given the best result in terms of time reduction (for the task reported in Figure 3).

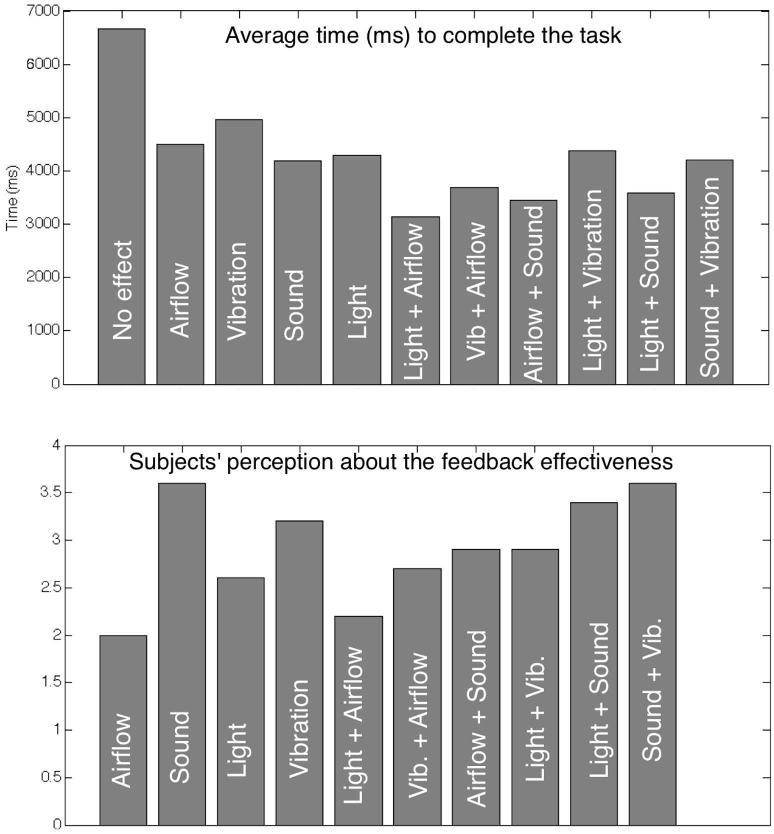

Figure 3. A comparison of the testing average times and the subjects' perception (5-points Likert scale) of the feedback effectiveness

However, most of the users declared they were not aware of the presence of the airflow. That is also the reason why they considered it as not effective after we have explained them the aim of the tests. Actually, it is worth saying here that, the time data reported in Figure 3, are the average times we measured while we noticed an overall difference on the subject "performances" according to the following two aspects: the first one is their height since from this value should depend the proper placement of the feedback devices while we set a unique position for every subject; the second one is related to their dominant hand. We noticed that the vibration cues on the door worked well more for left-handed subjects than the right-handed ones. That is due to the fact (as shown in Figure 2) that left-handed subjects were used to find the object using the left hand while keeping the right one on the door. For right-handed subjects, who were not keeping the hand on the door, the vibration was perceived as a sound.

4 CONCLUSIONS

In this study we explored different feedback modalities that can be used to inform people about their behaviour when using a product. The intent was to find alternative or complementary ways to visual display to make users conscious about what happens in terms of energy consumption when e.g. they keep open the fridge door. We designed four multisensory stimuli to make the user "physically" involved in the consumption process. They are: a visual feedback through which the internal cavity changes colour from white to red (to simulate the increase of the internal temperature); a haptic feedback given by an airflow on the user's face (to simulate the feeling of outlet flow of the internal cold air); a haptic feedback on the user hand; a sound feedback coming from the door. We used a background questionnaire to investigate how people daily use and what they think of their fridge. We used the results to design the stimuli. These have been prototyped by means of the Arduino platform. Finally we run tests with 10 subjects. The results show that people are used to consider, as the most effective, feedback that are well-known, such as sound alarms or vibrations. Actually the results show that also the effects given by the airflow and the light change could be promising. It is worth saying that it is too early for considering these results as fully reliable since a higher number of tests is necessary also to assess the influence given by, for example, the height of the subjects in perceiving the specific feedback. However, the user-centred design approach described in this paper, could be seen as a way to explore alternative feedback modalities to positively influence users' behaviour for a more sustainable approach when using products.

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