

Controlling Human Perception of Haptic Profiles Using Contextual Cues

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Abstract— Haptics are commonly used to convey alerts or simple notifications in commercial applications. Expanding the use of haptics to more complex scenarios is a promising area of development. The results from testing indicate that participants associate meaning with haptic profiles based on the context in which they are presented. Such results lay the groundwork for controlling perception of haptics using contextual cues. The haptic profiles in this study are customized patterns generated by linear resonant actuators (LRAs). They are intended to convey complex meanings to the test participants. The extent to which contextual cues determine participants' perception of the haptic profiles was investigated for various types of haptic profiles and contextual cues, including variations of specificity levels and cue modalities (picture, sound, video, etc.). The results indicate that contextual cues can significantly impact perception of haptics such that the cues effectively "control" the human perception.

I. INTRODUCTION

Haptics are currently used in billions of smart phones, smart watches, wristbands, and other wearable devices as alert notification systems. More informative haptic profiles can be implemented in current devices; however, there are no established standards for linking haptic profiles to meaning, such complex profiles might lead to user confusion or misinterpretation. As a result, rich and meaningful sensations available for smart wearable devices are currently limited.

The research presented here focuses on the use of contextual cues to control, or at least to influence, the perception of haptic profiles in everyday communications that extend beyond simple notifications.

The correct interpretation of haptic profiles has been a concern that delays integration of haptics into devices [1], [2]. Inaccurate perception of the meaning of haptic profiles can result in mistakes and fatigue for users [1]. Previous studies on the interpretation of haptic profiles have focused on interpretation uncertainty and cognitive control [3]–[5], as well as emotional content and pleasantness of haptic profiles [6]–[10]. In this study, haptic profile recognition, based on the given context, is shown to significantly impact user perception of the meaning of a haptic profile.

Section II presents the physical experimental setup and methodology. Section III contains the experimental procedure. Section IV presents the results. Section V contains the conclusions of the research.

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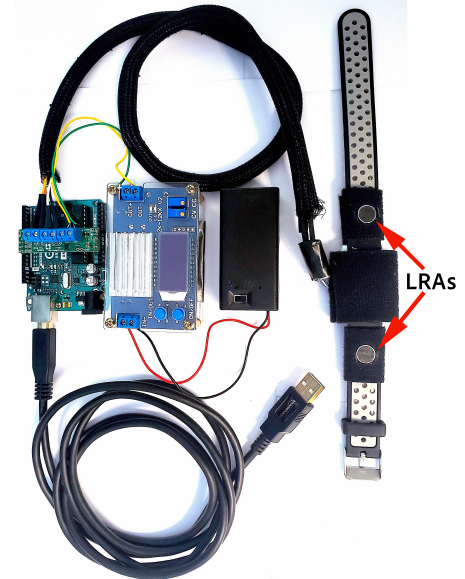


Fig. 1: Wristband test setup.

II. METHODOLOGY

A. Physical Experimental Setup

The testing apparatus, shown in Fig. 1, produced haptic profiles using two linear resonant actuators (LRAs) on a test participant's wrist. LRAs are small motors that are placed in the wristband test setup and used to create haptic sensations. The apparatus includes an Arduino Uno, a motor driver, a battery pack, a voltage stepper, and a wristband with embedded LRAs on each side of the wrist. Two Vybronic Inc. VG1040003D LRAs are used in the system. The Arduino Uno sends signals to the motor driver to drive the two haptic motors separately, so that the two LRAs can simultaneously play different haptic profiles. This allows the setup to generate complex haptic profiles that significantly expand the set of sensations, beyond those available with a single haptic actuator [11]–[15].

B. Haptic Profiles

The study included seventeen (17) haptic profiles representing a variety of concepts. The haptic profiles were developed in the Arduino IDE, through translation of a sound file through Matlab, or 'handcrafted' to elicit a desired meaning. Fig. 2 shows a voltage plot of the "Caress" profile for the left LRA. The signal for the right LRA is the same

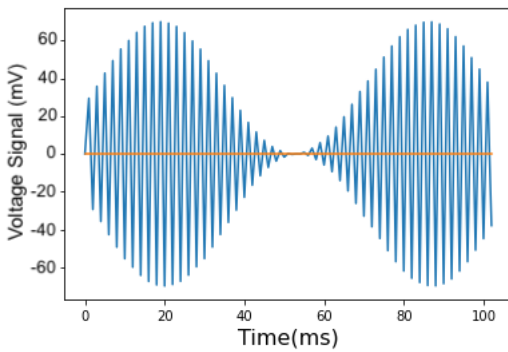


Fig. 2: Voltage signal vs. Time plot of a subsection of the Caress profile for the left LRA.

sine wave, but is delayed so that its maximum amplitudes occur when the left LRA is driven by low amplitudes.

C. Contextual Cues

During testing, haptic profiles were paired with the presentation of contextual cues. As a control, a subset of participants received haptic profiles without any accompanying contextual cues. The desired purpose of contextual cues is to guide the test participant towards a desired meaning of the haptic profile. In essence, the cues are control inputs that affect system outputs (perceived meanings). Context is usually available in real-life applications in some form; therefore, various types of cues were tested. Six categories of contextual cues were designed:

- **Picture:** One or many picture(s).
- **Video:** Gifs with no audible component.
- **Sound:** Sound clips.
- **Written Description:** A description of the concept that the profile represents.
- **Situation Description:** A description of a situation in which the profile is used in communication.
- **Text Message:** A text message chat in which the profile is used as a part of communication.

These categories included cues designed with four levels of specificity, ranked from highest to lowest:

- **Exact**
- **Specific**
- **Moderate**
- **General**

Contextual cues were designed as follows:

The use of the actual name of the profile within textual cues (written description, situation description, text message) was avoided for levels other than **exact**. Visual (picture, video) and auditory (sound) cues at the **exact** level of specificity were designed to depict the precise intended meaning of the haptic profile.

At the other extreme, all **general** contextual cues were standardized to give a broad overview of the category, while not necessarily including any details about the specifics of the haptic profile. The **moderate** level was slightly more



Fig. 3: Contextual cues by specificity levels for "Dog Bark" picture category.

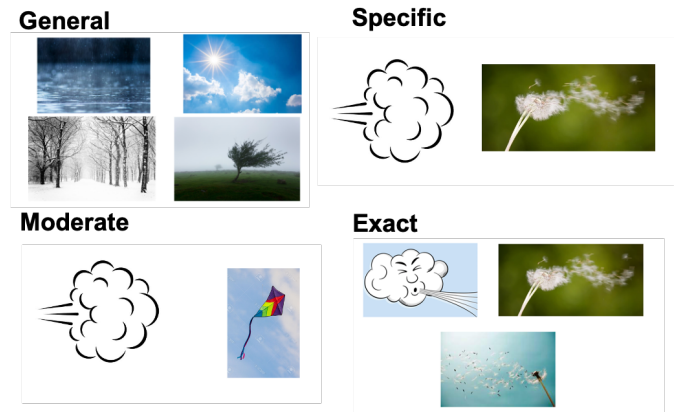


Fig. 4: Contextual cues by specificity levels for "Wind Puff" picture category.

informative compared to the **general** context, while the **specific** context was a slight generalization compared to the **exact** context. To add specificity beyond the **general** level, **moderate** cues added details to narrow down options within a category. **Specific** cues included synonyms and highly similar words to the profile name, but included fewer informative details than exact cues.

Examples of picture contextual cues at all four specificity levels for the "Dog Bark" and "Wind Puff" haptic profiles are shown in Fig. 3 and Fig. 4. For "Dog Bark," the general and moderate cues inform the participant that the profile is related to the larger category of animals, while the specific and exact cues show a dog and a dog barking, respectively. For "Wind Puff," the general cue suggests to the participant that they are feeling a weather profile. Moderate through exact cues add more detailed imagery that is specific to a wind puff as the cues become more exact.

As mentioned above, some profiles were designed using raw sound files from objects and animals, while others were designed to mimic or reference a specific tune, rhythm, or

sensation. For various conceptual and linguistic profiles, the designers created haptic effects with characteristics meant to elicit the thought of that concept or phrase. These profiles include animal sounds, types of weather, common phrases, alerts, and emotions. In order to enhance the quality of the haptic profile and to limit residual buzzing, input-shaping algorithms described in [16] were used for the majority of profiles.

The next section details the haptic profiles used in this study. The descriptions focus on ten haptic profiles which test participants recognized the meaning of the most frequently. These profiles are:

- **Siren:** A blaring alarm.
- **Rain:** Drops of rain at the start of a rainstorm.
- **Rooster:** In the rhythm of "cock-a-doodle-doo."
- **Ok:** Two quick sets of dot taps.
- **Fun:** An exciting, interesting vibration full of energy.
- **Cat Purring:** A purring sound from a cat.
- **Knock Knock:** The sound of a double knocking on a door.
- **What:** Three slow dot taps, "..."
- **Dog Bark:** Emulates a non-threatening dog bark.
- **Wind Puff:** Emulates wind with two rising and falling gusts.

III. EXPERIMENTAL PROCEDURE

Participants were students and visitors at the Georgia Institute of Technology, between the ages of eighteen (18) and eighty-eight (88), conversationally fluent in English, and were not hearing impaired. All participants gave their informed consent to the protocol approved by the Georgia Institute of Technology's Internal Review Board (IRB). Participants were not compensated for their participation. Seventeen (17) haptic profiles were tested on one hundred twelve (112) total participants. Each profile was evaluated by between thirty-eight (38) and sixty-eight (68) different test participants and a total of nine hundred eighty-three (983) trials were conducted. Each participant completed between one (1) and thirty (30) trials (average = 8.8, STDEV = 5.3). Test participants were asked to "describe the profile" as well as to "name the profile." Ten (10) participants formed a control group that was not provided contextual cues.

A. Experimental Design

The three steps in each trial of the testing procedure are illustrated in Fig. 5. First, participants read, listened to, or viewed a contextual cue presented by the experimenter. Next, the corresponding haptic profile was played by the experimenter, and the participant replayed the profile as needed. Lastly, participants responded with a name and description for the profile.

Test participants were asked to wear the wristband comfortably, as they would wear a smartwatch or wristband. Participants who normally wore watches in daily life were instructed to wear the wristband on the same wrist. Other participants wore the watch on their non-dominant wrist.

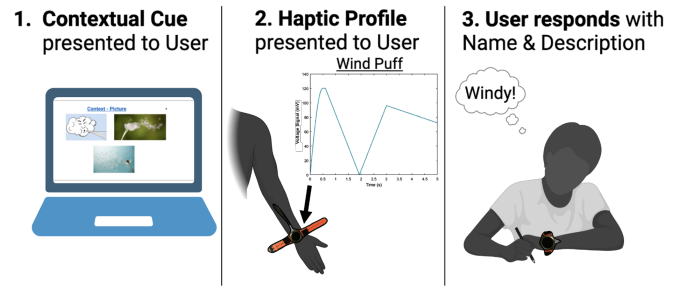


Fig. 5: Example test protocol.

To initiate the testing, the test administrator played a sample profile that was not one of the seventeen test profiles to ensure the participant could feel the haptic signals. Following the sample profile, the test administrator presented the participants with a contextual cue immediately prior to, or while feeling, a haptic profile. Then, test participants were asked to describe and name the profile. Before answering, participants were permitted to replay the haptic profile as many times as desired. Participants were informed of the general categories of the haptic profiles, which were described as "animals, weather, common phrases and communication, alerts, and emotions or feelings."

IV. RESULTS

A. Performance of Haptic Profiles

Out of the seventeen tested haptic profiles, ten profiles were identified correctly more consistently than others. These profiles were correctly identified approximately half (45%) of the time. An example of one of these profiles is "Cat Purring," a haptic profile created with a raw sound file from a cat purring. Results from testing with this profile are shown in Fig. 6.

Blue color indicates correct identification of the profile, red indicates incorrect identification of the profile, and light blue indicates partial identification of the profile. There is one circle plot for each of the four levels of contextual cues, along with a fifth plot for trials completed with no contextual cues. A sixth plot, at the bottom, shows the total results across all trials with and without cues.

Correct responses are those that include the words "cat," "purring," or a synonym or explanation of either, i.e. "kitten," "grumbling," or "the sound a cat makes." Examples of responses that were scored as partial (light blue) are "dog" and "cute," as these responses either accurately identify the category of the profile, or are highly related to the haptic profile's meaning. This scoring schema was applied to all other profiles. Exact identification of the name of the profile or of a synonym was scored as correct, while identification of the profile category or of something highly related to the intended meaning of the profile was scored as partial. Responses for both naming and describing the profile were included in scoring.

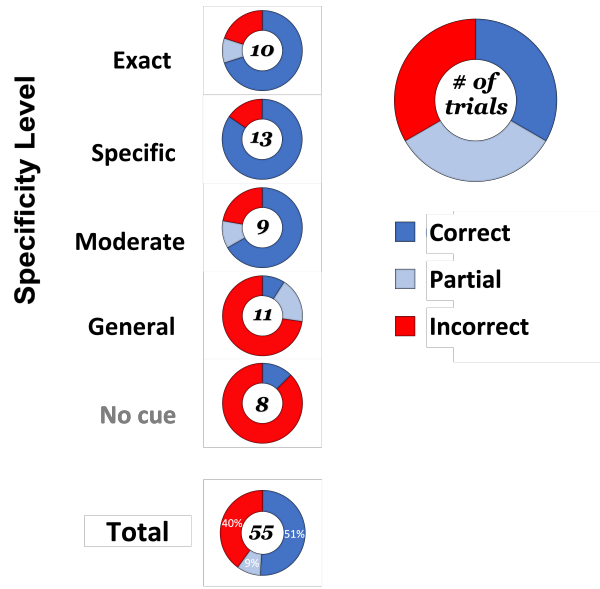


Fig. 6: Performance for the "Cat Purring" profile.

Results for each profile were ranked using the difference between the proportion of correct and incorrect trials to account for partial responses.

The performance rating by proportion is:

$$\text{Performance} = \% \text{Correct} - \% \text{Incorrect} \quad (1)$$

Data for the ten most recognizable profiles tested are shown in Fig. 7. The profiles are ranked from left to right according to their performance by proportion, as measured by (1).

Higher performance for these haptic effects can be explained by several factors. An effectively designed haptic profile, which communicates the intended meaning to test participants, may explain the performance of profiles like "Siren" and "Rain," given the high level of homogeneity of participant responses across all cue specificity levels for these profiles. The majority of participants also identified "Siren" without any context, indicating that this profile was especially well-designed. Although only two out of nine participants identified the "Rain" profile without any context, the positive performance across all levels of contextual cues indicates that general context, which indicates the broad category of the profile to participants, may be sufficient for users to consistently recognize the "Rain" profile as designed.

Fig. 7 shows a larger decrease in performance between more specific and less specific cues for "Cat Purring" and "Dog Bark" than for "Siren" and "Rain," indicating that participants depended more on contextual information from cues to recognize "Cat Purring" and "Dog Bark." Exact and specific cues for "Dog Bark" unambiguously depict a dog (Fig. 3). Exact and specific cues for "Cat Purring" use the

TABLE I: P-values for single-factor ANOVA between responses at each level of specificity and with no cue.

	No cue	General	Moderate	Specific	Exact
No cue	1				
General	5.2×10^{-5}	1			
Moderate	4.1×10^{-11}	9.9×10^{-5}	1		
Specific	1.7×10^{-15}	9.6×10^{-8}	0.13	1	
Exact	1.6×10^{-17}	1.6×10^{-9}	0.03	0.52	1

word "cat" in the description, and moderate cues used the word "pet." The difference in performance between trials that more explicitly show or describe the animals compared to those that do not suggests that the above-average performance of "Dog Bark" and "Cat Purring" is impacted by the inclusion of a picture or description of the animals themselves within the contextual cues. The result for these two animal profiles can be viewed in comparison to the "Rain" and "Siren" profiles, which exhibited excellent performance on all levels, including general, indicating a well-designed haptic profile when paired with any level of context.

B. Effect of Contextual Cues

The contextual cues had a significant effect on whether the intended meaning of a haptic profile could be correctly identified by a participant. The effect of contextual cues on participants correctly identifying a haptic profile was analyzed by comparing the results for given specificity levels of the cues and with trials with no cues.

Overall, the results for trials with no cues were distinctly different from trials with cues. This is supported by the results from single-factor ANOVA tests between levels and trials with no cues, with p-values shown in Table I. Table I also shows that responses for general cues were significantly different from the other three levels of contextual cues. Fig. 8 shows the overall performance for each specificity level and for no cue, as calculated in (1). Asterisks on Fig. 8 indicate the number of single-factor ANOVA comparisons from Table I that return a corrected p-value < 0.005 , using Bonferroni correction with ten comparisons.

These results suggest that performance increased with the addition of contextual cues, and also increased between specificity levels, most dramatically from general to moderate cues.

The middle column of Table II shows p-values for single-factor ANOVA tests between scores for trials with no cues and trials with cues for each of the profiles in Fig. 7. For profiles with lower p-values such as "Rain," "Rooster," and "Ok," the results indicate that the introduction of contextual cues made a significant impact on participants' performance. For other profiles like "Dog Bark," only the introduction of more specific cues made a significant positive impact on performance. A single-factor ANOVA comparison between

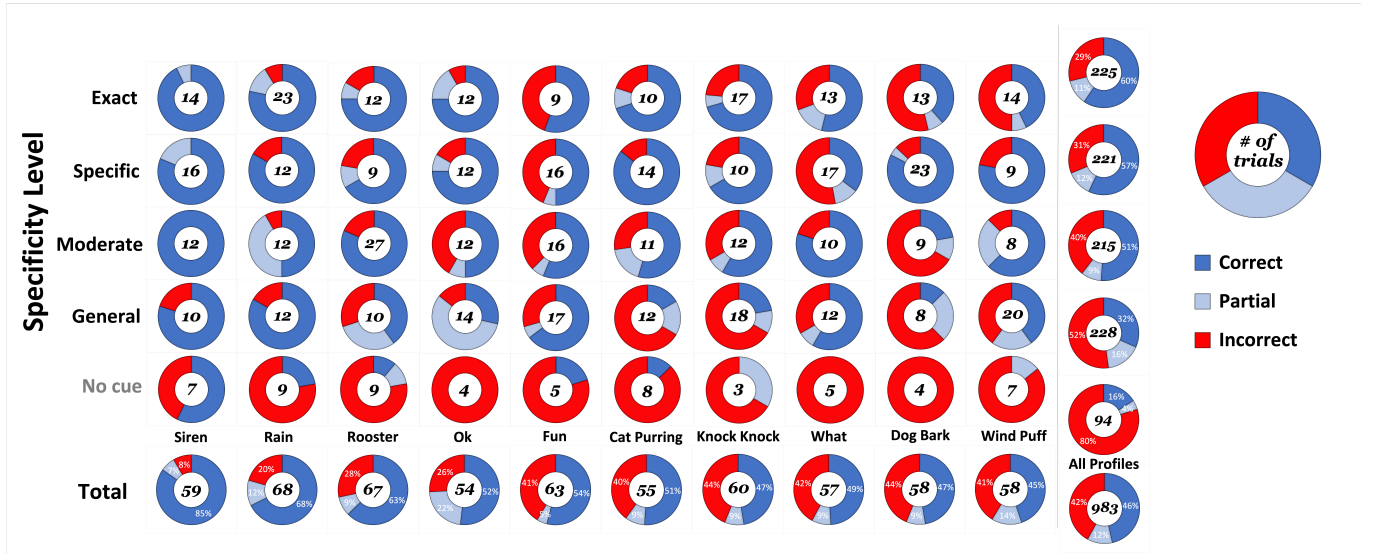


Fig. 7: Haptic profiles ranked by proportion correct minus proportion incorrect.

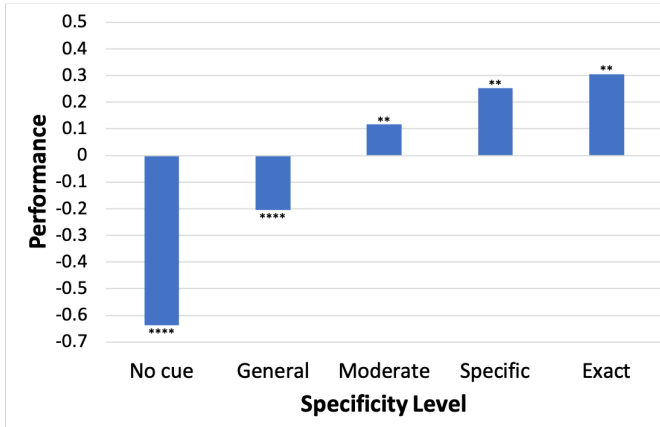


Fig. 8: Overall performance (proportion correct minus proportion incorrect) by level of contextual cue and for trials with no cue.

TABLE II: P-values for single-factor ANOVA between trials with and without contextual cues, and between general and exact trials, for each haptic profile.

Profile Name	No cue vs. With cue	General vs. Exact
Rain	1.9×10^{-5}	0.906
Rooster	1.5×10^{-4}	0.190
Ok	0.001	0.054
Siren	0.003	0.183
Cat Purring	0.005	0.010
Wind Puff	0.006	0.831
What	0.008	0.960
Dog Bark	0.024	0.407
Fun	0.082	0.553
Knock Knock	0.174	0.004

trials with no cues, and trials with specific or exact cues for "Dog Bark" ($F(1, 38) = 9.24$, $p < 0.005$) indicates that for "Dog Bark," only the introduction of an at least specific-level cue makes a significant impact on performance.

The final column of Table II shows p-values for single-factor ANOVA tests comparing scores between trials with general and exact cues. Haptic profiles with lower p-values, and a larger difference between responses to general and exact cues, had a well-designed and understood relationship between exact and general contextual cues. Haptic profiles with larger p-values may have been well-designed haptic profiles with a high floor of test participant performance even with little context, including "Siren," "Rain," and "What," which all received highly-consistent word responses from participants. Additionally, a large p-value could indicate

a lower-than-expected difference between the effect of contextual cues at different levels. For example, the large p-value of the "Dog Bark" profile ($p = 0.407$) is caused by a lower-than-expected performance at the exact level.

Recall that Fig. 3 shows the picture contextual cues at all four levels for "Dog Bark." The over-performance of specific cues compared to exact cues indicates an overly-specific cue or poorly-designed contextual cue at the exact level. This may have led participants away from responding simply with "dog" or "bark/barking" when viewing the exact cue. Many participants given the exact level cue chose to respond with "alert," "notification," and "generic," indicating that the specificity of the contextual cue either confused participants or led them to ignore it. Participants given the specific level

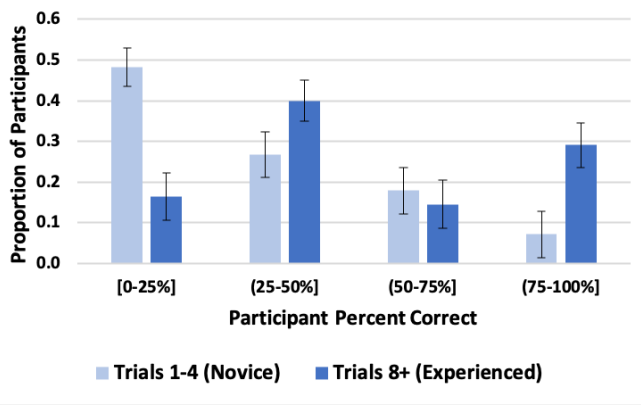


Fig. 9: Performance on Novice trials vs. Experienced trials.

were much more likely to guess "dog" or "bark." The results from "Dog Bark" show the possibility of an overly-specific or poorly-designed contextual cue and how it may confuse participants.

With some profiles, including "Wind Puff," "Dog Bark," "What," and "Fun," the contextual cues may have led to incorrect answers because too much information may have distracted the participant. For example, for the "Wind Puff" picture contextual cues, shown in Fig. 4, the specific level resulted in a higher ratio of correct profile recognition, whereas the exact level included an additional picture and a higher ratio of incorrect responses were given.

C. Improvement over Trials

Results from this study indicate that with practice, study participants improve the accuracy of their identification of haptic profile meaning. Being exposed to more haptic profiles in more trials increased the proportion of correctly identified haptic profiles by the study participants. However, this effect was only significant once participants completed at least an average number of trials.

To investigate whether participants improved over the course of testing, test participant performance (proportion of haptic profiles correctly identified) was compared between the first 4 trials (novice) and trials 8 through 21 (experienced). Only participants that completed at least 8 trials were included in this section of the analysis.

Initial single-factor ANOVA results between percent correct by participant for novice and experienced trials ($F(1,108) = 6.31$, $p = 0.014$) indicate that a form of learning or improvement occurred among participants who completed at least an average number of trials. Figure 9 shows the proportion of participants grouped by percent of responses that were correctly identified. The Novice trial group shows a greatly decreased proportion of participants that scored between 50% and 100% correct on identifying profiles compared to the Experienced trial group.

V. CONCLUSIONS AND FUTURE WORK

There are many factors that affect interpretation of haptic profiles, including the quality of the haptic generating device, the design of the haptic profile, and the contextual cues used in conjunction with the haptic signal. Results from testing of complex haptic profiles indicate that contextual cues significantly affect interpretation of haptic profiles and can, in effect, control human perception. Gaining an understanding of how contextual cues affect human perception of a haptic profile can inform both the design of haptic profiles and the contextual cues. The results also indicate that over a short period of time, test participants can significantly improve their ability to identify the meaning of haptic profiles. This study has provided results on various levels of context and different categories of context with which participants can be aided in their recognition of haptic profiles. The testing protocol can also be used as a template to evaluate and iterate on the design of haptic profiles and their associated contextual cues.

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