Poster: Exploring the Limits of Vibrotactile Numeric Information Delivery

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Abstract
We test ActiVibe, a previously reported vibrotactile method for communicating numeric values between 1–10, in the face of an audio distractor task, as well as when conveying not just one numeric value in a single message, but three values in succession. Results of a 12 participant user study comparing three different rendering methods indicate that ActiVibe maintains its advantage vs. two different duration-based methods when conveying a single value, but largely loses this advantage when presenting three sequential values. In these challenging conditions, the more concise duration-only approach may be preferable since it uses less power and demands attention for less time.

Author Keywords
Haptics; Tactons; Vibrotactile icons; Mobile computing.

ACM Classification Keywords
H.5.2. [Information Interfaces and Presentation (e.g. HCI)]: User Interfaces; Haptic I/O []

Background & Related Work
In mobile devices, vibrotactile haptic feedback is typically used for notifications. However, there is an increasing desire to convey information beyond simple alerts. For example, Brewster and King used vibrations to present progress bar status for a long-running process, finding that a multi-

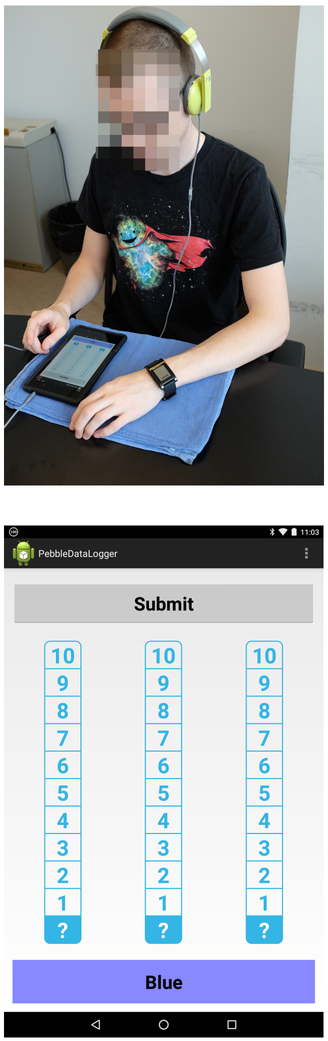


Figure 1: Experiment setup and tablet UI

part sequence of vibrations performed better at providing background status than a visual progress bar [1]. Creating patterns that are succinct yet clear even when the receiver is engaged in another task, is difficult but critical. Oakley and Park conducted an experiment with three distractor tasks (transcribing poems, data-entry, and walking) while receiving various vibrations, finding that distraction significantly lowered the recognition rate [5].

Baseline PreVibe Design

This work builds on Cauchard et al.'s ActiVibe [2], which successfully conveys the numbers 1–10 in real-world conditions. The ActiVibe final design (AVF) uses easily countable discrete vibrations, augmented with longer actuations representing "5" (Fig.2). However, we hypothesized that the multiple pulses for each value could become difficult to track while rendering multiple values or when the user is distracted. Despite being tested in-the-wild, participants were "Stationary" during 67% of the ActiVibe in-the-wild trials, which may correlate with being relatively undistracted. We were therefore motivated to test under more strenuous conditions, as well as try a novel rendering.

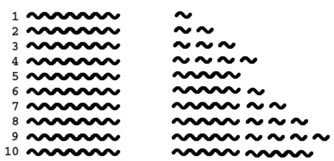
Cauchard et al. explored six patterns. The worst-performing was a duration-only (DO) method (ActiVibe "B"), with a single vibration lasting 100 ms times the value (e.g., the value "3" is $3 \times 100 = 300\ ms$). However, DO was the only option not requiring counting multiple vibrations per value, making it potentially more robust under load or when rendering multiple values per message. Ideally, however, we would somehow boost DO's accuracy. The mean DO error magnitude ranged from about 0.5–2, with larger target values exhibiting worse accuracy. This leads to two observations. First, although accuracy is worse with DO than AVF, it is not terrible if only an approximate value is needed. Second, improved performance at the higher values will have the largest impact on overall accuracy, since DO error when conveying values at the bottom of the range (e.g., 1,2) is consistently lower than for higher values (e.g., 9, 10).

These observations, coupled with reported user desire for a "heads-up" introductory PreVibe [2], lead us to propose using a PreVibe to not only focus attention, but also to use its duration to represent a baseline value, comparable to a following DO information pulse to calibrate its meaning. We refer to this new design as *Baseline PreVibe* (BPV). With BPV, the pattern begins with a vibration that reminds the user what a value of 5, or 50% of the range, feels like. For example, a vibration longer than the PreVibe is a value greater than 5. A vibration twice the PreVibe duration is 10.

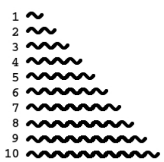
We hypothesize that BPV will have greater accuracy vs. the pure DO design, yet also require less mental load, and therefore be more resistant to distraction, than the counting-based AVF approach. This may be particularly beneficial for higher values, since the PreVibe specifically targets the middle of the range. We test this by comparing the different rendering options in the presence of a distracting task, and then adding the complexity of rendering more than one value in a single message. Under these more strenuous circumstances, we expect that AVF's performance may deteriorate more than simpler alternatives, such that its advantages vs DO or BPV may disappear.

Experiment

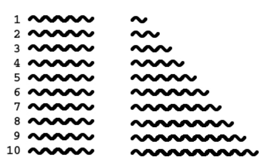
Participants' *primary* task was to attend to an audio stream of spoken colors and tap a button when hearing "blue", similar to Chan et al. [3]. The *secondary* task was to attend to the smartwatch vibrations, and enter the value(s) perceived via one of the three pattern conditions (AVF, DO and BPV, summarized in Table 1). Twelve participants (5 Female; ages 21–37, median=24) received CAD$15 to participate.



AVF (ActiVibe Final)



DO (Duration Only)



BPV (Baseline PreVibe)

Figure 2: Patterns as shown to participants, describing each rendering condition. Based on design from Cauchard et al.'s ActiVibe study.

Participants sat and wore a Pebble smartwatch (model 301) and headphones playing pink noise. They used a tablet (Fig.1) to enter perceived value(s). Participants were told to enter their best guess even if unsure, but to choose "?" (default response) if they had no idea of the value.

Phase 1 compared all three renderings (BPV, DO, AVF) when presenting a *single value*. Similar to the ActiVibe lab study, after a description of the current pattern, the participant felt all ten values, in order, to learn the rendering. All ten values were then presented in random order, three times, for 30 trials per condition. The gap between trials, from the end of the entire pattern to the onset of vibrations for the next, was fixed at 8 s. Trials continued automatically.

Phase 2 compared all three rendering conditions when conveying not just one value, but *three values in succession*, referred to as BPV3, AVF3 and DO3. The PreVibe and individual value patterns were identical to Phase 1. A single PreVibe preceded each set of three values in AVF and BPV. Values were separated by a gap of 800 ms.

Timing: If the "Submit" button was not pressed within 8 s of a trial's vibrations ending, all values were considered unknown. This was generally adequate, with the submit button pressed within 6 s in the vast majority of trials, and typically faster for the single value conditions.

Results

Cauchard et al. reported three performance metrics: Miss Rate (MR: % of trials with no response), Error Rate (ER: % of trials with incorrect response), and DIA, or absolute value of the difference between the value actually rendered and the perceived value. To obtain a single measure of performance, we incorporate the MR into the DIA by assigning missed values a DIA of 10, or one more than the maximum DIA when a value was selected, on the assumption that it is worse to have no idea of a value than to be able to at least make a guess. DIA results for Phase 1 and the first of the three values in Phase 2 are shown in Fig.3.

When comparing DIA results between conditions, we use a non-parametric Friedman test of differences among repeated measures, via the Agricolae package in R. Where the Friedman test showed a significant difference, post-hoc analysis used Agricolae's built-in Friedman LSD pairwise tests, followed by Holm-Bonferroni correction.

For the one value trials (Phase 1), the Friedman test showed a significant difference ($X^2 = 7.79, p = 0.02$) between conditions, with post-hoc pairwise comparison indicating only a difference for AVF-DO (p=0.01). Thus, AVF has better accuracy than DO in this condition, mirroring Cauchard et al.'s results even in the face of the audio distractor task. We cannot claim BPV has better accuracy than DO.

For the three value conditions (Phase 2), there were no significant differences between conditions within each of the three values, indicating that none of the designs had significantly better accuracy. However, Friedman tests comparing Phase 1 to 2, on AVF-AVF3, DO-DO3, and BPV-BPV3, for the first value presented, showed a significant difference in AVF-AVF3 (p=0.039). This indicates that AVF had the only significant drop in DIA performance, causing its accuracy to fall near the level of BPV and DO. AVF-AVF3 accuracy deterioration for the 2nd and 3rd values is at least as severe.

Discussion, Next Steps, Conclusion

When rendering three values in the face of a demanding audio task, AVF's accuracy indeed declines more than the simpler duration-based rendering options, to an extent that the differences in accuracy are no longer statistically significant. When taking into account ActiVibe's greater total time to render values, as well as the resulting increased mo-

Abb.	Name	Brief Description	PreVibe (ms) [gap]	Value (ms) [gaps]	Max ms	Max vibe ms
AVF	ActiVibe-Final design	Roman-numeral style	700 [1200]	value pattern [200]	3900	1900
DO	Duration Only	ActiVibe design B	none	value*100	1000	1000
BPV	Baseline PreVibe	“5” calibration + DO	500 [1200]	value*100	2700	1500

Table 1: Experiment conditions. Only DO does not have a PreVibe. Pauses between vibration pulses (gaps) in []. “Value pattern” for AVF is identical to the ActiVibe longitudinal study: 150 ms short, 600 ms long, 200 ms gaps. “Max ms” is the longest pattern duration for a single value, incl. vibration time + gaps. “Max vibe ms” is how long the longest value actually spins the vibe motor, corresponding to power used.

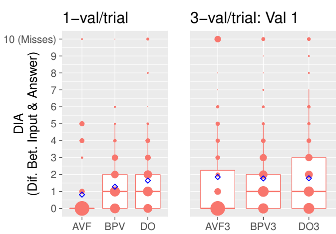


Figure 3: Accuracy (DIA), misses assigned DIA=10. Box plot hinges 25% quartiles, whiskers 1.5 * IQR. Blue diamonds represent mean DIA. Dot sizes proportional to number of trials at each DIA level, e.g., the number of misses increased for all renderings between the 1 and 3 value/trial conditions.

tor power consumption (Table 1), DO may thus be a legitimate option for some applications. However, the hope that BPV, with its perceptual calibration before information vibes, would prove superior to AVF is not supported. We conjecture that any benefit from the BPV perceptual calibration in the 3-value phase may be undermined by adding a fourth vibration that needs to be processed, and can be confused with the information vibrations. This implies that when making the pattern even somewhat more complicated, e.g., with a calibration PreVibe, any advantage may be outweighed by the increased complication.

Nonetheless, BPV perceptual calibration may yet prove useful. For example, confounds such as motion during a haptic stimulus can cause a stimulus to be perceived as less intense [4]. An untested hypothesis is that the BPV calibration vibration would help interpret vibrations specifically when perception is skewed by motion.

In sum, our results indicate that although ActiVibe indeed has superior accuracy when conveying single values, its advantages can be largely eroded when rendering multiple values in a high-distraction environment, providing insight into the limits of vibrotactile numeric information delivery.

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