Re manuscript: IJHCS-D-18-00053.  
Title: A Sense of Ice and Fire: Exploring Thermal Feedback with Multiple Thermoelectric-cooling Elements on a Smart Ring.  
Authors: Zhu Kening; Taizhou Chen; Shaoyu Cai; Simon Perrault; Roshan L Peiris.  
  
Article Type: Original Article.  
  
  
Dear Dr. Zhu Kening,  
  
Your paper has now been reviewed and the comments are attached below for your information.  
  
The reviewers have indicated that major revisions will be needed to your submission, before this can be considered for publication in International Journal of Human-Computer Studies  Therefore we ask you to prepare a new version of your paper, which  fully addresses the comments of the referees.  
  
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Comments:  
AE SUMMARY:  
  
This paper measures, in three studies -- a pilot (n=9), and two full studies (n=12 each) -- participants' spatial acuity for thermal stimuli and the accuracy of identifying thermal patterns presented on a thermal ring worn on the finger.    
  
The full-study ring prototypes utilized multiple TECs - up to 8, but generally used in a 4-point combination of either hot or cold - to display a set of TEC patterns. The construction of the prototypes (with their miniaturized TECs) itself something of a contribution, and is generally well described.  
  
The authors conclude much better spatial acuity than had been presumed based on earlier research and argue for an optimal number of thermoelectric coolers (TEC) to have in such a display. The accuracy found is 87.5%. The authors discuss some applications, such as direction cueing.   
  
META REVIEW:  
  
  
The reviewers and AE agree in the interesting nature of the research, and suitable scope involved. The results, if substantiated, are of interest to the HCI community and could inform further design of thermal notification.   
  
The reviewers identified a number of issues with the current manuscript, which I have summarized below. The most crucial of these involve statistical analysis, study design and support for conclusions drawn (items 2, 3 and 4 below). These are somewhat related to one another, and the very most critical is R1's observation that the statical tests reported were apparently done incorrectly and this will have a marked effect on the actual significance achieved. It is difficult to assess the studies' contributions without the correct results.   
  
Given the general quality and scope of the work described, I am recommending a Major Revision, with the understanding that should the new statistical analysis not give similar results as below, then the present studies may be of considerably less interest (in that the performance would not be such an improvement over other published results). In addition, the authors would need to address the other reviewers' comments, and in particular argue a response to R2's request for a re-run of the study with a larger or different set of stimuli - we do recognize that there are limits on study size, but the choices made need to be better defended than they are now.  
  
  
  
1. COMMUNICATION SYSTEM DESIGN:  
-     R2: concerned about arbitrary nature of mappings (spatial location to convey abstract information), and difficulty in learning them  
  
2. STUDY DESIGN  
  
Both external reviewers had concerns about simplifying assumptions that the researchers made in their study design, which may be the same one. The implication would be an over-estimate of generalizability of results to the untested conditions.  
  
-     R2: "While the pilot showed similar accuracy in identifying left vs. right, this cannot be "assumed" to be the case when multiple sites are stimulated, because of poor localization and spatial summation in the thermal sense. This leaves the question half-answered, it only provides part of the picture. I feel that, for the paper to be accepted with this study in it, the authors would need to re-run this study with all possible pairings"  
-     R1: May be noting the same issue in a different way, by raising the need for informed discussion on perceptual acuity (specifically thermal) of various skin surfaces (dorsal vs glabrous surface). This would be a reason to not assume uniformity of acuity on different adjacent pairs.   
      
3. ANALYSIS  
  
-     R1: major results in question due to bad statistical analysis. Is this a show stopper?  
-     R2: doesn't account for individual TEC temp, despite authors knowledge of a location/temp interaction in terms of localization  
-     R2: "single ANOVA was carried out only on the individual T+R stimuli, but not the individual B+L stimuli? This should have been a two-way ANOVA analysing both the spatial location and the thermal pattern."  
  
4. CONCLUSIONS DRAWN   
  
In addition to the questions raised about the assumptions made in study design (noted in item 1 above), the reviewers had additional concerns about concerns.  
  
-     R2: # of patterns that are learnabable (12-15) not supported by results given study design (number of stimuli presented, and participant priming), making their identification task easier. Confusion was already fairly high. At best conclusions are preliminary.   
-     AE: seems to be inconsistency in the results summarized on pg 3 (Intro): 10 thermal patterns, 86.2%) and in abstract (87.5, implied 12 patterns).   
  
5. MISSING DETAILS:  
  
-     Prototypes: while in most cases well described, there is vagueness about how many different prototypes there were, and the differences between them. It is possible that a single prototype was used for all three studies, with the difference being how many TECs were installed and used at a given time. Some of the confusion for this reader arose from references to both ring cases, and rings, without really defining either. (they seem to be intended sometimes as different things).     
-     R2: Temperature changes (base from which changes were made)  
  
6. SITUATING THE RESEARCH IN THE LITERATURE:   
-     AE: There is substantial literature on tactile icon (generally vibrotactile) perception and information transmission and perception generally. A few classic references are noted below [1-5], with [1] being a review. In particular, these (particularly [2] give design approaches and experimental structures to evaluate effectiveness of abstract information transmission mechanisms through the sense of touch which comprise obvious starting points for tactile information display in other submodalities.   
  
  
  
1.     MacLean, K. E., "Foundations of Transparency in Tactile Information Design," IEEE Trans on Haptics, vol. 1:2, pp. 84-95, July-December 2008.  
2.     Chan, A., MacLean, K. E., and McGrenere, J., "Designing haptic icons to support collaborative turn-taking," Int'l J Human Computer Studies, vol. 66, pp. 333-355, January 2008. E-publication Nov 17, 2007.  
3.     Gallace, A., Tan, H. Z., and Spence, C., "The body surface as a communication system: The state of the art after 50 years," Presence: Teleoperators and Virtual Environments, vol. 16:6, pp. 655-676, December 2007.  
4.     Brown, L. M., Brewster, S. A., and Purchase, H. C., "A first investigation into the effectiveness of Tactons," in Proceedings of 1st Worldhaptics Conference (WHC '05), pp. 167-176, Pisa, Italy, March 2005.  
5.     MacLean, K. E. and Enriquez, M., "Perceptual design of haptic icons," in Proceedings of EuroHaptics, pp. 351-363, Dublin, Ireland, Eurohaptics Society 2003.  
  
  
  
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Reviewer #1: This is an interesting paper in which the authors have measured the spatial acuity for thermal stimuli and the accuracy of identifying thermal patterns presented on a thermal ring worn on the finger. The findings indicate much better spatial acuity than had been presumed based on earlier research and with their design they have been able to determine the optimal number of thermoelectric coolers (TEC) to have in such a display.   
  
A major issue with the manuscript is the statistical analyses that have been conducted that form the basis of the results. The authors have not used a repeated measures ANOVA and have taken each data point as an observation as if it comes from a different participant and so the denominator degrees of freedom are incorrect as are the analyses. All of the statistical analyses need to be repeated using the correct ANOVA. This error has also been made in Experiments 1 and 2 with 12 participants where each data point has been considered as being independent (i.e. from a single participant) in the t-test (Experiment 1) and ANOVAs (both experiments) performed.   
  
The authors do refer to some of the limitations of their prototype device (p. 25) in terms of form factor, rigidity, user comfort, and power requirements. A more detailed discussion as to how these will be addressed would be of interest.  As the review of "ring-type" tactile and haptic devices indicates (pp. 5-6) there have been many devices developed as prototypes but little beyond this in terms of applications. It would be good to consider what are the major impediments to using rings as a communication device and have these could be addressed.   
  
In some of the analyses conducted it seems that there are marked differences between patterns/stimuli delivered on the dorsal surface of the finger (hairy skin) as compared to the glabrous surface.  The authors may want to consider these effects in terms of the skin surfaces and their relative sensitivity to thermal stimuli.   
  
Minor comments:  
p. 2 line 33-34: The thermal effects of "small thermal-haptic devices" are referred to as thermal sharpening effects due to the thermal gradients on the skin. The "devices" are calipers that have been heated or cooled which is not clear from the description provided in the manuscript  
p. 2 line 38: closed-by - close by   
p. 4 line 96: The hand is thermally sensitive, particularly the dorsal surface.  It is important that readers don't assume that this statement means that the fingertips are highly thermally sensitive as with tactile spatial acuity.    
p. 5 line 123: skin dragging is generally referred to as lateral skin stretch which is a better description of the mechanical input (also p. 6)  
p. 6 line 171: As shown in.., - something missing here  
p. 9 line 221: was record before - was recorded before  
p. 11 Fig. 11: The label on the y-axis should be changed - the numbers are not percentages  
p. 13 lines 315-325:  Why have these results been placed in the Discussion section rather than under Results?  
  
  
  
  
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Reviewer #2: The paper represents a good amount of work, covering three studies, and on a topic that warrants further investigation, based on the previous research. There is a good amount of background research presented, although more could be discussed about spatial summation. Overall, I am rather split on the paper. The results aren't very surprising based on the existing literature, but it is still valuable to have confirmation about localisation of thermal feedback on the finger. There are some fixable issues with the writing/conclusions and some analysis can be extended or re-done, there are also fundamental and unfixable issues with the experimental design. Only comparing a small subset of neighbouring stimulators leaves the question half answered, as it is not fully known how well all neighbouring pairs can be perceived, and I believe it was wrong to assume otherwise based on the pilot research. There is also the strange choice to use Bh multiple times when the pilot study clearly showed it to be unsuitable for use (which the authors argue themselves!). I do think the paper could make a potentially useful contribution with improved writing and reframing the conclusions about how many (and which) stimuli could be suitable. However, I would have to recommend that Experiment 1 be re-run to include all possible neighbouring pairs, as I don't feel this study yet answers the question it claims to. I also urge the authors to be more selective and pragmatic in which patterns they propose as suitable, both in terms of identification accuracy and in how they are used in applications.  
  
My individual comments are:  
\*     As the research is using closely-packed stimulators, it is necessary to discuss spatial summation in the thermal sense. While tactile stimulation improves localisation of a single point, multiple stimulating points are still "summed" if they are too close, which is an issue for the use of neighbouring stimulators.  
\*     I am curious that a 3°C/sec change was painful: what temperature did this start from and how many TECs were used? A 3°C change should not be painful, unless strong spatial summation all around the finger somehow magnified the sensation. I'm also very surprised that the gentle stimulus 3°C at 1°C/sec could potentially lead to pain, leading the experimenters to exclude people based on "overly sensitive skin". How many were excluded? How was this judged? I would ask for clarification again as to what temperature this stimulator started at, as I have to imagine it was high (~35°C or above) for a 3°C change to cause pain in anyone. It's also not clear what temperature the TECs started from during the main study.  
\*     While it is good to have the confirmation, the results of the pilot study aren't very surprising, being very much in line with previous research.  
\*     The choice of stimulation locations in Experiment 1 and 2 is odd, as the pilot showed that warming the bottom TEC is poorly localised, and so this shouldn't be used, yet it is used in several patterns. Also, it makes the analysis odd too, as it does not take into account what temperature each individual TEC was, there is only a pairwise comparison between T+R vs. B+L, even though the authors know that there is a location x temperature interaction in terms of localisation (cold at bottom is accurate, warm at bottom isn't). A further issue with the analysis is that a single ANOVA was carried out only on the individual T+R stimuli, but not the individual B+L stimuli? This should have been a two-way ANOVA analysing both the spatial location and the thermal pattern. It feels like an incomplete analysis.  
\*     I think it was a mistake to not include all possible pairs of neighbours in Study 1. While the pilot showed similar accuracy in identifying left vs. right, this cannot be "assumed" to be the case when multiple sites are stimulated, because of poor localisation and spatial summation in the thermal sense. This leaves the question half-answered, it only provides part of the picture. I feel that, for the paper to be accepted with this study in it, the authors would need to re-run this study with all possible pairings.  
\*     There is a potential issue in using essentially arbitrary locations to convey information: e.g., using T+R to show an unknown number or representing different social networks, as there is no logical association, leaving the user burdened with having to learn numerous mappings of information to stimulator locations. The navigation, and spatially-relevant comparison, examples are fine, as there is an inherent association between stimulator location and the information being conveyed. But I am highly sceptical about using spatial location to arbitrarily represent information.   
\*     I feel that the conclusions about there being 12, even 15, patterns that would be suitable for use in feedback is unwarranted, because only a small number of the possible stimuli was possible in each study, and participants were told which would be presented in each study during training. Therefore, it is not known what identification accuracy would be in a situation when any one of these patterns could be presented. Given the already quite high level of confusion for many stimuli, I imagine that accuracy would drop further. So I feel that this conclusion should come with an explicit caveat and qualification that these results are preliminary, and it is not known how accurate people would be if more options were possible. Particularly in Figure 14 and the line in section 8.3.1 "Our set of 10-15 spatial thermal patterns, which can be perceived with the accuracy over 80%". I think this is misleading.  
\*     Formatting/presentation:  
o     There is a missing Figure reference at the bottom of page 6 "As shown in ,".  
o     The Y axis in Figure 6 is inappropriate, as it's labelled as "%", but it shows fractions (0-1.0). Either the scale values or the label should be changed to fit each other.