Actualizing Agency through Smart Products: Smart Materials and Metaphors in Support of the Ageing Population

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Technological innovation is increasingly contributing to the development of Smart Products- SPs-, meant as autonomous devices augmented by sensing, processing and network capabilities. Given the reduced familiarity that the ageing population has with technological products, it is deemed appropriate to deploy SPs to enhance the experience with technologies of this population segment. Recent studies in interaction design demonstrate how analogies and metaphors, powerful learning tools for written, verbal and visual communication, can be physically embedded into products to improve the interaction with the users. Metaphors, that can trigger established knowledge domains, allow users to create bridges between old and new products making the product more intuitive.

This study proposes that Smart Materials (SMs) may be more successful for embedding multi-sensorial metaphors into novel SPs, increasing the chance of adoption among ageing users.

A novel device has been designed using four different SMs families in order to evaluate which design would be more intuitive among the users. 62 participants (N=31 under-60 years-old and N=31 over-60 years-old) assessed the 32 interactions designed. Findings reveal how age impacts the selection of the preferred interaction and how SMs can embed metaphors to support the users re-establishing their own subjective awareness, hence control, of the world around them.

Keywords*: smart products, ageing, agency, smart materials, metaphors*

Introduction

In the last decades material sciences have made technological advancements and discoveries that have radically changed the role

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consumer products have in everyday life (Jung, Stolterman 2011), (Kuniavsky 2010), (Peters 2011). As a result, technology is progressively more embedded in daily life and products are increasingly gaining context awareness, responsiveness and cooperation abilities. It is therefore legitimate to postulate that technical products could be considered as 'agents' with regards to the increased level of self-activity they are endowed with and to the degree of actions they can perform (Rammert 2008). As reported in Rammert (ibid), there are three levels of an action: a first one where a difference of state is produced, a second one where a difference of options is clarified, and a third one where actors can give an explanation for their actions. We can simplify the three levels as namely: I Do, I Decide, I Understand. Rammert interprets them as different levels of agency, respectively called '*causality*', '*contingency*' and '*intentionality*'. The constellation of agencies created by the growing number of interconnected and pervasive devices are therefore considered able to maximize the exchange of information between human/human and human/environment at the basic level of causality that the human agent will eventually convert into volitional actions. Embedded intelligence may change the way designers conceptualize and develop products, as it will no longer be just about the physical form of the product, but about intangible features able to actualize the contingency and intentionality of the human agency (fig. 1).

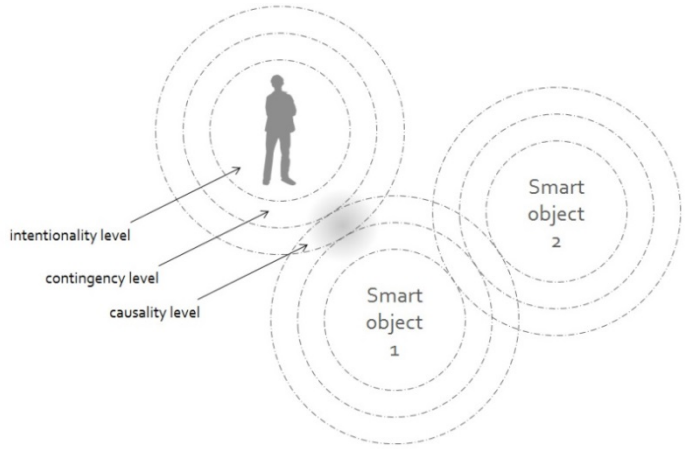


Fig. 1 Three level of 'actions' and their interplay at the 'causality level'

In order to provide a broader understanding of this issue, Smart Materials are presented in this paper as means to unobtrusively enhance products and the environment with intelligent and seamless features that enhance technological devices with causality agency mediating the relation between user and product. The dynamic and sensory-oriented features characterizing these materials are envisioned as effective vehicle of metaphorical messages, where the information conveyed is physically represented for an intuitive understanding of the novel technology. The *older adults* group emerged as a target group where the potential applications of Smart Materials could have a significant impact due to the changing requirements that the ageing process determines.

The research proposition aims to investigate how older adults could be supported through Smart Materials embedded into product to be aware of their surroundings and take actions accordingly. The following two objectives were, therefore, defined:

- Identify whether there is a relationship between age and 'familiarity with the technology';
- Explore whether the adoption of SMs as embodied metaphors could provide benefits at a cognitive level with no distinction of age.

The investigation was conducted adopting a quasi-experiment method and testing 32 embodied analogical/metaphorical messages into a novel communicative device, a Smart Radio.

Metaphors and Analogy: actualizing agency through comparison

Studies conducted on intuitiveness (Mohs, Hurtienne et al. 2006, Blackler, Hurtienne 2007, Blackler, Popovic et al. 2011), explain how the intuitive use of a product is the subconscious application of prior knowledge that leads to effective interaction. Literature reveals that the familiarity with similar technology and prior exposure to products with similar features help the overall understanding of the technology adopted with the completion of the tasks required in a more intuitive and rapid way (Blackler, Popovic et al. 2010). The concept of familiarity with a certain technology and the age factor of the user involved are strictly intertwined by an inverse correlation: evidences demonstrate that the older the user, the lower his familiarity with the technology is (Blackler, Popovic et al. 2010, Fisk, Rogers

et al. 2012). Therefore, older adults are considered users whose understanding of novel technologies is hindered by their limited prior exposure to them. Cognitive tools for comparison such as 'analogies' and 'metaphors' are seen in this paper as a successful way to invert this trend and let older adults understand products they are not familiar with. According to a definition provided by Gentner (1983), analogies occur when a relational structure that normally is applied in one domain can be applied in another domain (e.g. *"The Xl2 star system in the Andromeda galaxy is like our solar system"*), while metaphors are predominantly relational comparison with a specific focus on the attributes they match (e.g., *"She's a giraffe,"* used to convey that she is tall). This attributes sharing makes metaphors relevant in terms of understanding also one experience in terms of another, considering them as cognitive phenomenon that go beyond the linguistic tricks of verbal language; Metaphors are already powerful tools in both written and verbal communication, but new ways to embody them into Smart Products should be investigated. This is the focus of the next section.

Smart Materials as a physical mapping of knowledge

The term *'Smart Materials'* (SMs) refers to a generation of engineered materials that have changeable properties and are able to reversibly alter their shape or color in response to physical and/or chemical influences, e.g. light, temperature or the application of an electric field (Ritter 2007). The application of SMs within this paper lays in the hypothesis that the enhanced signals they help to shape are able to build a metaphorical language that involves all human senses and can therefore support older adults in the acquisition of new knowledge. Based on the definition that in a metaphorical language inferences are created by developing a *mapping of knowledge* from one situation to another as an act of building a conceptual correspondence between source and target domains also with tangible features (Hey, Linsey et al. 2008, Cila 2013), we propose to investigate SMs as means to physically map information from two selected domains and facilitate the representation of abstract concepts into a physical target domain (fig.2).

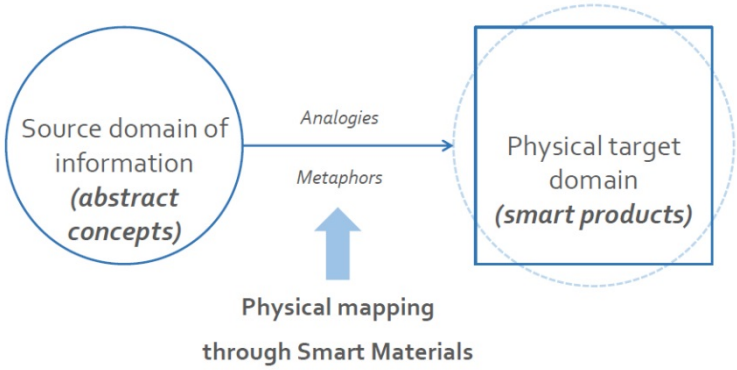


Fig. 2 Mapping of knowledge across domains with Smart Materials

For exploratory purposes, four families of SMs are identified as representative of the potential visual and tangible effects the dynamic materials can achieve: *Light Emitting Materials, Shape Changing Materials, Rheological Changing Materials and Colour Changing Materials*. These four families of SMs have been embedded into the prototype of a Smart Radio. Considering that older adults find less intimidating those devices they had prior exposure with (Blackler, Popovic et al. 2010), a radio appeared to be a product whose components, commands, functions are straightforward and familiar enough to let the user be focus on the interaction proposed, and overcome the cognitive and emotional limitations occurring when using a radically new device.

Main study

Prototyping the device

The Smart Radio was designed to keep only the aesthetics of a 'conventional' radio; instead of broadcasting music, the radio was hypothetically able to share information between people using it, wireless connected each other. The Smart Radio could potentially allow each user to browse among four different friends/relatives (instead of radio stations) and receive with the aim to enhance the communication between peers and provide lightweight details of the activities they are performing (fig. 3).

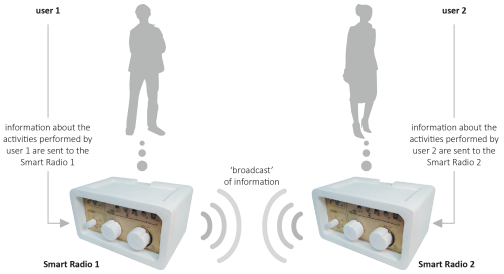


Fig. 3 Functionality of a set of Smart Radios. Each device detects information about the level of activity of the user using it and broadcasts that information to a connected device

Messages were displayed on the top surface of the Smart Radio and they were shaped by embodied analogical/metaphorical messages based on the four families of SMs identified. Each group of materials showed eight signals, by meaning of four analogical messages and four metaphorical messages for each family of SMs for a total of 32 messages (fig. 4).

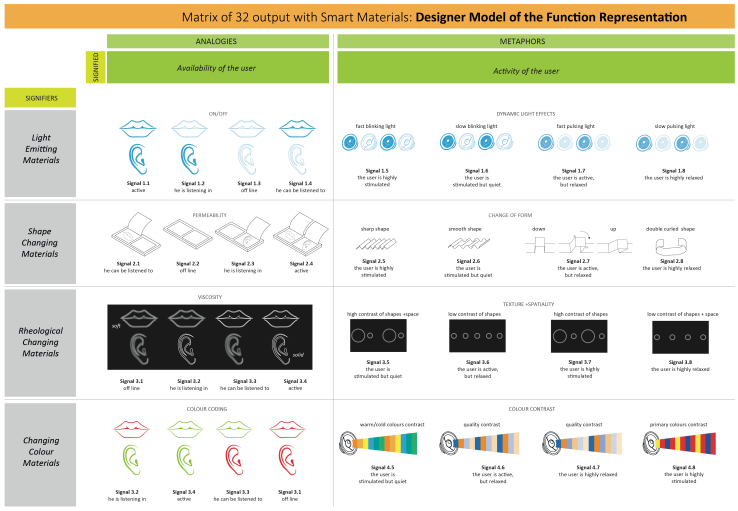


Fig. 4 Matrix of the 32 messages designed

Analogical messages were selected to communicate the '*availability of the user*' from whom information are sought, represented by the dynamic

on/off alternation of two symbols by means of 'ear' and 'lips' appearing on the surface of the radio:

- *Off line*: the connected device is off (ear and lips symbols are off);
- *He is listening in*: the connected device is receiving information (only ear symbol is on)
- *He can be listened to*: the connected device is sending information (only the lips symbol is on)
- *Fully active*: the connected device is both sending and receiving information (ear and lips symbols are on)

SMs were adopted to enhance the appearing symbols in order to have alternation of lighting symbols (*Light Emitting Materials)*, movable flaps revealing underneath symbols (*Shape Changing Materials)*, popping up and tangible symbols (*Rheological Changing Materials)* and appearing symbols with a traffic light colour coding (*Changing Colour Materials),* as shown in Figure 3.

In order to render the desired metaphorical messages, a 'rhythm' has been used to interpret the level of 'intensity' and 'activity' performed by the users connected, namely:

- the connected user is highly stimulated (e.g. doing exercises);
- *the connected user is stimulated but quiet* (e.g. housekeeping, gardening, cooking);
- *the connected user is active but relaxed* (e.g. eating, watching television, reading a book);
- the connected user is highly relaxed (e.g. sleeping).

The level of activity of the user with *Light Emitting Materials* was interpreted by the alternation of blinking and pulsing light communicating whether the user is exercising (fast blinking light), walking (slow blinking light), eating (fast pulsing light) or watching television/reading/sleeping (slow pulsing light); *Shape Changing Materials* helped to convey the idea of the actions performed by creating a sharp shape, a smooth shape, slow pace up/down movement and a double curled shape; *Rheological Changing Materials* built a haptic feedback with a series of popping up 'bubbles' each of those simulating the activities performed by the user connected, represented by a high contrast of shapes, high contrast of shape with a spatial gap in between bubbles, small bubbles with no contrast of shape, small bubbles with no contrast of shape with a spatial gap in between them; finally, *Changing Colour Materials* displayed messages shaped by primary colours contrast, warm/cold colours contrast and contrast of saturation,

dynamically playing with the hue and brightness of colours. A 'Designer Mental model of the Function Representation' was applied as a potential association of the 32 SMs output and their meanings. This mental model linked of signifiers (SMs) and signified (activity of the user) in what the designer considered the best pair and was therefore used as initial benchmark to evaluate participants' responses. A representation of the model adopted can be seen in Figure 4. Figure 5 and Figure 6 show the prototype of the Smart Radio and the interface.

Fig.5 The prototype of the Smart Radio

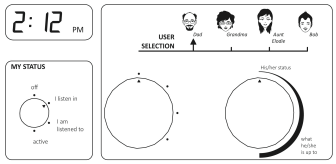


Fig. 6 Display of the Smart Radio in the default modality with the three knobs indicating: the status of the device, the peers browsing and the level of information to acquire.

Protocol of the study

A total number of 62 participants took part in the study (male = 22, female = 40) whose age span from 21 and 84 years old (median age = 59.5). Participants were distributed in this way:

- Under-60 years old: N = 31, age span from 21 to 59 years old, median age = 32 years old; male = 14, female = 17.
- Over-60 years old: N = 31, age span from 60 to 84 years old, mean age = 71 years old; male = 8, female = 23.

Heterogeneity in age was sought in the two samples with the intent to understand commonalities and differences in the interpretation of the given answers. Furthermore, the two age brackets selected helped to explore whether the Smart Radio, as a familiar interface, could positively impact the interpretation of the messages across generations and whether the diverse families of SMs were equally understood among age brackets. Participants were recruited within Brunel University Students (last year undergraduate

students in Human Factors, PhD students in Design, staff members, and visiting students), 50+ group At Brunel University London, London Age UK branches, a nursing home in Uxbridge (London) and the Uxbridge Library.

Participants were asked to individually fill two questionnaires: the Technology Familiarity questionnaire (TF) and the Main questionnaire.

Two independent variables were considered: the age of the participants and the familiarity with the technology, assessed with TF questionnaire based on the template designed by Blackler et al. (2010) and adapted on the product category of a Digital Radio. The TF questionnaire was a self-rating questionnaire designed to ask participants about how often they used certain smart and interactive devices and technologies, and how much of the functionality of those products they used. In the questionnaire, more exposure to, and knowledge of certain products specifically selected, produced a higher technology familiarity score. The maximum possible score on this questionnaire was 100, and the hypothetical minimum was 0. A £5 amazon voucher was given to each participant to thank them for their time and input.

The Main questionnaire included four sections, each of those referring to one of the family of SMs. In each section participants found a table with the list of the signal they were asked to assess and a list of their potential meanings. Participants were instructed to provide only one association signal/meaning and to give a score from one to three where one meant a weak, poor association, and three was a really intuitive and powerful association. They were invited to tick the column of 'others' if they found an alternative interpretation among those proposed.

Three open questions at the end of main questionnaire were included to let their preferred signals and personal comments on the device. Questions asked participants which of the signals identified better represent the availability and the level of stimulation of the connected user and how participants though the Digital Radio should be improved.

Each participant signed a formal consensus where he/she accepted to perform the test and to share his/her data for research purposes. Participants were assured no

Fig. *participant during the test*

personal information would have been used and that their names would have been carefully replaced to protect their privacy.

After a detailed explanation of the test and after the TF questionnaire was filled, a simulation was performed: participants were individually asked to use the Smart Radio to select one of the four hypothetically connected users at time and receive messages from them (fig. 7) in order to 'browse' the four families of SMs and the corresponding messages. The 32 messages were individually shown simulating the interaction with the Smart Radio and participants were invited to complete the main questionnaire matching each message with a potential meaning.

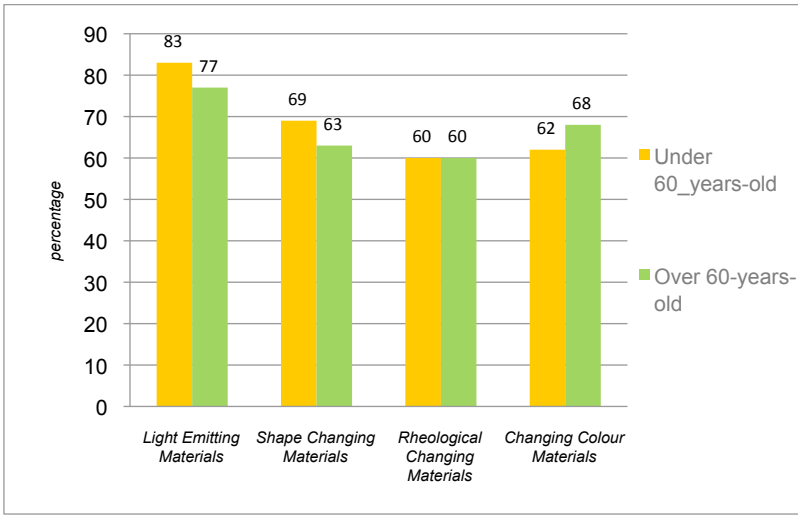
Findings

Table 1 shows the median value of the familiarity with the product category selected. The value reveals a decreasing trend related to the growing age of the participant confirming a reduced familiarity for over-60 years-old participants also with radio-related technologies. Because of this different prior exposure to these technologies, different patterns of interpretation of the Smart Radio were expected between the groups investigated.

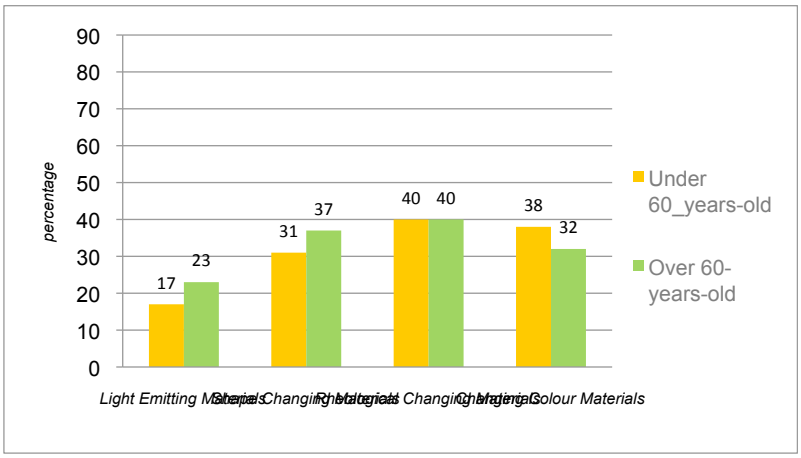
Table 1 Median value of the Familiarity with the Technology score recorded in relation to Radio-related technologies. The value decreases as the age grows.

Samples	N	Median Value: age	Median Value: Familiarity with the Technology
Under 60 years-old	31	30	62
Over 60 years-old	31	71	36

Interestingly, results show a different trend. The following graphs showthe percentage of participants matching the 'Designer Model of the Function Representation' (Graph 1) and the percentage of participants reporting scattered answers (Graph 2) with a distinction of the groups investigated and the SMs families assessed.



Graph 1 Percentage of participants matching the 'Designer Model of the Function Representation'



Graph 2 Percentage of participants reporting scattered answers

Data reveal a significant high percentage of participants matching the 'Designer Model of the Function Representation' with an always lower percentage of scattered answers recorded for each SMs family. Interestingly, the percentage of matches follows a common trend of interpretation, meaning that the Smart Radio was similarly interpreted by participants with no apparent influence of the prior exposure they had with radio-related technologies. Although no significant differences in percentage are observed within SMs families, each age bracket showed certain 'preferences' while interacting with the Smart Radio. Under-60 years old people recorded an higher percentage of matches that the Over-60 years old group for the *Light Emitting Materials* and *Changing Shape Materials*; Over-60 years old participants showed a clear understanding of *Changing Colour Materials*, compared to the Under-60 years old participants. Differences among the two groups observed were further analysed upon the qualitative feedback recorded and presented in the next two paragraphs.

Under-60 years old group

Light Emitting Materials: Higher percentage of matches recorded (83%). Under-60 year-old participants reported how easier was to discern the extreme messages among the four proposed (blinking lights as representation of 'highly stimulated' status and pulsing light as representation of 'highly relaxed') compared to the ones in the middle (Samantha, 24 years old, Female). Chul (32 years old, Male) stressed how working with lights reduces the amount of mental errors because the user does not have to spend time and think.

Changing Shape Materials were ambiguously perceived by the Under-60 years old participants, meaning that the application of these materials in terms of their kinetic properties have to be improved. William, (21 years old, Male) said that the movable flaps of the analogical messages are efficient enough to convey the message and that the symbols appear reinforced by the flaps movement; Gabriele (29 years old, Male) considered the opening/closing windows really intuitive. William highlighted how the *Changing Shape Materials* give just a little margin for error and they help to show exactly the availability of the user. Nonetheless, Mario (27 years old, Male) said that the four metaphorical messages are really chaotic because users are not familiar with this kind of interfaces, therefore the addition of the 'time' parameter will help to connect the changing shape to the activity of the user, creating a more descriptive message. The key aspect is then to let the materials be dynamic (Mario, 27 years old, Male and Bobby, 30 years

old, Male) and to visually mimic the human physical behaviour (Mary, 28 years old, Female).

Rheological Changing Materials was the SMs with the lowest percentage recorded (60%). Georgia (52 years old, Female) reported how the users must have an education about the new means. However, she acknowledged the relevance of the unexpected tactile experience. Both Gabriele (29 years old, Male) and Nastaran (30 years old, Female) reported how the haptic shapes have a code of interpretation not fully understood and users have to work with extreme signals and then try to understand the intermediate messages. An interesting potential is highlighted by Margaret (42 years old, Female) claiming how the haptic surfaces could accurately mimic the sense of 'action' and movement of the human body.

Changing Colour Materials were easily understood when embodying colour coding in the analogical section (green = go, red = not go) but as claimed by Samantha (24 years old, female), colours have different meanings in different cultures therefore, it could be counter-productive to work on them. She noticed how symbols appear similar and that four different symbols could work better. Johnny (25 years-old, male) suggested how colours can be improved by dynamically activating them and *"letting them move to actually see them changing".* He purposed to see the colours dynamically fading rather than have them all appearing simultaneously.

Over-60 years old group

Light Emitting Materials for the Over-60 years old people were scored with the highest percentage recorded for this age bracket (77%). Participant found this means really intuitive and effective, although further comments were recorded to improve the interface for future applications. Ivan (67 years old, Male) said: *"A combination of light and touch is good and maybe adding a vibrating signal to enhance the message would be beneficial".*

Changing Shape Materials recorded a lower percentage compared to the *Light Emitting Materials* (63%). Although a relatively high percentage of scattered answers (37%) is recorded, participants appreciated how the changing interface could maximize the way information are displayed. Stella (71 years old, Female) appreciated how the moving flaps give a visual contribution to the device and Sasha (71 years old, Female) considers them "*really amusing*". Justin (79 years old, Male) preferred the lighting symbols to the movable flaps, considered not effective. Allison (69 years old, Female) considered the metaphorical messages really effective, especially for their

potentiality to visually represent human-like or nature-inspired behaviours: *"like a cat sleeping or a dog wagging the tail and jumping. Simple and understandable".*

Rheological Changing Materials were recorded with the highest number of scattered answers (40%). Participants were intrigued by the novelty provided by the haptic interfaces but they could barely identify a code of interpretation. Sasha (71 years old, Female) liked the movable spots: *"they are interesting because they could actually convey the stimulation of who I'm listening in".* Justin (79 years old, Male) reckoned how the tangible symbols are effectively working, mainly for visually impaired people but he explained how messages require a clarification in order to stand out, maybe with colours, and have their meaning clarified.

Colour Changing Materials where easily understood by Over-60 years old participants with an higher percentage of matches recorded compared to the under-60 years old participants (68%). Nevertheless, participants appeared concerned about the effectiveness of the application of colours, given that ageing processes affect the perception of colour coding and contrasts (Elizabeth, 76 years old, Female). Brightness of colours adopted as a way to convey different status of the user was appreciated by Ivan (67 years old, Male): he suggested clarifying the colour coding by displaying the spectrum on different bars and play with the intensity. In order to have a clear understanding of the message, he thought each colours should have a dedicated bar that gradually change to communicate the desired information.

Discussions

Data collected show a promising application of embodying SMs into novel technological products. The high correspondence between the answers collected and the 'Designer Model of the Function Representation' provide further research opportunities in consideration of the role of embodied metaphorical messages to maximize the way people get acquaintance of external stimuli, in reactivation of their *contingent* and *intentional* agency.

Although little differences in interpretation were observed among age brackets, participants gave interesting feedback on their preferred means. The interpretation of metaphors embedded with *Light Emitting Materials* show a surprising high peak for both age brackets. Under-60 years old participants reported how was easier to discern the extreme messages among the four proposed compared to the ones in the middle; a recurrent

concern is observed: the changing speed and intensity of light can convey general status of activity like excitement, stimulation and relaxation, quiet status, but messages are not always clear. What the under-60 years-old participants reported explains the confusion also perceived by over-60 years-old people while interpreting these signals: they often missed a code of interpretation, such as high frequency meaning high activity, to interpret the metaphorical messages.

The interpretation of messages with *Changing Shape Materials* has a drastic reduction of the participants' understanding compared to the *Light Emitting Materials*, in both age brackets. These materials are perceived as an excellent way to mimic human behaviour and therefore depict a plethora of human status but the changing shapes as they were presented for the study resulted static and inexpressive; therefore, participants encouraged the adoption of 'time' parameter to properly discriminate among signals: a continuous changing shape with different speeds of movement would help building strong metaphors recalling anthropomorphic behaviour.

Rheological Changing Materials appeared an effective way to shape messages in a tactile way but the unfamiliarity with look-alike interfaces prevented the participants to find a proper code of interpretation. Participants found intriguing the adoption of tactile interfaces and therefore suggested to implement the efficacy of the popping up symbols. An interesting way to enrich the adoption of the *Rheological Changing Materials* is in the addiction of the rhythm of the pulsing symbols and the tangible reproduction of sound waves.

Participants suggested the addition of the 'time' parameter to shape powerful metaphors with *Changing Colours Materials* too. The way the interface was made dynamic was more important and effective than the final composition itself. The colourful patterns were not fully perceived due to the static nature of the signal designed. Participants understood the power of this means but they suggested enhancing the contrast of colours by showing them in different time segments to depict a specific activity of the user. The over-60 years old participants stressed how was important to compare signals before attempting a proper evaluation and they suggested to improve the application of the changing colours by working with the brightness of colours rather than just colour coding.

Conclusions

This paper investigates the role of Smart Products as actuator of the human agency and explores the role of SMs and metaphorical languages to shorten the gap of understandability among under-60 and over-60 years-old people. We demonstrated how embodied metaphorical messages can effectively convey information in a more intuitive way, by providing a maximized set of stimuli. We observed that both age brackets have they preferred means of interaction: while *Light Emitting Materials* are preferred among under-60 years-old participants, *Changing Colours Materials* have a great potential within the over-60 years-old people. Nevertheless, the high correspondence of the given answers with the 'Designer Model of the Function Representation' provide an optimistic way to design inclusive Smart Products that mitigate differences in ages and make technologies more familiar even when prior exposure is limited. Feedback from participants reveal how important was the implementation of the signals based on the 'tempo' parameter, making the case for further investigations where embodied metaphors are structured to express their narrative abilities.

This study does not attempt to determine a one-to-one correlation between a certain material property and a specific user response but rather it moves towards the conceptualisation of an alternative and efficient way to elaborate information and to actualize the volitional abilities of the human agent. Interestingly, the study reveals how the combination SMs and metaphors has benefits in the way people show a common pattern in the acquisition of new knowledge, effects of lack of prior exposure to technologies could be minimized and the gap in perception among ages could be effectively bridged. Opportunities are observed in the design of smart artefacts endowed with agency; the interaction with the Smart Radio has been proved to lead toward a simplification of the relationship human/environment and a common interpretation of the changeable actions and situations emerging from the environment. The influence that the renewed causality agency of the smart artefacts has on the human agent has been proved to effectively reactivate the ability of older adults to choose between options and attribute a meaning to their preferences; in other words, smart artefacts do have agency but their agency get value in correlation with the human agent and the re-establishment of his ability to act, decide and understand.

Acknowledgments

This research study has been supported by the EU-funded FP7 collaborative research project Light.Touch.Matters (LTM), under agreement n°310311

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