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The influence of color association strength and consistency on ease of processing of ambient lighting feedback

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ABSTRACT

Lighting feedback may use colors that through their associations help users to easily process feedback messages and adapt their behavior. Study 1 showed more ease of processing (of feedback messages) only for participants receiving *strongly*-associated lighting feedback, as their processing times were *not* increased by additional cognitive load. Also, lighting feedback that was strongly associated with the message had stronger persuasive effects on behavior. Study 2 tested the effects of *consistency* of color association with the message. For example, while normally green is associated with low energy consumption, the inconsistent feedback condition showed green colors indicating high energy consumption. Results showed that only the *inconsistent* version of *strongly*-associated lighting feedback slowed down the processing of feedback messages. Also, consistent feedback had stronger persuasive effects on behavior. These findings increase our understanding of the psychological mechanisms of ambient persuasive technology showing the important role of strong and consistent associations of ambient lighting.

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1. Introduction

According to the International Energy Outlook 2015, growth of global primary energy consumption continues to accelerate in 2014 despite stagnant global economic growth. The threats of growing green-house gases and exhaustion of natural resources have urged nations worldwide to seek for substantial reduction in energy consumption. Next to the importance of technological solutions such as efficient systems and renewable energy sources, consumer behavior plays a crucial role in reducing the level of energy consumption. For instance, an actual 1 °C decrease, from 20 °C to 19 °C, results in heating-energy savings of 7% (Briand & Pras, 2010). Therefore, the question of how to promote pro-environmental behavior (e.g., energy saving behavior) has become highly relevant in the domain of energy sustainability (Midden & Ham, 2012).

Various interventions and incentives have been used to promote energy conservation behavior (Abrahamse, Steg, Vlek, & Rothengatter, 2005; Midden, Kaiser, & Mccalley, 2007). One strategy is embedding feedback in user-system interaction, and such feedback interventions have been employed to promote energy conservation behavior. For example, McCalley and Midden (2002) demonstrated in several studies that immediate feedback by adding an energy meter to the user interface of a washing machine could persuade users to use 21% less energy. Another, more recent, novel smart home system (Jahn et al., 2010) used intuitive user interfaces that could show energy consumption data, (e.g. energy price, energy source, standby consumption etc). This kind of feedback allowed users to judge levels of household energy consumption and consume energy efficiently. Relatedly, Ham and Midden (2010) proposed another form of interactive feedback by making use of a social robot. This social robot can show signs of disapproval or negative social incentives as feedback about energy consumption. This form of social feedback (i.e., a persuasive robotic agents) showed to be able to create greater behavior change among human users, compared to the effects of (interactive) factual-evaluative feedback (directly indicating the amount of kWh) (Ham & Midden, 2010).

However, some forms of Persuasive Technology, designed to change people's attitudes or behaviors in a predetermined way (Fogg, 2003), might not be very practical in many day-to-day situations. For example, factual feedback messages may be relatively complex and might lose their persuasive power in situations that require high cognitive capacity. Likewise, social feedback requires user's focal attention because users have to consciously focus on

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the feedback messages. So, in daily situations, people might lack the focal attention or cognitive capacity to consciously process these feedback information (Bargh & Williams, 2006).

To investigate a form of feedback that might be less sensitive to this lack of focal attention and cognitive capacity, earlier research proposed to use another form of feedback that is easier to process: ambient feedback. Ishii and Ullmer (1997) suggested the use of ambient media such as light, airflow, and sound to act as background influences and work at the periphery of human perception. The concept of ambient persuasive technology was investigated by research (Aarts, Markopoulos, & De Ruyter, 2007; Davis, 2008; Ham, Midden, & Beute, 2009; Martinez & Geltz, 2005; Schmidt, 2005; Wisneski et al., 1998), in which ambient persuasive technology was shown to be effective while being at the "periphery of our attention"(see Wisneski et al., 1998; at page 22), "without conscious attention"(see Ham et al., 2009; at page 5).

In line with the proposed concept of ambient feedback, Arroyo, Bonanni, and Selker (2005) presented ambient feedback through providing colored lighting about the temperature of the water without altering the function of the sink. For example, one of their designs was called Heat Sink, and consisted of colored LEDs mounted around the faucet aerator that could illuminate the stream of water with a red light when water was hot, and blue when water was cold. Also, a case study by Wilson, Lilley, and Bhamra (2013) suggested that effective ambient (heating system) feedback can be provided through light and sound on the status of heating system in tandem with the status of their windows, so to convey directly the energy consequences of their behavior. For example, if a window is opened in tandem with a detected increase in radiator surface temperature, the colored light corresponding to temperature immediately displays a warning light (e.g., red) to indicate waste.

Feedback given through this kind of persuasive technology can help users in those day-to-day situations, in which users lack cognitive capacity or focal attention to process feedback information. In line with earlier research (Petty, Cacioppo, & Kasmer, 2015; Strack & Deutsch, 2004), the processing of this more simple information, as provided by ambient feedback, requires less cognitive capacity and attentional resources compared to the processing of complex information, as provided by factual feedback.

Recent research indeed confirmed that ambient persuasive technology can still be effective in situations in which more focal persuasive technology (e.g., factual-evaluative feedback as described above) loses its effectiveness. That is, research by Maan, Merkus, Ham, and Midden (2011) explored the fundamental characteristics of ambient feedback. They tested the effect of feedback through a lamp that could gradually change color dependent on the amount of energy consumption of the participant in a certain task, and compared these effects to a more widely-used factual feedback (i.e., numerical feedback in kWh). Results indicated that feedback though ambient lighting was more effective than numerical feedback. In addition, processing ambient lighting feedback seemed easier in the sense that performing an additional cognitive load task did not interfere with the feedback. However, the underlying mechanisms behind the effectiveness of processing ambient feedback remain largely unclear.

In the current research we explore the role of associations. We argue that colors of lighting feedback could carry meaning that has pre-existing associations with the target behavior (i.e., energy conservation behavior in the current research). These associations could help users to easily understand the feedback messages, and thereby, increase the persuasive effectiveness of ambient lighting feedback. For instance, the color pair, red vs. green (as used in Maan et al., 2011), indicated higher energy consumption levels for shades of red and shades of green indicated relatively lower consumption levels. And indeed, these associations of colored lighting feedback lead to less energy consumption behaviors compared to the factual feedback. However, this research did not study the content of the associations and the nature of the associative process.

Confirming the importance of associations, earlier research has shown that associations, especially color associations, can be very important in object recognition tasks, like detecting a target object (e.g., animal) in either color or gray-scale natural scenes (Otsuka & Kawaguchi, 2009). These color associations can help people to easily detect the target object for the reason that color information in the image is similar to the daily vision, and linking to pre-existing associations.

The aim of current research is to test whether lighting feedback with colors that have pre-existing associations with energy saving as target behavior, is easier to process compared to lighting feedback with colors that have not these associations. We argue that lighting feedback with colors that have pre-existing associations (with energy consumption) could help users to easily process the feedback messages. Such associative process is less dependent of user's cognitive capacity. In contrast, when lighting feedback uses colors lacking these pre-existing associations, it will be a lot more difficult to learn whether the message indicates high or low energy consumption. Furthermore, in the current research, we explore whether these pre-existing associations of colored lighting feedback could promote users to consume less energy than the lighting feedback with colors that have not these associations.

2. Study 1

In Study 1, preceding the lab experiment, an online survey was conducted to explore the strength of different color associations with energy consumption. Fifty-two participants (average age 23.0 years old, SD = 40) were invited to fill in a questionnaire about the association strength of 21 color pairs (e.g., red vs. purple; yellow vs. blue, etc.). For each color pair, we posed the question "Please indicate whether you think a following specific color pair is strongly associated with high vs. low energy consumption?" Results of this survey showed that participants reported the color pair, red vs. green, to be the most strongly associated with energy consumption, and the color pair, yellow vs. purple, to be the most weakly associated with energy consumption.

Therefore, we defined two types of lighting feedback: strongly-associated vs. weakly-associated lighting feedback (see Table 1). The strongly-associated lighting feedback can gradually change colors between red and green dependent on heating energy consumption through ambient LED wall washer. Likewise, the weakly-associated lighting feedback could gradually change colors between yellow and purple. Using these two types of lighting feedback, a lab experiment was set up in which participants had the opportunity to conserve energy in a series of tasks while receiving the lighting feedback.

First of all, to test whether strongly-associated lighting feedback was easier to process than weakly-associated lighting feedback, we manipulated the cognitive load of participants. To manipulate cognitive load, we distracted half of the participants while they were performing the energy conservation task. For this, we used an

Table 1
The *strength* of color associations in Study 1.

Strongly-associated feedback	Weakly-associated feedback
Red = high[a]	Yellow = high
Green = low	Purple = low

[a] High = high energy consumption level; and low = low energy consumption level.

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