Incorporating Thermal Feedback in Cutaneous Displays: Reconciling Temporal and Spatial Disparities

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Abstract. There are fundamental differences between the tactile and thermal sensory systems that must be accommodated when designing multisensory cutaneous displays for use in virtual or teleoperated robotic environments. In this review we highlight the marked temporal and spatial differences between the senses of cold and warmth as revealed in psychophysical experiments. Cold and warmth are distinct senses with marked differences in the time taken to respond to stimulation and in their temporal filtering processes. Such variations must be taken into account when time-varying profiles of thermal stimulation are delivered to the skin concurrent with tactile stimulation since the resulting sensations will not be perceived on the same time scale. Although it is often reported that the thermal senses are markedly inferior to the sense of touch with respect to their spatial acuity, it is also clear that there is considerable variability across the body in the accuracy with which thermal stimuli can be localized. The distal to proximal gradient in thermal acuity suggests that locations other than the palmar surface of the hand are better suited for displaying thermal cues, in contrast to the situation for tactile inputs. As was noted for temporal processes, there are differences between localizing warmth and cold stimuli, with localization being superior for cold. These properties provide benchmarks that can be used in designing thermal and multisensory displays.

Keywords: Cutaneous sensing · Multisensory · Thermal displays

1 Introduction

Multisensory displays that present visual and auditory cues to users have been extensively investigated. There is also a substantial body of research that has evaluated how the tactile sense interacts with visual and auditory processes and the conditions under which it provides added benefit to such interactions [1]. The latter research has highlighted the contribution of tactile inputs as part of multisensory interfaces where they complement the information provided by other sensory channels. One function that can

C. Saitis et al. (Eds.): HAID 2022, LNCS 13417, pp. 48–58, 2022.
https://doi.org/10.1007/978-3-031-15019-7_5

be supported by adding tactile cues to an interface is an increased bandwidth of information transfer in complex data-rich environments, where the visual and auditory channels have traditionally been heavily relied upon. In these applications, the sense of touch is being used to offload the visual and auditory modalities and to present information that would otherwise be delayed or not available at all.

Displays that optimize the information conveyed by stimulating the skin are of widespread interest due to the pervasiveness of mobile devices and wearable technologies, both of which rely excessively on vision for communication [2–4]. By combining vibration, pressure, and skin stretch in a single display the information provided to the user can be augmented and particular cues can be associated with specific types of tactile inputs. Although there are numerous studies of the visual and auditory senses that indicate that with increased dimensionality of a display there is an increase in the amount of information that can be received by the user [5], much less is known about multi-dimensional tactile displays. What has been studied has typically focused on static displays and information transfer rather than dynamic displays and the rate of information transfer.

Changes in skin temperature provide an additional signal that can be combined with tactile cues to create a multisensory cutaneous display. Early research on thermal displays focused on simulating the thermal cues associated with holding an object to determine if these cues could be used to assist in identifying its material composition [6, 7]. Results from this research demonstrated that users were able to identify the material composition of a variety of objects based on the output from these model-based thermal displays. User performance was determined to be comparable to that achieved with real materials [8, 9]. More recently, thermal displays have been evaluated in the context of enhancing user interactions with objects presented on digital media or in virtual environments, for example by changing skin temperature to convey emotional content [10, 11], to present scalar information that is mapped onto temperature [12] or to improve situational awareness in driving scenarios [13, 14]. These displays have also been used to create thermal icons [15] by analogy to tactile icons or tactons in the tactile domain. Thermal icons have been designed by varying the direction (warming or cooling), amplitude, spatial extent and duration of thermal stimulation. The contexts in which thermal icons have been evaluated include enhancing affective communication in human computer interactions [16], assisting in navigation by giving proximity cues [17], and providing prompts regarding the source and importance of incoming text messages on mobile devices [18]. The parameters of the thermal icons created for these experiments were based on data from pilot studies rather than being derived from models of the changes in skin temperature and resulting sensations associated with different thermal inputs.

To address this shortcoming, Singhal and Jones [19] used linear system identification techniques to develop a dynamic model of the changes in skin temperature as a function of thermal input signals. The model could predict changes in skin temperature from unrelated experiments involving thermal icons. Further work by Ho et al. [20] using linear systems theory modelled the temporal profile of the resulting sensation as a function of the waveform of the thermal input. This model predicted the response delay and the distortion in the temporal profile of the resulting sensation when perceiving dynamic thermal inputs. These two models provide the foundation for a model-based approach to creating thermal icons.

The combination of tactile and thermal inputs in multi-sensory cutaneous displays has the potential to increase the sense of realism and immersion in virtual and augmented reality environments and enhance the bandwidth available for skin-based communication [10, 21, 22]. For multisensory feedback to be effectively implemented it is important to understand the fundamental properties of the tactile and thermal sensory systems, and in particular how their temporal and spatial features differ. In this paper we provide an overview of thermal perceptual processes from the perspective of designing cutaneous displays that enhance object recognition or information transmission; the particular focus is on temporal and spatial processing. The findings presented are from research studies conducted over a number of years in which we have sought to characterize tactile and thermal perception as it relates to the design of thermo-haptic devices.

2 Temporal Processes

One of the challenges associated with presenting tactile and thermal cues concurrently is the profound difference between the senses in the time taken to process information. Reaction times for tactile stimuli are much faster than those for thermal stimuli which means that concurrent thermo-tactile stimulation will not necessarily be perceived as simultaneous. In addition, decreases in skin temperature signaled by cold thermoreceptors are responded to more rapidly than increases in skin temperature sensed by warm thermoreceptors. These variations in response times primarily reflect the conduction velocities of the peripheral afferent fibers with the Aβ fibers associated with tactile mechanoreceptors having conduction velocities of 35–75 m/s as compared to the conduction velocity of 5–15 m/s of the Aδ fibers from cold thermoreceptors and the 1–2 m/s of C fibers that innervate warm thermoreceptors [23, 24]. A further temporal factor to consider is the time course of the response of the skin to thermal stimulation. As illustrated in Fig. 1 below, when the skin is in contact with a Peltier-based thermal display there is a delay in its response to warming and cooling, and the gain is less than one due to its lower bandwidth [25].

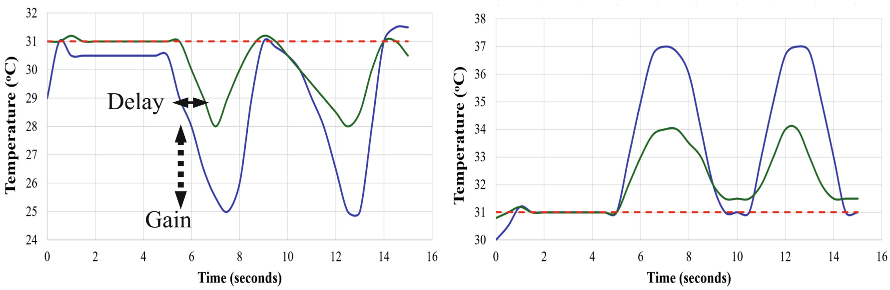

Fig. 1. Temperatures measured using thermistors mounted on a Peltier module (blue) and at two locations on the skin, one in contact with the thermal display (green) and one not in contact with the display (red). Redrawn and adapted from [25]. (Color figure online)

An additional consideration in thermal temporal processing is that humans perceive temporal information regarding warming and cooling differently due to the distinct temporal filtering properties of the senses of warmth and cold [20]. As demonstrated in Fig. 2A, the temporal impulse response function of the sense of cold has a shorter system delay and a larger transience factor than that of the sense of warmth. In other words, the sense of cold responds to a stimulus quicker, and the resulting sensation declines in a shorter time than the sense of warmth. This difference in the temporal filtering properties directly modulates the resulting sensations for dynamic warming and cooling stimulation. For example, the senses of warmth and cold have distinct sensations resulting from a full-cycle sinusoid stimulation (Fig. 2B) and a half-cycle sinusoid stimulation (Fig. 2C). The peak responses, that is the coolest or the warmest sensations, are delayed

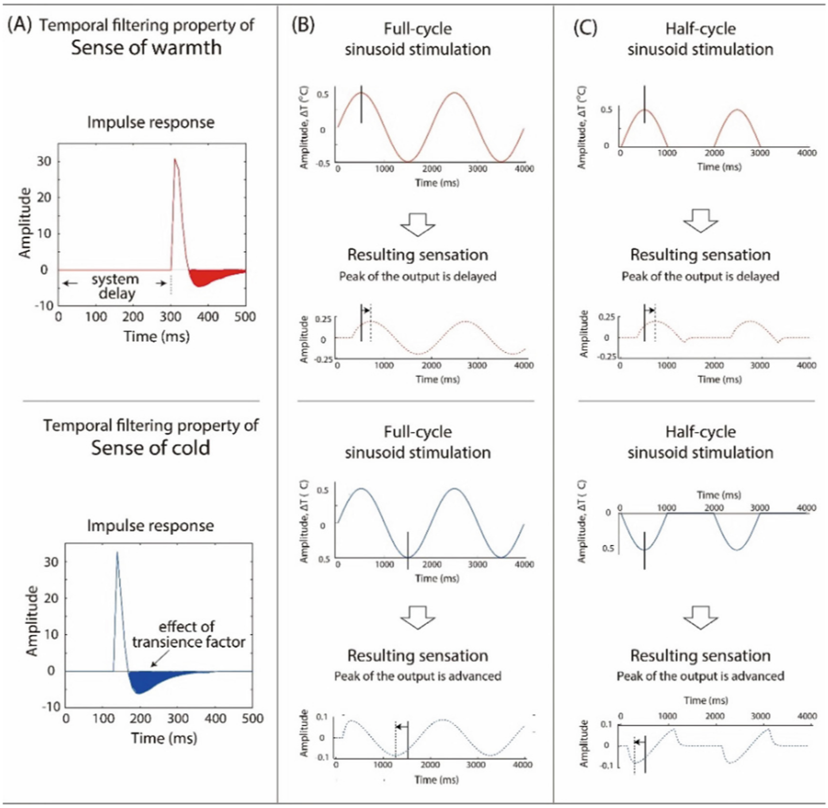

Fig. 2. Differences in temporal filtering properties of the senses of warmth and cold. The difference is demonstrated in the impulse responses of the warm and cold systems and the output responses to the full-cycle and half-cycle sinusoid stimulations. The vertical solid (dashed) lines represent the timing of the physical (perceptual) warm peak, and physical (perceptual) cold peak. Note that the gain is arbitrarily set to 1 in both systems, so the absolute values of the amplitude in the impulse responses and output responses are not informative, and the units are omitted. Attention should be paid to the relative change in amplitude across time. Redrawn and adapted from [20].

for the warming stimulation but advanced for the cooling stimulation. It is crucial to consider these differences in the temporal filtering properties of the senses of warmth and cold, especially when presenting tactile feedback with dynamic warming/cooling stimulation concurrently.

3 Spatial Processes

3.1 Pattern Recognition

With respect to the spatial properties of the thermal senses, the vast landscape of skin provides an extensive area for communication. As with the sense of touch, there are substantial variations in thermal sensitivity across the body with the cheeks and the lips being the most sensitive and the extremities, particularly the feet being relatively insensitive [26]. Even within the hand itself there is a five-fold variation in warm and cold sensitivity, with warm thresholds being twice the size of cold thresholds measured at the same site [26]. In contrast to tactile sensitivity which shows a proximal to distal increase in spatial acuity (palm to fingertips), the opposite occurs for thermal sensing with sensitivity increasing in the distal to proximal direction for both glabrous and hairy skin [27, 28]. In addition, hairy skin on the dorsal surface of the hand is more thermosensitive

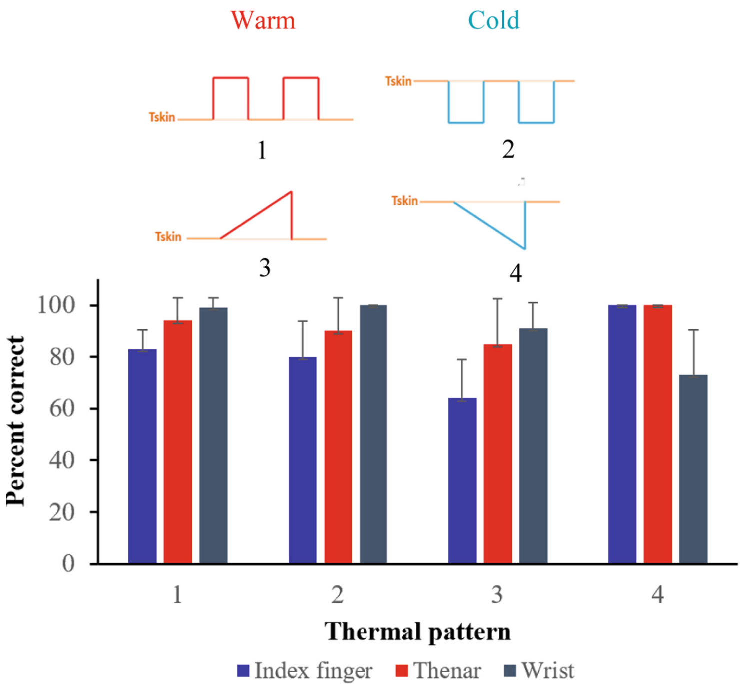

Fig. 3. Upper: Representative thermal patterns that varied in terms of the direction of temperature change (warming and cooling) and waveform. Lower: Percent correct score identifying the four thermal patterns at three sites on the arm. The group (N = 10) mean (standard deviation) responses are shown.

than glabrous skin, when evaluated in terms of warm and cold thresholds [29] or ratings of the magnitude of supra-threshold stimuli [30]. These variations in thermal sensitivity are also reflected in differences in the ability to identify thermal patterns.

In a series of studies, we compared the accuracy with which participants could identify thermal patterns that varied with respect to the magnitude and rate of change in temperature. Three sites were tested: the fingertips, the thenar eminence at the base of the thumb and the wrist. Participants identified the stimulus using a visual template of the thermal waveforms [19]. The objective of this work was to determine whether specific sites on the hand and arm would be optimal for mounting a thermal display due to their enhanced capacity to process thermal cues. As illustrated for a set of representative thermal stimuli shown in Fig. 3, patterns displayed on the thenar eminence or wrist were identified more consistently (92% and 91% correct respectively) than those displayed on the fingertips (82% correct) (Friedman's test, $p < 0.01$).

These findings indicate that variations in thermal sensitivity at different locations on the hand occur for all types of suprathreshold stimuli. In addition, there is consistent evidence across a broad range of studies of a distal to proximal progression in thermal acuity and overall perceptual performance. In the context of a multisensory cutaneous displays, it may be more efficacious to distribute tactile and thermal feedback across the hand and arm rather than co-locating them, for example by displaying tactile cues on the fingertips and thermal information more proximally on the wrist or forearm.

3.2 Localization

The ability to localize a stimulus in space is a fundamental feature of all sensory modalities and is particularly important when information from the external environment is mapped onto the body. Numerous studies have demonstrated that spatial information maps well on to the skin, particularly the torso and forearm, making the tactile sense the preferred medium for displays conveying cues related to orientation and navigation [31]. In contrast, the thermal senses are markedly inferior at localizing the site of thermal stimulation and at differentiating two thermal stimuli placed in close proximity. This is not surprising in that as homeothermic mammals, sensing the overall thermal state of the body is essential to regulating body temperature and so spatial summation across the skin surface is a critical feature for maintaining core temperature. It has been reported that low intensity warm stimuli presented 150 mm apart on the forearm are not perceived as distinct [32], although localization errors for warm stimuli are much smaller on the dorsal surface of the hand averaging 19 mm [33]. There do not appear to be any studies that have used an identical protocol to examine localization accuracy for warm and cold stimuli at the same location.

A direct comparison of the precision with which the location of cold and warm stimuli is perceived would provide insight into the underlying perceptual processes for the thermal senses and give a benchmark for determining the optimal density of thermal actuators in an array based on localization acuity. In a series of experiments, we have examined localization accuracy for warm and cold stimuli presented along the forearm using the setup depicted in Fig. 4. The display comprised three Peltier modules (22 mm long and 19 mm wide, and 3.8 mm thick) with a center-to-center distance of 75 mm between the modules. The contact area of each module was 418 mm^2. Ten participants (24–36 years) took part in each of the experiments.

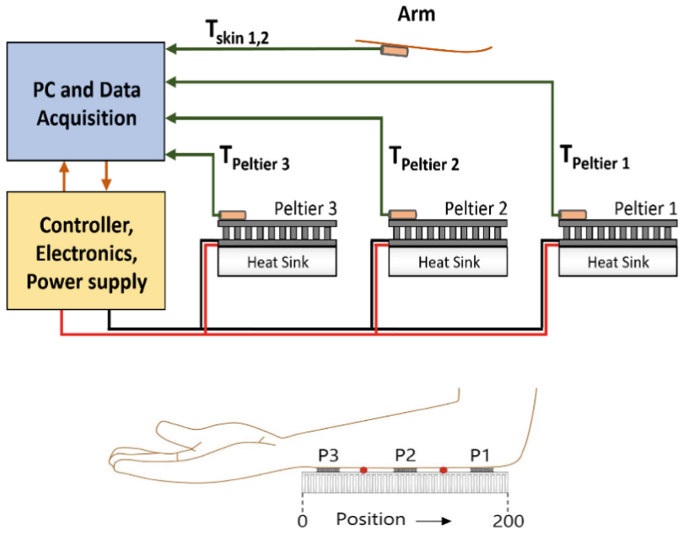

Fig. 4. Schematic diagram of the thermal display and its location on the forearm with three Peltier modules (P1–P3) mounted on heat sink and thermistors measuring the temperatures (T) of the modules and at two locations on the forearm (red dots in the lower diagram). (Color figure online)

Four thermal pulses 2 s in duration that either cooled (8 °C decrease) or warmed (6 °C increase) the skin were presented on the forearm. The rate of temperature change was 3 °C/s with an inter-stimulus interval of 4 s. The warm stimuli had a smaller absolute magnitude than the cold stimuli to ensure that they did not elicit pain. The first two stimuli were always delivered at the same location and the position of the other two pulses varied. The focus of the results presented here is on the perceived position of the first two stimuli that were delivered either near the elbow (P1) or the wrist (P3) as illustrated in Fig. 4. Participants were not informed about the specific locations of the stimuli and used a cursor to indicate the positions of the two stimuli on a visual representation of the forearm presented on a GUI on a computer screen. In order to avoid any adaptation, the arm in contact with the thermal display changed after every two trials. Each stimulus set was presented five times giving a total of 20 stimuli for each condition. The cold and warm stimuli were presented on different days.

The perceived location of the two stimuli were digitized using the Image Processing Toolbox in MATLAB (Mathworks, Inc.) with the distance being measured from the wrist as shown in Fig. 4. A format originally devised by Goldreich [34] and employed in studies of thermal illusions [35] was used to conceptualize the actual and perceived locations of the thermal stimuli on the forearm. These results are shown in Fig. 5. As evident in Fig. 5 for both cold and warm stimuli, localization was more accurate for pulses delivered around the elbow as compared to the wrist ($F(1, 18) = 18.48$, $p < 0.001$). This may be due to the importance of anatomical landmarks such as the elbow or the spine in facilitating spatial localization as has been reported for the tactile modality [36].

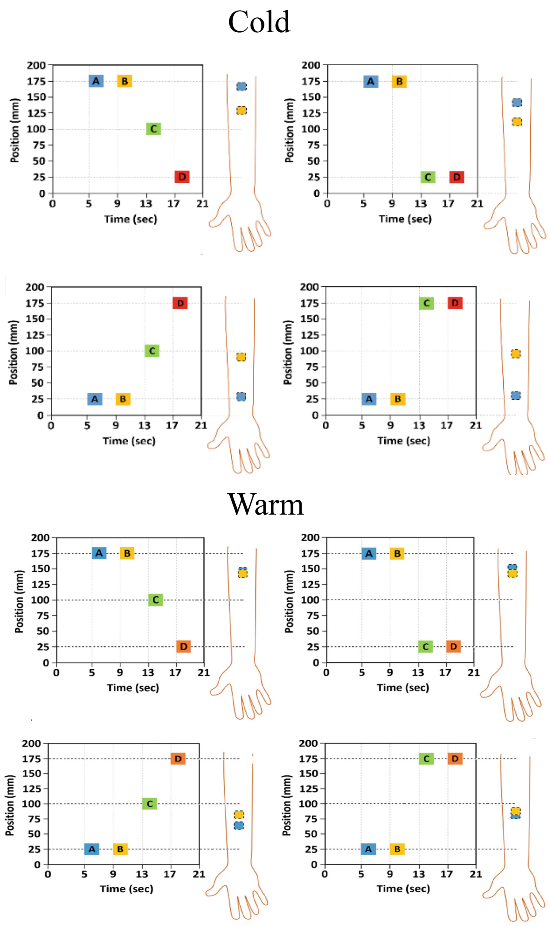

Fig. 5. Schematic depiction of the position of the physical stimuli on the graph and the group mean perceived position of those stimuli on the forearm. The dashed lines indicate the actual location of the Peltier modules on the arm.

A comparison of localization accuracy for cold and warmth reveals superior localization for the first cold stimulus as compared to the equivalent warm stimulus, although even for cold stimuli localization errors are still in the order of 10 mm. This result is consistent with those from other studies which have also reported better localization for cool than for warm stimuli [37]. These findings have been interpreted as indicating that the cold sensory system provides better somatotopic information than the warm sensory system. It is interesting to note, however, that the perceived location of the second stimulus delivered at the same location as the first changes much more when the skin is cooled as compared to warmed as shown by the greater spatial separation of the pulses in the upper plots in the figure as compared to the lower ones. The group mean change in perceived position between the first and second stimulus was 45 mm for cold stimuli as compared to 6 mm for warm stimuli. This difference may reflect the time course of the return to baseline skin temperature (i.e., the temperature of the skin prior to stimulus delivery) and/or the effect of the subsequent stimulus (pulse C) on thermal spatial processing, with cold localization being more labile. It is also possible that this divergence between warm and cold stimuli is due to the difference in their transience factors noted earlier (Fig. 2) with the sense of cold declining more rapidly than the sense of warmth. The design of the display ensured that participants could not use tactile cues to identify the location of the Peltier modules and so these localization differences reflect thermal and not tactile spatial processing.

The ability to localize a point of stimulation provides one metric that can be used to specify the configuration of a thermal display. For example, if users cannot distinguish between two sites of stimulation on the skin, then there is little added benefit associated with having a large number of thermal modules in a display, particularly if independent inputs are to be processed. A further caveat to consider in multi-element thermal displays is that for the thermal senses changing the area of stimulation affects the perceived intensity of the stimulus rather than its perceived spatial extent. What this means, is that a larger stimulus in terms of area is perceptually a more intense stimulus, a unique feature of the thermal modality. There is the potential, therefore, that when large areas of skin are heated or cooled the stimuli may no longer be innocuous but be perceived as painful.

4 Conclusions

As detailed in this paper, there are unique features of the thermal senses in terms of their temporal and spatial properties that need to be considered when designing thermo-tactile displays. In addition, due to differences between the senses of cold and warmth, various aspects of stimulus presentation such as the duration and time-varying profile of stimulation must be optimized for each sense. There is a considerable body of evidence indicating that sites beyond the hand are more effective at detecting and processing thermal cues. These locations should be considered for presenting thermal information and when coupled with tactile cues in a wearable device do not need to be co-located.

Acknowledgments. Research supported by the National Science Foundation under grant IIS-2006152, JSPS KAKENHI Grant Number 22H03679, and ULVAC-Hayashi MISTI Seed Fund, MIT-Japan Program.

References

1. Gallace, A., Spence, C.: In Touch with the Future. The Sense of Touch from Cognitive Neuroscience to Virtual Reality. Oxford University Press, New York (2014)
2. Dunkelberger, N., et al.: Improving perception accuracy with multi-sensory haptic cue delivery. In: Prattichizzo, D., Shinoda, H., Tan, H.Z., Ruffaldi, E., Frisoli, A. (eds.) EuroHaptics 2018. LNCS, vol. 10894, pp. 289–301. Springer, Cham (2018). https://doi.org/10.1007/978-3-319-93399-3_26

3. Jung, J., et al.: Speech communication through the skin: design of learning protocols and initial findings. In: Marcus, A., Wang, W. (eds.) DUXU 2018. LNCS, vol. 10919, pp. 447–460. Springer, Cham (2018). https://doi.org/10.1007/978-3-319-91803-7_34
4. Turcott, R., et al.: Efficient evaluation of coding strategies for transcutaneous language communication. In: Prattichizzo, D., Shinoda, H., Tan, H.Z., Ruffaldi, E., Frisoli, A. (eds.) EuroHaptics 2018. LNCS, vol. 10894, pp. 600–611. Springer, Cham (2018). https://doi.org/10.1007/978-3-319-93399-3_51
5. Stein, B.E.: The New Handbook of Multisensory Processes. MIT Press, Cambridge (2012)
6. Ho, H.-N.: Material recognition based on thermal cues: mechanisms and applications. Temperature **5**(1), 36–55 (2018). https://doi.org/10.1080/23328940.2017.1372042
7. Jones, L.A., Ho, H.-N.: Warm or cool, large or small? The challenge of thermal displays. IEEE Trans. Haptics **1**, 53–70 (2008)
8. Drif, A., Citerin, J., Kheddar, A.: Thermal bilateral coupling in teleoperators. In: Proceedings of the 2005 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), pp. 2818–2823. IEEE Press, New York (2005)
9. Ho, H.-N., Jones, L.A.: Development and evaluation of a thermal display for material identification and discrimination. ACM Trans. Appl. Percept. **4**, 1–24 (2007)
10. Gabardi, M., Chiaradia, D., Leonardis, D., Solazzi, M., Frisoli, A.: A high performance thermal control for simulation of different materials in a fingertip haptic device. In: Prattichizzo, D., Shinoda, H., Tan, H.Z., Ruffaldi, E., Frisoli, A. (eds.) EuroHaptics 2018. LNCS, vol. 10894, pp. 313–325. Springer, Cham (2018). https://doi.org/10.1007/978-3-319-93399-3_28
11. Tewell, J., Bird, J., Buchanan, G.R.: The heat is on: a temperature display for conveying affective feedback. In: CHI 2017, pp. 1756–1767 (2017)
12. Tewell, J., Bird, J., Buchanan, G.R.: Heat-Nav: using temperature changes as navigational cues. In: CHI 2017, pp. 1131–1135 (2017)
13. Meng, X., Han, J., Chernyshov, G., Ragozin, K., Kunze, K.: ThermalDrive - towards situation awareness over thermal feedback in automated driving scenarios. In: Proceedings of the 27th International Conference on Intelligent User Interfaces, pp. 101–104 (2022)
14. Di Campli San Vito, P., Brewster, S., Pollick, F., Thompson, S., Skrypchuk, L., Mouzakitis, A.: Purring wheel: thermal and vibrotactile notifications on the steering wheel. In: Proceedings of the 19th ACM International Conference on Multimodal Interaction, pp. 461–469 (2020)
15. Singhal, A., Jones, L.A.: Dimensionality of thermal icons. In: IEEE World Haptics Conference, pp. 469–474. IEEE Press, New York (2015)
16. Halvey, M., Henderson, M., Brewster, S.A., Wilson, G., Hughes, S.A.: Augmenting media with thermal stimulation. In: Magnusson, C., Szymczak, D., Brewster, S. (eds.) HAID 2012. LNCS, vol. 7468, pp. 91–100. Springer, Heidelberg (2012). https://doi.org/10.1007/978-3-642-32796-4_10
17. Wettach, R., Danielsson, A., Behrens, C., Ness, T.: A thermal information display for mobile applications. In: Proceedings of the Mobile Human-Computer Interaction Conference 2007, pp. 182–185 (2007)
18. Wilson, G., Brewster, S., Halvey, M., Hughes, S.: Thermal feedback identification in a mobile environment. In: Oakley, I., Brewster, S. (eds.) HAID 2013. LNCS, vol. 7989, pp. 10–19. Springer, Heidelberg (2013). https://doi.org/10.1007/978-3-642-41068-0_2
19. Singhal, A., Jones, L.A.: Creating thermal icons – a model-based approach. ACM Trans. Appl. Percept. **15**, 22 (2018). Article 14
20. Ho, H.-N., Sato, K., Kuroki, S., Watanabe, J., Maeno, T., Nishida, S.: Physical-perceptual correspondence for dynamic thermal stimulation. IEEE Trans. Haptics **10**, 84–92 (2017)
21. Gallo, S., Rognini, G., Santos-Carreras, L., Vouga, T., Blanke, O., Bleuler, H.: Encoded and crossmodal thermal stimulation through a fingertip-sized haptic display. Front. Rob. AI **2** (2015). Article 25

22. Murakami, T., Fernando, C.L., Person, T., Minamizawa, K.: Altered touch: miniature haptic display with force, thermal and tactile feedback for augmented haptics. In: SIGGRAPH 2017 Emerging Technologies, pp. 1–2 (2017)
23. Leone, C., et al.: Conduction velocity of the cold spinal pathway in healthy humans. Eur. J. Pain **24**, 1923–1931 (2020). https://doi.org/10.1002/ejp.164
24. Yarnitsky, D., Ochoa, J.L.: Warm and cold specific somatosensory systems. Brain **114**, 1819–1826 (1991)
25. Singhal, A., Jones, L.A.: Perceptual interactions in thermo-tactile displays. In: IEEE World Haptics Conference, pp. 90–95. IEEE Press, New York (2017)
26. Stevens, J.C., Choo, K.C.: Temperature sensitivity of the body surface over the life span. Somatosens. Mot. Res. **15**, 13–28 (1998)
27. Filingeri, D.: Neurophysiology of skin thermal sensations. Compr. Physiol. **6**, 1429–1491 (2016)
28. Li., X., Petrini, L., Defrin, R., Madeleine, P., Arendt-Nielsen, L.: High resolution topographical mapping of warm and cold sensitivities. Clin. Neurophysiol. **119**, 2641–2646 (2008)
29. Johnson, K.O., Darian-Smith, I., LaMotte, C.: Peripheral neural determinants of temperature discrimination in man: a correlative study of responses to cooling skin. J. Neurophysiol. **36**, 347–370 (1973)
30. Filingeri, D., Zhang, H., Arens, E.A.: Thermosensory micromapping of warm and cold sensitivity across glabrous and hairy skin of male and female hands and feet. J. Appl. Physiol. **125**, 723–736 (2018)
31. Jones, L.A., Sarter, N.B.: Tactile displays: guidance for their design and application. Hum. Factors **50**, 90–111 (2008)
32. Vendrik, A.J.H., Eijkman, E.G.: Psychophysical properties determined with internal noise. In: Kenshalo, D.R. (ed.) The Skin Senses, pp. 178–193. Charles Thomas, Springfield (1968)
33. Nathan, P.W., Rice, R.C.: The localization of warm stimuli. Neurology **16**, 533–540 (1966)
34. Goldreich, D.: A Bayesian perceptual model replicates the cutaneous rabbit and other spatiotemporal illusions. PLoS ONE **2**, e333 (2007)
35. Singhal, A., Jones, L.: Space-time dependencies and thermal perception. In: Bello, F., Kajimoto, H., Visell, Y. (eds.) EuroHaptics 2016. LNCS, vol. 9774, pp. 291–302. Springer, Cham (2016). https://doi.org/10.1007/978-3-319-42321-0_27
36. Cholewiak, R.W., Brill, J.C., Schwab, A.: Vibrotactile localization on the abdomen: effects of place and space. Percept. Psychophys. **66**, 970–987 (2004)
37. Lee, D.K., McGillis, S.L.B., Greenspan, J.D.: Somatotopic localization of thermal stimuli: I. A comparison of within- versus across-dermatomal separation of innocuous thermal stimuli. Somatos. Mot. Res. **13**, 67–71 (1996)