Everything's Cool: Extending Security Warnings with Thermal Feedback

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CHI'17 Extended Abstracts, May 06-11, 2017, Denver, CO, USA
ACM 978-1-4503-4656-6/17/05.
http://dx.doi.org/10.1145/3027063.3053127

Abstract
Today's web security warnings often rely on visual cues such as colour, e.g., red URL highlighting indicates a security risk. However, such cues often go unnoticed by users and, even when noticed, are ignored. Our aim is to investigate the potential for using other modalities to improve comprehension of, and adherence to, security warnings, starting with *thermal feedback*. Thermal stimulation has inherent links to emotion and danger, so may provide unique advantages over current visual cues. However, interpretation of feedback varies, so research is needed to measure associations. We used an online questionnaire (n=45) and lab study (n=12) to investigate whether people associate a particular temperature range with different states of web security. Our results indicate that people generally associate a cold temperature with a secure page and warm with an insecure page, findings we will take forward into future work on the effect of thermal feedback on security-related behaviour.

Author Keywords
Browser security warning; SSL warning, thermal feedback; web security.

ACM Classification Keywords
H.5.2. Information interfaces and presentation (e.g., HCI): Haptic I/O.

Introduction

Current approaches for conveying browser security warnings use visual cues to encourage users to not only notice the security warning, but to adhere to and comprehend the warning [4]. For example, visual changes in the colour of a browser's address bar and the display of a "lock icon" are intended to warn a user that their current connection may be unsafe. Previous research has demonstrated the difficulties with designing an effective security warning, e.g., [1,3,4]. Designs typically use several textual and visual features to improve users' performance with recognising, comprehending and adhering to a warning. We sought to investigate whether other means of feedback might result in more salient security warnings.

While modalities such as sound or vibration could be used to enhance security warnings, thermal feedback potentially provides unique advantages. Temperature is inherently tied to social and emotional experience [8,13], has strong links to physical danger (e.g., fire) and can cause instinctive, reflexive actions (e.g., recoiling hand from hot surface). These in-built associations/responses could be leveraged to improve security applications, as safety information would not necessarily need to be learned/interpreted if it were instinctive. Thermal feedback is also entirely silent and private to the individual, unlike sound and even vibration, which can be heard/felt by others.

Previous research indicates that cold stimuli are associated more with negative emotions while warm stimuli was mostly used to relay positive feelings [10,14,15]. However, it has also been observed that such associations may vary depending on context [11,12]. Therefore, to evaluate the usefulness of thermal feedback for security, we wanted to determine which thermal stimuli were associated with secure and insecure web interactions. These associations would then be used in future research to investigate whether thermal feedback influences security-related behaviour.

Thus, in this paper, our aim is to investigate the feasibility of associating thermal feedback with a security warning. We ran two experiments, an online questionnaire (n=45) and a lab study (n=12), in which we asked participants to indicate the temperature level that they would associate with a set of web pages with different security levels (based on the use of different coloured icons for indicating the level of SSL security). Our results indicate that, in general, people associate cold temperatures with secure web connections and warm temperatures with insecure connections.

Related Work

Security Warnings

Designers have used several different features in order to convey warning information to users. Wogalter et al. review the use of text, colour, symbols, and signal words for warning design, and suggest evaluation methods for assessing their suitability [17]. Recent designs to draw users' attention include so-called *attractors* [2] and opinionated design [4]. Yet designs have predominantly used only the visual interface.

Thermal Feedback

Researchers have been increasingly interested in the use of thermal feedback in HCI, using warming and cooling stimulation to e.g., convey information [9] or social/emotional messages [10,12,15]. Most relevant for this paper, research has investigated the *inherent* interpretation or meaning conveyed by thermal

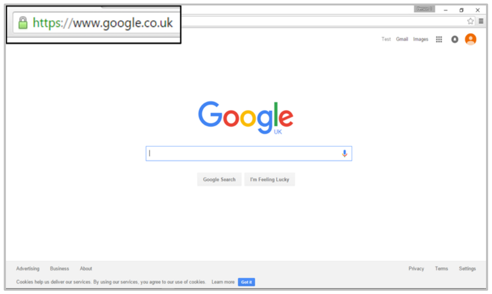

Figure 1: Page with Green SSL security icon used in both studies. URL magnified for clarity.

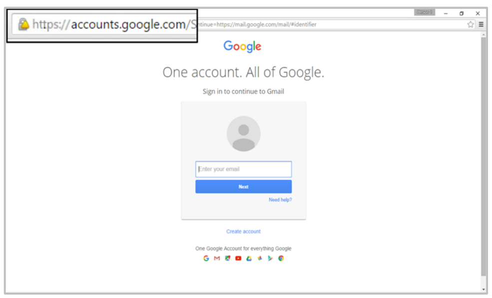

Figure 2: Page with Yellow SSL security icon used in both studies. URL magnified for clarity.

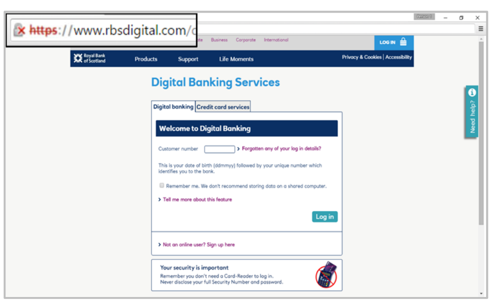

Figure 3: Page with Red SSL security icon used in both studies. URL magnified for clarity.

feedback, rather than *learned* mappings. The benefits are the potential clarity and reliability in interpretation: poor adherence to existing security cues shows users cannot necessarily be relied upon to learn mappings. Users tend to associate warm sensations with positive or pleasant emotional messages [10,14,15], but these associations are not necessarily universal, as research [11,12] has found that warmth can lead to negative or unpleasant emotion/experience. Cooling changes are also more physically comfortable than warm changes [7,16]. Therefore, the framing of the task influences the meaning of thermal feedback, so associations of temperature to security cannot be reliably assumed.

Methodology

We conducted two studies: an online questionnaire and a lab study. Both were approved by our university's ethics board and participants were recruited via email and social media posts. For both experiments we used 12 images of web pages that covered 4 security warning levels (green, yellow, red, and a neutral page with grey highlighting) for each of three types of web activities: searching, email, and online banking (see examples in Figures 1-3). The number of possible page-order permutations was too high to guarantee each was presented to participants an equal number of times, so we generated 12 pseudo-random permutations of the 12 images that did not present the same activity or security warning in more than two consecutive images.

Online Questionnaire

We used Google Forms [5] for our questionnaire and data collection. Participants were first provided a short description of our study in which they would be asked to "associate temperature levels to the security of [each] web page." Participants who consented were then asked to complete a short demographic questionnaire. Then, for each of 12 web page images, participants were asked three questions: **1.** *"How would you rate the security of this page?"* Answered on a 5-point scale: Very Unsecure, Unsecure, Neutral, Secure, Very Secure. **2.** *"Would you consider it safe to continue using this website?"* Answer: yes or no. **3.** *"What temperature level would you use to describe the security of this page?"* Answered on a 5-point scale: Very Cold, Cold, Neutral, Warm, Very Warm.

The first two questions were to gauge participants' perception of each page's security, so that we could better relate this perception to the choice of temperature level. This was particularly important since we did not prime participants beforehand with information about the security information provided on the web pages (i.e., the coloured URL bar and lock icon). To prevent participants from automatically mapping the security scale to the temperature scale (e.g., mapping "Very Cold" to "Very Insecure"), each page presented to each participant randomly showed the original order or the reversed order for each scale.

Lab Study

The purposes of the lab study were to: 1) confirm the associations found in the questionnaire when participants are presented with actual thermal feedback (i.e., made an informed choice); 2) record absolute temperature values for each security level to produce feedback design guidelines. We used a Peltier-based device from previous research [14,15] to provide thermal stimulation (see Figure 4). It used a comfortable temperature range from 20 to 38°C, and changed temperature at 3°C/sec to maximize the salience [16]. Participants rested the first two fingertips

Figure 4: Peltier thermal stimulators (2 x 2cm^2) used in the lab study, with heatsinks.

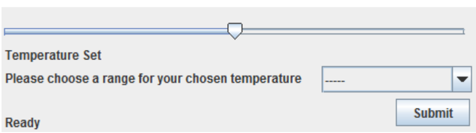

Figure 5: Interface to provide an absolute temperature (slider) and temperature label (drop-down menu) in the lab study.

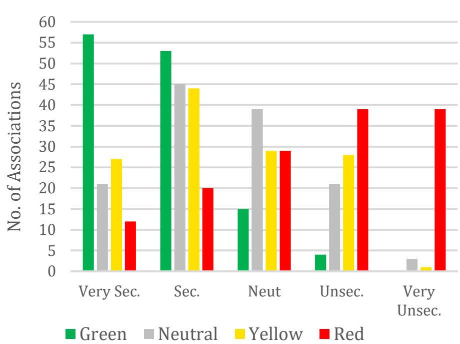

Figure 6: Number of times each security level was associated with each security colour in the questionnaire.

of their non-dominant hand on the Peltiers, mimicking the resting position on a thermal-augmented mouse. Similar to our online questionnaire, participants were first provided a short description of our study. Participants were then asked to complete a short demographic survey and, differing from the online questionnaire, were informed of the four levels of security warnings, to ensure their responses were based on full knowledge of page security [6].

For each of 12 web page images, participants were asked to perform two tasks: **1.** Select a temperature between 20°C and 38°C to represent page security. **2.** Select a corresponding textual temperature level (same 5-point scale as in the Questionnaire: Very Cold to Very Warm). The textual level was recorded for two reasons. First, individual differences in temperature perception mean that the same temperature, e.g. 35°C, could be "Warm" for one person but "Very Warm" for another, so we wanted to have both a numerical measure (absolute temperature) and a magnitude measure (label). Second, the labels allowed us to compare responses in the lab study to those in the questionnaire.

Participants (different from the questionnaire) were presented with the same images as in the online questionnaire, and we created a small Java application to present the web pages and interact with the Peltier device. The Peltiers were maintained at 30°C neutral skin temperature between trials; participants moved a horizontal slider (far left = 20°C, far right = 38°C; see Figure 5) and the temperature changed in real time (reverting to 30°C after each trial). At the end of the study, each participant performed an exit interview in which they were asked to describe the temperature that they perceive as being the most/least secure.

Results & Discussion

Online Questionnaire

We had 45 participants (20 female) with a mean age of 27 (min=17, max=59): 20 (44%) were students and 26 (58%) were employed -- there was an overlap of 5 student participants (11%) who also worked part time. When asked to self-assess their technology skill level (novice, average, or expert), 31 (69%) self-identified as average, while 3 (7%) were novice and 11 (24%) expert. Two male participants were removed from the data set, as their responses were entirely inappropriate (i.e., 'comical'); we report results from 43 participants.

Understanding of Page Security

A Pearson Chi-Square showed a significant association between warning colour and the perceived security ($X^2(12) = 195.1$, $p<0.001$). Participants rated pages with Green security icons as either "Secure" or "Very Secure" in 85% of responses (110/129), but only rated Red or Yellow warnings as "Unsecure" or "Very Unsecure" in 60% and 22% of responses, respectively (Figure 6). This suggests that web users better comprehend safety than risk. This is also seen in the continue data: 93% of responses (120/129) would continue through a Green warning, but 43% of responses (56/129) would also continue through a Red warning. This was partly influenced by the page activity (search/mail/banking), with participants more likely to continue on a red search warning, but 27.9% of responses would continue on a red banking page.

Relationship Between Security Level and Temperature

A Chi-Square showed a significant association between the perceived security of a page and the temperature level that represented it ($X^2(16) = 522.47$, $p<0.001$), shown in Table 1. The most common temperatures

	Very Sec.	Sec.	Neut	Unsec.	Very Unsec.
V. Warm	49	1	0	3	19
Warm	15	102	14	19	1
Neutral	13	35	76	14	1
Cold	13	24	12	51	2
V. Cold	27	0	0	5	20

Table 1: Number of times each temperature level was associated with each security level in the online questionnaire.

	Green	Neutral	Yellow	Red
Very Warm	0	9	4	23
Warm	8	6	16	4
Neutral	6	5	7	0
Cold	6	8	7	0
Very Cold	16	8	2	9

Table 2: Number of times each temperature level was associated with each security colour in the lab study.

chosen for secure pages were warm labels: "Secure" was "Warm" in 63% (102) of responses; "Very Secure" was "Very Warm" in 42% (49) of responses. The most common temperatures for unsecure pages were cold: "Unsecure" was "Cold" in 55% (51) of responses; "Very Unsecure" was "Very Cold" in 46% (20) responses. This shows a strong association across the population. However, for both "Very Secure" and "Very Unsecure", the second most common response was for the opposite thermal pole: "Very Cold" for "Very Secure" and "Very Warm" for "Very Unsecure". This suggests there is more ambiguity in interpretation for "extreme" states of security, particularly for "Very Unsecure".

A Pearson chi-square found no significant association of activity to either security level or temperature level. However, participants assigned different security levels to Green or Red pages depending on the activity: more assigned "Secure" for Green and "Unsecure" for Red under Search, but "Very Secure" for Green and "Very Unsecure" for Red under Banking (and less so email). Thus, it seems that, the more sensitive the activity, the more secure or insecure a page is perceived.

Lab Study

12 participants (2 female) aged 19 to 27 (mean = 22) participated. 10 (83%) were students and 4 (33%) were employed -- 2 student participants (17%) also worked part time. In terms of their technology skill level: 6 (50%) self-identified as average, while 2 (17%) were novice and 4 (33%) expert.

ASSOCIATION OF SECURITY LEVEL TO TEMPERATURE

Participants had a significant association of temperature to security level ($X^2(12) = 68.43$, $p<0.001$): Green secure pages were predominantly associated with "Very Cold" (44%) and Red insecure pages were associated with "Very Warm" (63.9%; see Table 2), a clearer association than in the questionnaire. The absolute temperatures chosen to represent pages were analysed using Activity (3) x Colour (4) repeated-measures ANOVA. There was a significant effect of Colour on the chosen temperature ($F_{(3,33)} = 3.28$, $p = 0.03$): Red warnings had significantly higher temperatures (33.1°C) associated to them than both Green (28.0°C) and Neutral warnings (30.0°C; Yellow had a mean of 30.5°C). There was no effect of Activity on the temperature chosen, and no interaction effect.

These associations are in line with the above textual security levels chosen (warm = Red and cold = Green), however, the temperatures chosen (28/33°C) are not particularly far from starting skin temperature (30°C). When asked to attach a temperature label to the temperature chosen, there was a clear linear mapping ($r = 0.99$) from Very Cold -> Very Warm (Figure 7). "Very Cold" had an average temperature of 24.4°C and "Very Warm" was 36.1°C. These temperatures are in line with previous research on the subjective intensity of thermal feedback [7,16], yet the temperature for "Secure" and "Unsecure" were only 33°C and 28°C.

In the post-study interview, participants were asked "What temperature do you perceive as being most [/least] secure?" and why. Cold temperatures were perceived as most secure and hot temperatures as least secure. But, for both questions, 58% of participants (14/24) responded with an extreme temperature such as "very hot" or "very cold". Green warnings (the most secure) were mostly associated with the label "Very Cold", yet were only given a temperature of 28°C, while "Very Cold" was considered

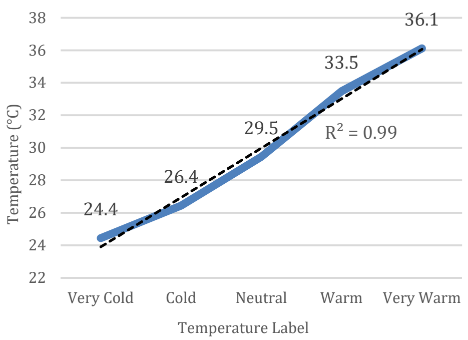

Figure 7: Average temperature assigned to each textual temperature level in the lab study

24.4°C. Similarly, Red (least secure) pages were mostly "Very Warm" yet were only 33°C, when "Very Warm" was considered 36.1°C. The reason for this is most likely that individual differences in judging what temperature is "Very cold" are smaller than those in judging what temperature a green security warning should get. Also Green vs. Red warnings may only indicate binary "Secure" vs. "Unsecure", with users unaware of, or unconcerned with, gradations.

When asked why cold was perceived as the most secure temperature, the most common reason was an association of heat to danger (e.g., fire, oven, warnings). Participants also mentioned that "cold is more comfortable" (P2, also found in [7,16]), "I feel calm with cold" (P6) or "less on edge when it's cold" (P7). When asked why heat was perceived as the least secure, again the association of heat to danger or injury was most common, but also that heat "made [me] feel uneasy. [My] palms are sweaty" (P7) and that heat means "you'll be well-informed" (P12), in the sense that the sensation is more salient and alerting.

Comparing Questionnaire to Lab Study

The associations of temperature to security are *opposite* in the two studies: security was associated with warmth in the questionnaire but cold in the lab. However, questionnaire responses for "Very Un/Secure" were split between both thermal poles, suggesting an ambiguity in judgements. This split was much less prevalent in the lab, so it may be that the physical sensation of the stimuli is very different to imagining it, and this clarifies the previous ambiguity.

The temperatures chosen to represent each temperature label ("Very Cold" -> "Very Warm") are in line with previous research on the perceptual distinction and comfort of thermal stimuli, so if feeling the feedback had an influence on reports (questionnaire vs. lab), and the lab results are in line with previous research, we can more confidently hypothesise that the absence of physical sensation leads to inaccurate or inappropriate responses in the online questionnaire. This has ramifications for the use of feedback-less questionnaires in HCI research.

Conclusions and Future Work

In this paper, we used an online questionnaire and lab study to determine what temperatures people associate with secure and insecure web pages, to potentially use thermal feedback to improve awareness and comprehension of, and adherence to, SSL warnings. The lack of physical stimuli in the online questionnaire led to more varied responses, potentially due to the ambiguity in imagined temperatures. However, the lab study, where participants felt thermal stimulation, led to clear associations: secure = cold, insecure = warm.

This paper presents our first step in investigating the efficacy of augmenting security warnings with thermal feedback. Having identified the temperatures commonly associated with secure and insecure web pages, our future research will present pages either with or without thermal feedback and measure two things: 1) if thermal feedback makes the participant more aware of the page's security, and 2) if the feedback changes their behaviour in terms of continuing/using insecure sites. We will also compare thermal feedback to other forms of multimodal cues, including vibration and audio, to determine if the unique features of temperature (emotionality, danger, privacy) make them better suited to augmenting warnings.

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