A First Look at Individuals' Affective Ratings of Vibrations

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Abstract

Affective response may dominate users' reactions to the synthesized tactile sensations that are proliferating in today's handheld and gaming devices, yet it is largely unmeasured, modeled or characterized. A better understanding of user perception will aid the design of tactile behavior that engages touch, with an experience that satisfies rather than intrudes. We measured 30 subjects' affective response to vibrations varying in rhythm and frequency, then examined how differences in demographic, everyday use of touch, and tactile processing abilities contribute to variations in affective response. To this end, we developed five affective and sensory rating scales and two tactile performance tasks, and also employed a published 'Need for Touch' (NFT) questionnaire. Subjects' ratings, aggregated, showed significant correlations among the five scales and significant effect of the signal content (rhythm and frequency). Ratings varied considerably among subjects, but this variation did not coincide with demographic, NFT score or tactile task performance. The linkages found among the rating scales confirm this as a promising approach. The next step towards a comprehensive picture of individuals' *patterns* of affective response to tactile sensations entails pruning, integration and redundancy reduction of these scales, then their formal validation.

Index Terms: H.1.2 [User/Machine Systems]: Human factors—Human Haptic Perception, Affective Haptics;

1 Introduction

Touch is an important means of obtaining information about objects, but it is also highly connected to our emotions [9]; as a consequence, affective reactions are influential in the many small decisions we make about the objects that surround us. Only a few studies have investigated affective response to touch stimuli of any kind [8, 21, 22, 18]; but affective study of synthetic tactile stimuli such as vibrations or variable friction is even more sparse.

While the programmable synthetic stimuli available to interaction designers are currently far less expressive than natural textures, growing attention to surface interaction in recent years means tactile technology is evolving rapidly. Already designers need to optimize its affective potential. However, we lack relevant measures and methodology for quantifying tactile affect. A multidimensional picture of subjects' opinions will help reveal *patterns* of preference more effectively than can a single preference measure.

There is also a dearth of data on individualized responses. Affect studies have typically reported only responses averaged over subjects [8, 24]. There is tantalizing evidence that such variances may be substantial: e.g. Levesque et al.'s findings for subjects' preference for different patterns of variable friction [17]. Tactile designers must understand this variation's extent and driving factors.

Evidence from the literature and our own early analyses suggest that differences in everyday touch behavior, tactile abilities, and demographics might explain substantial affective response variation. A recently developed scale ('Need for Touch' (NFT)) assesses individual differences in extracting and using haptic information for everyday pleasure or utility evaluation [20]). Tactile task performance, employed as an indicator of tactile memory and processing resources, also can vary considerably across subjects [17, 5, 7]; are functional touch ability and hedonic preferences linked?

Together, these factors raise questions about the relation of demographics, NFT scores and tactile task performance to variations in affective response. Long-term, we aim to optimize and validate a set of rating scales which reflect relevant dimensions of subjective response to tactile sensations; link affective and sensory perception of tactile technology parameters (e.g. frequency, amplitude); and assess the individual differences in affect and perception and parameters that contribute to these differences.

Here, we more specifically ask: what are the relevant dimensions for measuring affective response, and can we integrate multiple rating dimensions? How does the vibration design space impact affective response? How is affective response linked to demographics, NFT scores, and tactile task performance? Below, we discuss these questions in light of our study results.

For maximum vibrotactile expressivity, we used a recent electroactive polymer (EAP) display from Vivitouch [1]. We examined 30 subjects' affective ratings of 1s vibrations (*e.g.*, alerts and notifications). The rating scales, tactile stimuli and tasks were drawn from the literature and refined via pilot studies. The main study used five rating scales to examine the effect of the vibration parameters and individual differences on the subjective ratings for vibrations. The contributions of this work are:

- An initial examination of five proposed affective and sensory dimensions for rating tactile sensations (thorough validation requires further study);
- Qualitative and quantitative data on the effect of rhythm pattern and frequency on affective and sensory ratings;
- Quantitative data on individuals' variation in time and frequency matching performance;
- Preliminary findings on the effect of demographic, NFT, and tactile task performance on variations in affective ratings.

In the following we describe our apparatus, and the design and selection of the vibrations, tactile tasks and affective and sensory rating scales we used (Section 3). We report the main study and its results (Section 4), then discuss our findings and outline future work.

2 Related Work

Affective Evaluation: The touch literature lacks a consistent vocabulary for affective response. Guest et al. recently collated a large list of emotion and sensation words describing tactile stimuli [10]; then, based on Multi-Dimensional Scaling (MDS) analysis of similarity ratings, proposed *comfort* and *arousal* as underlying dimensions for the tactile emotion words, and *rough/smooth, cold/warm*, and *wet/dry* for sensation. We founded our affective rating scales on these words.

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Study of affective reaction to natural stimuli [8, 21, 18]. revealed dependencies on many factors, such as materials and body sites, preventing generalizations [8]. Swindells et al. obtained valence and arousal response to touching various natural materials. Comparing self report ratings and physiological recordings from subjects' bodies (EMG and skin conductance), they found self report more sensitive in discriminating the subtle affective variations to these stimuli [21]. Others have examined affective reaction to synthetic stimuli in a variety of contexts [24, 17]. Most relevantly, Takahashi et al. studied feelings of pleasantness and animacy for low frequency vibrations (0.5 to 50 Hz) applied to finger tips and wrists of six subjects [22]. They found a significant effect of frequency on animacy but no effect on pleasantness. They also found an inverted-U relation between ratings of pleasantness and animacy. Swindells et al. studied the link between the utility of various haptic feels and subjects' preference for the feel, in the context of a Fitts' law targeting task and without it. In some cases, subjects preferred the feedback providing inferior task utility [21]. In contrast, here we examine the relation of affective ratings to human tactile *abilities* rather than feedback utility.

Vibrotactile Stimuli: Past studies have examined the impact of several parameters on information transfer, salience and learnability of vibrotactile icons; these include frequency, rhythm, waveform, and texture [23, 12]. These parameters are also promising candidates to evaluate in terms of their affective properties.

Tactile Tasks: Both sensory acuity and tactile processing resources, such as tactile working memory, contribute to a person's tactile abilities. Examination of tactile acuity for different demographics and for various body locations has shown that acuity is lower in sighted individuals and declines in old age [16]. However, acuity and Just Noticeable Difference (JND) studies did not report individual differences [16, 11]. On the other hand, tactile individual differences were reported in some studies involving remembering or processing of tactile stimuli [17, 5, 7]. Thus, we focused here on the tasks involving tactile working memory.

Most short-term or working memory evaluation has focused on visual (iconic memory) and auditory (echoic) stimuli. A few studies have investigated time and capacity constraints of haptic working memory using tasks such as delayed matching-to-sample task or n-back task (see [14] for a review). These report 5-10s of sensory memory, which is consistent with our observations.

Individual Differences in Tactile Task Performance: Considerable individual differences in tactile tasks have been reported in the literature [17, 5, 7, 13]. An early study on vibrotactile pattern recognition with the Optacon [5] found four distinct groups based on subjects' performance in three tactile tasks and their overall pattern of learning. The grouping remained consistent across the tasks and two participant pools. Another study reported two groups of learners and non-learners in a spatio-temporal pattern matching tactile task [7]. Non-learners showed little improvement over four task sessions (400 trials), while learners had better initial performance and improved. Another study with variable friction feedback showed considerable individual differences in task performance and found various preferences for different friction patterns [17]. Finally, there is evidence of individual differences in texture perception [13]. An MDS analysis on a texture similarity rating task suggested a three-dimensional space for some participants, two-dimensional for others.

In everyday life, people vary in the extent that they seek information through touch or use it for sensory pleasure [20]. 'Need for Touch' (NFT) is a 12-item questionnaire developed for consumer research that measures these differences on dimensions of pleasure (Autotelic) and information (Instrumental) touch [20]. An example Autotelic item on the questionnaire is "Touching products can be fun", whereas, "I place more trust in products that can be touched before purchase" is an Instrumental item. NFT is based on motivational differences among individuals in using touch, whereas scores on a tactile task show tactile ability differences among individuals.

Later studies have shown that higher NFT individuals have greater memory access to haptic information, seek and use it more for forming judgments [20]. These NFT studies used a relatively large number of subjects (60-100); our 30-subject exploratory trial provided less power than it required, but we included the NFT questionnaire to get an estimate of its effect size and to determine its utility for future research.

3 Design of Setup and Assessment Tools

In this section, we describe our apparatus and the vibrations, tactile tasks and rating scales used in our main experiment.

3.1 Apparatus

We used an EAP vibrotactile actuator from Vivitouch, a subsidiary of Artificial Muscles Inc. [1]. The module translates an input audio waveform to a tactile output, with an effective range of 20Hz-200Hz. Biggs et al. empirically modeled the actuator performance and the resulting fingerpad and palmar sensations [3]), estimating a palmar stimulation of approximately 22 dB for 75Hz and 175Hz, and 29 dB at 125Hz, with a peak of 32 dB at 100Hz. For our prototype (Figure 1), we sandwiched the actuator between two thin rectangular plastic plates, each $0.5mm \times 12.5cm \times 6cm$; and encased the assembly in a protective case with same size, shape and markings of a smartphone. The prototype's total mass was 64 grams.

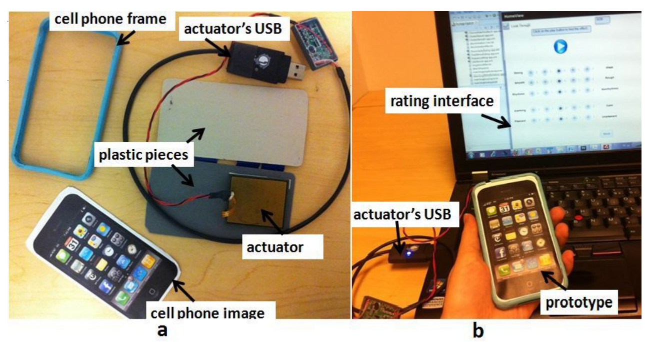

Figure 1: (a) Actuator, (b) Prototype and setup for the study

3.2 Stimuli Design

Focusing on vibratory stimuli, we wanted to know which parameters could most impact subjective response and to choose a relevant range. In pilots, subjects showed some patterns of preference for longer vibrations (1s for alerts and notifications) compared to no preference among various short vibrations (0.1-0.3s for keypress feedback). Thus, we focused on 1s signals. Follow-up pilots with a large set of simple and complex waveforms suggested the importance of frequency and temporal (rhythmic) pattern on subjects' preference. Base frequencies of 75Hz and 175Hz captured variations in subjects' preference for different actuator frequencies in pilots; for rhythmic pattern, we drew from a perceptually validated set of rhythmic icons [23].

For our main study, we chose seven representative patterns from this rhythm set [23] (Figure 2-a). The patterns were each 1s, rendered in two frequencies (75Hz and 175Hz), and repeated twice (7 patterns $\times$ 2 frequencies $\times$ 2 repetitions = 28 ratings per subject).

3.3 Tactile Task Design

We wanted to know if subjective ratings for vibrations would be affected by tactile abilities. Studies in other domains (e.g., music)

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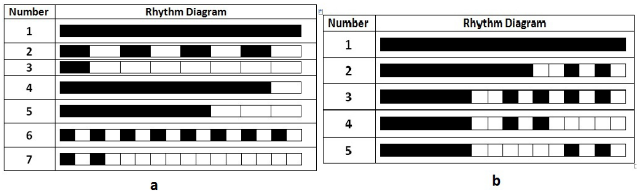

Figure 2: Rhythm patterns for (a) the affective ratings, and (b) the tactile tasks chosen from [23]. Filled slots represent a vibration; unfilled slots represent silence or pause.

have shown that proficiency with stimuli influences an individual's pattern of preference for the stimuli [19]. Also, research in processing fluency indicates a link between information processing and affective response [2]: people provided more positive affective ratings for easier-to-process stimuli, *e.g.*, with slightly higher contrast. In addition, our post-hoc analysis of data from [17] suggested that subjects preferred friction patterns that they were better at detecting; and subjects with better performance provided twice as many positive ratings as lower-performing subjects. Clearly, tactile processing abilities *may* contribute to affective response.

For our purpose, a tactile task must predominantly detect tactile abilities (as opposed to general cognitive abilities, such as intelligence); *i.e.*, have construct validity. It must engage tactile memory and processing resources since simple tactile acuity or JND tasks did not show considerable performance variations among subjects in past studies (Section 2). Finally, it must have a difficulty level that reveals individual differences, and be reliable enough to allow between-subject comparison. We are not aware of a standard battery of tasks that satisfies these criteria. There is one, however, for visual processing [6], and thus our task design is guided by this as well as the touch literature.

We examined rhythm, amplitude, time, and frequency matching tasks in which subjects matched a vibration to an available choice. Choices varied in rhythm, amplitude, time, or frequency. In pilot studies, rhythm matching did not rely on tactile abilities (lack of construct validity) and amplitude matching performance revealed very small individual variation. Time and frequency matching more closely met our criteria.

In our main study, tactile tasks comprised stimulus sets and a protocol. The stimulus set for both time and frequency matching tasks consisted of five rhythm patterns (Figure 2-b). *Time matching task (two alternative forced choice, 2AFC):* each rhythm was rendered at 75Hz and durations of 1s and 1.3s (pilots suggested 0.3s difference was appropriately difficult). *Frequency matching task (3AFC):* the same five rhythms were each rendered at 75, 125 and 175Hz and a duration of 1s.

The same procedure was used for both tasks. For each choice we asked subjects to indicate their confidence in the answer by choosing "Maybe" (for a score of 1 or -1, for correct and incorrect matching respectively) or "Sure" (2 or -2) (Figure 3) [4]. In each trial, subjects could feel the stimulus and the matching choices exactly once and were instructed to go through the choices from left to right to maintain control over order effects. Stimuli were presented in a random order and subjects were told that their choices differed in the feeling (frequency) or the timing of the vibrations.

3.4 Affective Rating Scales Design

Most affective haptics studies have used a single measure of affective response (*e.g.*, liking, pleasantness) or a set of self-selected scales [8, 15, 18]. An ideal affect measurement scale for our purpose must capture important dimensions of affect and perception, allow integrated analysis of those dimensions and examination of individuals' variations from average patterns of ratings, and ideally accommodate diverse tactile sensations including synthetic and natural stimuli. An integrated rating scale could also guide the design of new tactile sensations by revealing parts of the affect and sensation space based on subjects' ratings. In our discussion, we outline our progress towards these criteria, and identify future steps required for validation and further development of the scales. Nevertheless, the criteria for a desirable scale evolve as we further study affective response to tactile sensations. In the following, we use 'rating dimensions' and 'scales' interchangeably.

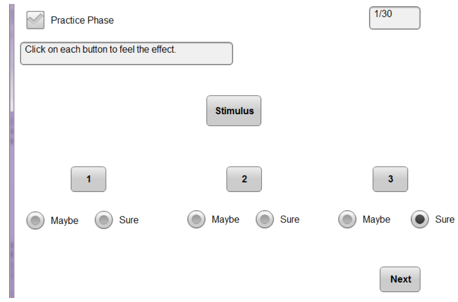

Figure 3: Interface for frequency matching task (similar interface for the time matching task but with two selection buttons.)

As a first step towards such an integrated scale, we designed an initial set of subscales based on the touch vocabulary derived by Guest et al. (see Related Work [10]). We chose a representative word from each part of their resultant emotion and sensation spaces, resulting in *unpleasant/pleasant, uncomfortable/comfortable*, and *boring/exciting* for emotion. From their sensation space, after removing words which our hardware cannot literally render (*e.g.*, cold/warm, and wet/dry), we were left with *smooth/rough* and *soft/hard*. We added *weak/strong* and *non-rhythmic/rhythmic* to better capture the characteristics of our vibrations. This resulted in eight initial scales: *weak/strong, smooth/rough, soft/hard, non-rhythmic/rhythmic, boring/exciting, unpleasant/pleasant, uncomfortable/comfortable, dislike/like*.

In a pilot, 6 subjects (4 males) used these scales to rate vibrations described in Section 3.2, using the interface shown in Figure 4. We removed the liking and comfort dimensions because of high correlation with pleasantness (r˜0.8). We also removed the *soft/hard* dimension as subjects had difficulty in attributing hardness to the vibrations. Further, we re-labeled the *boring/exciting* to *calm/alarming* to achieve neutral valence and avoid inconsistent interpretations. Although not deliberate, *unpleasant/pleasant* and *calm/alarming* dimensions map to well-known valence and arousal dimensions for emotions.

This resulted in five dimensions employed in the main study: three sensory (*weak/strong, smooth/rough, non-rhythmic/rhythmic*) and two affective (*calm/alarming, unpleasant/pleasant*).

4 Study

4.1 Procedure

30 subjects participated in a one-hour, 3-part study and were compensated with $10. (1) Subjects completed a general information questionnaire and the 'Need for Touch' survey; then (2) rated 28 vibrations (Section 3.2) each on five affective and sensory scales. Vibration presentation order was randomized across subjects. On the rating interface, labels were randomly placed on the left or right side of each scale for each subject to reduce rating bias. (3) Subjects completed two rounds of the time and frequency matching tasks (Section 3). Time and frequency tasks were interleaved and their order counterbalanced among subjects. Subjects held and felt the cell phone prototype in the non-dominant hand and listened to white noise to mask actuator noise.

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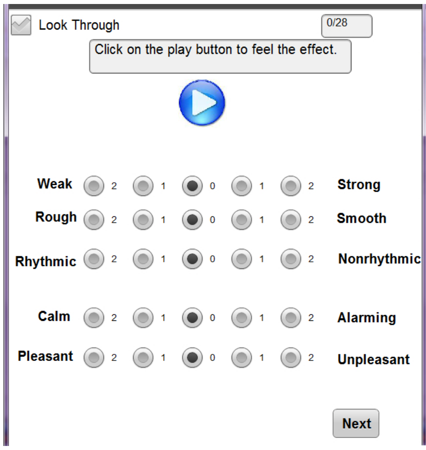

Figure 4: The user interface for the affective ratings

4.2 Results and Analysis

Subjects were diverse. All subjects were students between 18-45 years old, 15 female, 3 left-handed, 15 from computer science and 15 from psychology, arts, chemistry etc. 16 were from North America or Europe, 14 from Asia and Middle East. 14 had more than two years of musical background, 6 had less than two years and 10 reported none. 11 used eye glasses, and no one reported tactile deficiency. Touch tablets and smart phones, guitar, piano, Wii, and Dictaphone were mentioned as frequently used touch devices. NFT scores varied from -25 to +30. Following the same procedure as [20], we used a median split on NFT scores to divide the subjects into high and low NFT groups.

Rating scales revealed correlations. Overall, *smooth/rough*, *calm/alarming*, and *unpleasant/pleasant* ratings were significantly correlated. The bivariate Pearson correlation of the five ratings for all subjects showed medium significant correlation between *smooth* and *pleasant* (r=.53), *rough* and *alarming* (r=.42), *unpleasant* and *alarming* (r=.39), and *strong* and *alarming* (r=.38). Directionally, subjects found rougher patterns more alarming and unpleasant. Stronger patterns were perceived as more alarming and rhythmic patterns were more pleasant (r=.2).

Stimulus composition influenced subjective ratings. On average, rhythm significantly impacted ratings for all scales, while frequency only impacted the *calm/alarming* ratings. To examine the effect of rhythm and frequency on ratings, we ran five separate within-subject ANOVA tests with each rating scale as the dependent factor and rhythm, and frequency as two independent factors. All reported effects were significant at $p<0.01$. Rhythm had a main effect on all five scales (see Table 1). The long continuous vibration (pattern 1) was perceived as strongest, smoothest, and most non-rhythmic. The pattern with several very short vibrations (p6) was the roughest, most alarming and most unpleasant. The long vibration with one short silence (p4) was most pleasant and among the strongest. Patterns with few short vibrations (p3, p7) were the weakest and most calm. Frequency only had a main effect on the *calm/alarming* scale (Table 1). 175Hz vibrations were more alarming than 75Hz. There was an interaction effect of rhythm*frequency for *weak/strong* scale, *i.e.*, 75Hz was perceived stronger or weaker than 175Hz depending on the pattern.

Individuals' affective and sensory ratings varied. The average ratio of mean to standard deviation for the five scales were: *weak/strong*: 0.71, *smooth/rough*: 0.27; *non-rhythmic/rhythmic*: 0.87; *calm/alarming*: 0.45; *unpleasant/pleasantness*: 0.22. Thus, reactions varied most for *unpleasant/pleasant*, *smooth/rough*, and *calm/alarming* respectively, two of which are affective dimensions.

Table 1: Summarized results of the ANOVA tests on the five affective rating scales

Rating Scale	Significant Factors	F Value, Effect Size
Weak/Strong	Rhythm Rhythm*Frequency	$F(3.07,107.44)=49.46$, $\eta^2=0.58$ $F(6, 210)=7.5$, $\eta^2=0.18$
Smooth/Rough	Rhythm	$F(2.8,100.83)=6.44$, $\eta^2=0.15$
Non-rhythmic/Rhythmic	Rhythm	$F(3.11,112)=25.94$, $\eta^2=0.42$
Calm/Alarming	Rhythm Frequency	$F(3,109)= 10.64$, $\eta^2=0.23$ $F(1,36) = 10.62$, $\eta^2=0.23$
Unpleasant/Pleasant	Rhythm	$F(2.75,99)=4.1$, $\eta^2=0.1$

Individuals deviated from overall affective/sensory scale correlations. Since examining the complex patterns of all correlations for each subject is a large task, as a first step we analyzed the correlations for one pair of scales (*pleasant* and *alarming*). Post-experiment comments had suggested differences in subjects' opinions for these two dimensions, making it a promising place to look for evidence that differences exist. Alarming and unpleasant ratings did not correlate for 11 subjects ($r<0.35$ and non-significant), but were highly correlated for seven other subjects ($r>0.7$ and significant). Such a large variation in affect justifies further examination. In future analysis, we will investigate the complex patterns of correlations among all dimensions; for example, MDS and factor analysis may better reveal the structures in individuals' ratings.

Variation in subjective ratings did not correspond to demographic or NFT. For each scale, we ran a between-subject ANOVA using the sum of ratings for that scale as the dependent variable. Gender (two levels), culture (two), music background (three), and NFT category (two) were the between-subject factors. We did not find a significant effect of these factors on the ratings. The effect size of NFT was very small (less than 0.1) which did not justify its practical significance even for a larger sample size.

Task performance varied, but variation did not coincide with affective ratings. Total score in each task, calculated as the sum of negative and positive scores for all items, varied from 50% to 85% for both tasks. However, all subjects performed above chance (>50% in the time task and >33% in the frequency task). Also, the distribution of our task scores did not show distinct groups of performance, in contrast to previous individual difference studies [17, 5, 7]. The distribution for the time task suggested three overlapping normal distributions which we used to divide subjects into three groups. The distribution for the frequency task was even more flat. For consistency, we divided subjects into three groups of low, medium and high scores (see Figure 5); these groups held different members than for the time task. However, variations in subjective ratings did not correspond to time and frequency task performance in our study.

5 Discussion

We now relate our study results to our near-term research questions.

5.1 Dimensionality and Utility of Affective Response

What are the relevant dimensions for measuring affective response, and is there utility in multiple rating dimensions? We derived five affective and sensory dimensions for rating vibrations using literature and pilot studies (Section 3.4). Here we point to the findings that emerged from analyzing crosslinkages between affective and sensory dimensions.

Ratings showed a structure in affect and sensory ratings that might extend to other modalities. Based on the correlation among ratings, the vibrations were mostly perceived as *rough, alarming,* and *unpleasant*; or, *smooth, calm,* and *pleasant*. This organization can point to the inherent association of these attributes in subjects'

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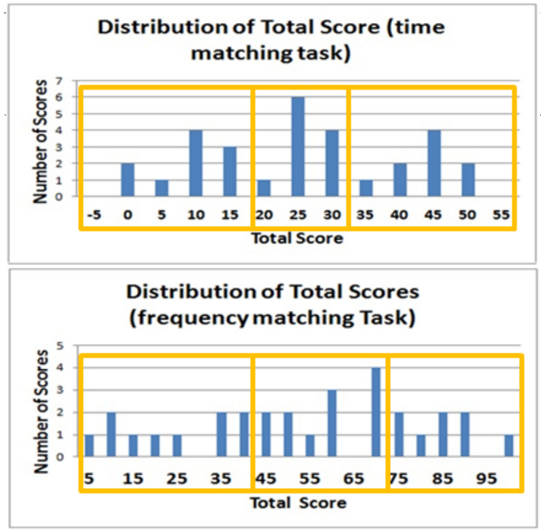

Figure 5: Distribution of total scores in time and frequency tasks; orange boxes show one possible grouping for the tasks.

mind. Future work can examine whether this structure holds for other vibrations and even other modalities.

Our stimulus set largely bypassed the positive valence/positive arousal region of the emotion response space. On average, few alarming vibrations received pleasant ratings. However, exciting rhythms (positive valence and arousal) are conceivable for vibrations and seem to be a relatively unexplored part in our vibrations. Thus, ratings on multiple dimensions can guide future stimuli design.

Affective and sensory ratings showed how individuals' patterns of preference deviated from average. Based on the correlation matrix for each subject, several subjects deviated from the overall correlation between unpleasant and alarming ratings. The integrated set of affective and sensory dimensions also enable investigation of more complex structures in future.

This initial set of scales needs further development and validation. As a first step, their utility in describing synthetic stimuli (*e.g.*, various vibrations and tactile technologies) must be developed. Eventually, the proposed dimensions must evolve to support rating of natural stimuli, as a means to compare users' response to synthesized and natural stimuli. We also need to determine how accurately these dimensions can reflect human affective response in real-world contexts. One possibility is to test how well the rating instrument assists haptic designers in creating tactile stimuli that are indeed preferred by users in real-world scenarios. Another is to use neuroimaging studies to compare brain patterns for ratings to those for natural pleasant stimuli, e.g., fur.

5.2 Vibration Parameters

What parameters from the vibration design space impact affective response, and how?

On average, rhythm pattern (duration of vibrations, number and timing of pauses) influenced subjective ratings for all five affective and sensory scales. Frequency only significantly impacted *calm/alarming*. Overall, rhythm pattern impacted the ratings the most.Drilling down: vibration duration directly influenced *weak/strong* ratings and the number of pauses determined *smooth/rough* and *calm/alarming* ratings. Overall, longer vibrations with fewer pauses were perceived as smooth and pleasant. Several short vibrations were considered rough, alarming and unpleasant.

The affective range in response to these vibrotactile stimuli is more limited than what we would expect to find for natural stimuli. However, even this small study found distinct preference for some vibrations over others. This suggests that having a scale can help designers now using this relatively inexpressive media in avoiding negative affect and designing more acceptable feedback. With improved rendering technology, we can expect to move towards more engaging touch sensations.

Some individuals' ratings diverged considerably from these overall trends, as indicated by the average ratio of mean ratings to standard deviation. Rating variations were especially high for *unpleasant/pleasant*, *smooth/rough*, and *calm/alarming* scales which were also highly correlated. In future, using a composite value based on ratings for the three dimensions might reveal different clusters of subjects and preferences.

5.3 Demographic, NFT Score and Tactile Performance

What is the link between affective response and demographics, NFT scores, and tactile task performance?

Subjective ratings did not coincide with demographics, NFT scores or tactile abilities. Our results are consistent with past studies which also did not find any considerable effect of demographics. Regarding NFT, we had determined *a priori* that 30 subjects would not have enough power to detect an effect (Section 2), but we included the NFT questionnaire to assess its sensitivity. Our results suggest a very small effect size for NFT (less than 0.1 on subjective ratings). Regardless of power of a later study, such a small effect on subjective ratings does not have practical significance. NFT might not be sensitive enough to account for the affective range of synthetic stimuli. We thus plan to exclude the NFT in future work with synthetic stimuli and focus on tactile performance. For natural stimuli with a larger range of affective response, NFT might prove a more useful instrument.

To assess our results for tactile performance, we need to answer two questions:

1. How well did the time and frequency tasks reflect tactile abilities? Our analysis suggested that the frequency task better reflected tactile abilities (reasonable validity and reliability) but the reliability of the time task needed improvement. First, both tasks had a reasonable difficulty level to generate a low to high performance range (50% to 85% of correctly matched items). Second, our analysis suggests that the tasks relied on tactile sensory memory (subjects' scores in the two tasks did not correlate with their report of using pitch or rhythm for matching the stimuli). As a future test of discriminant validity, we can compare subjects' performance in auditory vs. tactile matching tasks. Finally, the correlation between the two rounds of the frequency task (r=0.67) and the two rounds of the time task (r=0.37) indicated a reasonable reliability for the frequency task, while the time task needed improvement. Convergent validity of the tasks must be established in future, *e.g.*, by using time and frequency discrimination tasks.

2. Do individuals exhibit considerable differences in tactile processing ability? Although task score distributions showed some variations in performance, they did not suggest obvious groupings. In contrast, past studies reported distinct groups of performers. What was the reason for these different results? Are there real differences in people's tactile abilities? In retrospect, almost all studies reporting huge individual difference in task performance involve a spatial component [17, 5, 7]. So it could be that people are different in some aspects of tactile abilities and not in others. If so, a battery of tasks is needed to measure tactile abilities. Moreover, most of those past studies used a specific instrument (Optacon), and their tasks had a cognitive component involved: subjects needed to map a tactile pattern to its visual representation. Both the instrument characteristics and the cognitive element could cause the variations in performance. A next step would be to study the potential

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differences in spatial tactile tasks by eliminating those confounds.

Based on past work, we started with the hypothesis of considerable differences in tactile abilities; we did not see this in these particular conditions. Now, the question is: Do people vary substantially in their processing of tactile stimuli; if so, in what respect? Does learning account for those differences? Only after answering these questions we can examine links between tactile abilities and affective response.

6 Conclusion and Future Work

We have examined affective response to vibrations for a handheld device. We presented our progress towards an integrated set of rating scales for measuring various dimensions of affect and perception, specifically *weak/strong, smooth/rough, nonrhythmic/rhythmic, calm/alarming*, and *unpleasant/pleasant*. Using these scales, we measured subjective response to rhythm pattern and frequency of vibrations. The correlation of ratings indicated that subjects found smooth patterns and rhythmic patterns more pleasant. Rougher patterns as well as stronger vibrations were perceived more alarming. According to the overall ratings, pleasant and alarming vibrations were relatively underrepresented in our vibrations and can be explored further in future. Within-subject ANOVA on the subjective ratings showed a main effect of the rhythm on all five rating scales, a main effect of frequency on the *calm/alarming* ratings, and interaction of rhythm*frequency for the *weak/strong* scale. Ratings varied considerably among subjects for *unpleasant/pleasant*, *smooth/rough*, and *calm/alarming* dimensions. However, demographics, NFT scores and task performance did not coincide with these variations.

This study was a first step towards our long-term objectives. Future steps are guided by questions such as: 1) *Measurement tools*: Do affective responses to naturalistic stimuli differ qualitatively from those to synthetic stimuli, like vibrations; and can the same assessment tools uncover both types of responses? 2) *Key Attributes*: To what extent the effects of rhythm and frequency generalize to other tactile technologies? What other signal parameters are affectively important? 3) *Individual Differences*: How can we quantify individuals' deviation from the overall patterns of ratings for affect and sensation? Can we cluster people based on these patterns? To what extent individuals vary in other tactile tasks, *e.g.*, tactile spatial tasks? What is the role of learning?

Answering these questions not only provides a better picture of affect and perception of tactile sensations but can also guide the criteria for further development of the proposed set of scales.

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