Avances en Interacción Humano-Computadora, 2024, Volumen 9, No. 1, pp. 87-90
DOI: 10.47756/aihc.y9i1.151

RESEARCH PAPER

Cactus: A Mobile Haptic Interface to Define Vibrotactile Patterns Mimicking Surface Textures

Christian Gonzalez, Luis M. Zamudio, Jesus Favela, Monica Tentori

Published: 30 November 2024

Abstract
Sensory integration therapies are essential for aiding people with sensory differences or Autism Spectrum Disorder (ASD) in processing sensory-rich environments. Haptic computing has become a valuable tool in this context. To the best of our knowledge, few interfaces allow for manipulating vibrotactile patterns or mimicking texture variations used in therapies. In this paper we report Cactus, a user-centered mobile haptic interface designed for research. Cactus facilitates the creation of vibrotactile patterns representing textures like smooth, bumpy, rough, sharp, and adhesive. It connects one to six MetamotionS devices with an Android phone, which can be embedded in a ring, glove, or smartphone case. A preliminary evaluation with 24 adult participants revealed distinct haptic sensations for each pattern. However, showed only 52% accuracy in texture classification. This work aims to refine the Cactus App development and advance research into an interface tailored for vibrotactile therapies in children with ASD.

Keywords:
Human-centered computing; Haptic devices; Touch screens.

1 Introduction
Children with Autism Spectrum Disorder (ASD) experience a distinctive interplay of sensory processing, either extreme sensitivity or aversion to tactile stimuli. The children can manifest hypersensitivity or hyposensitivity. These differences in sensory processing influence how individuals with ASD engage with their surroundings, impacting their comfort levels and ability to navigate sensory experiences [1]. Research on haptic technology has focused on understanding the human touch and exploring its potential to connect physical and digital sensations. For example, a vibrotactile battery reveals that adults and children exhibit comparable performance levels in task completion [2]. Other studies have focused on modifying the roughness perception [3][4]. While others have generated haptic experiences similar to real textures [5][6]. On the other hand, a haptic plant interface promotes tactile interaction with gestures such as tap, grab, and pinch to foster multisensory therapy in children with ASD [7]. However, to the best of our knowledge, few interfaces allow for manipulating vibrotactile patterns and mimicking the textures commonly used in vibrotactile therapies for children with ASD.

Given that adults and children have comparable performance levels in task completion [2], our future goal is to utilize these patterns for sensory therapy. However, due to the unique characteristics of children with autism, it was essential first to evaluate these patterns with adults. This approach allowed us to establish a baseline for comparison and determine a "ground truth" and tolerance level that further can be applied to children. This paper studies how 24 adult participants identified and tolerated different textures. This helped us find ways to improve the Cactus App, a mobile tool designed to explore how five different vibrotactile patterns (bumpy, smooth, rough, sharp, and sticky) are perceived. Our findings are a step forward in developing tactile sensory interfaces, especially for children with autism. The contributions of this paper are:

- A prototype of a mobile haptic app that eases the making of vibrotactile patterns.
- Five vibrotactile patterns that mimic surface textures.
- Results from a pilot study to improve the app and the study protocol that, in future studies, can be used in children with ASD.

2 Methods
We followed a user-centered design methodology based on the Rapid Contextual Design approach. Initially, we conducted a literature review to identify haptic interfaces for generating tactile therapy textures. This was followed by semi-structured interviews to explore the context of children with autism and their environment concerning tactile sensory therapies. This process created an affinity diagram highlighting four key areas: children with autism, sensory therapies, vibration patterns, and biomarkers.

Based on these insights, we decided to develop further the Cactus App, which allows for prototyping vibration patterns that mimic real textures used in therapy, and to explore different interaction devices. The design sessions involved experts in Human-Computer Interaction (HCI), graduate students in HCI, a psychologist, an education specialist, and four adult participants. Finally, we evaluated the Cactus App, which generates vibrotactile patterns using a ring as the interaction device.

Gonzalez C., Favela J., Tentori M.
Center for Scientific Research and Higher Education (CICESE)
Ensenada, Mexico.
Email: christian@cicese.edu.mx, favela@cicese.mx, mtentori@cicese.edu.mx

Zamudio L. M.
Center for Scientific Research and Higher Education (CICESE) – Instituto Politécnico Nacional (CITEDI).
Ensenada, Mexico.
Email: lzamudio@cicese.edu.mx

2.1 Cactus: A Mobile Haptic Interface

We designed and developed an Android application named Cactus App, capable of establishing Bluetooth communication to modify the parameters of the coin vibration motor integrated into the MetamotionS device [8], which generates vibrotactile patterns. The application offers four distinct scenarios in its main menu: "Sequence," which runs a sequence of vibration stimuli that can vary with each touch interaction; "Vibration Only," intended for applying purely vibratory stimuli; "Mixed," users can also upload a background image and an associated sound effect for the vibratory stimulus, which combines vibratory stimuli with auditory and visual signals, stimulating touch, hearing, and sight; and "MultiHaptic," designed to place a set of 6 actuators on different regions of the hand, including the 5 fingers and the palm. These scenarios (see Figure 1: Center-right) can be used in vibrotactile pattern perception and tolerance studies.

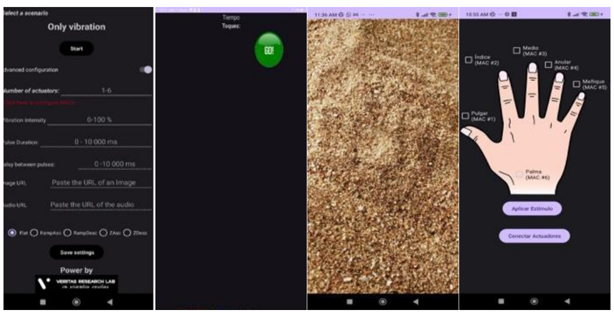

Figure. 1: Show different modes from the Cactus App; Left: Configuration mode; Center-Left: Only vibration; Center-right Mixed Mode; Right: MultiHaptic.

Besides the scenarios, users can adjust parameters such as vibration intensity (from 0 to 100%), pulse duration (from 0 to 10,000 ms), and the interval between pulses (from 0 to 10,000 ms) (see Figure 1: Left). Users can control the number of actuators and configure the associated MAC addresses to establish Bluetooth connections. It is possible to select between one and six MetamotionS devices. However, no more than three devices can be synchronized simultaneously, offering a wide range of customization options to enhance the app's versatility and functionality.

Finally, the users can select the type of pattern to generate from six options: random (patterns varying intensity over time), flat, ascending ramps, descending ramps, ascending buzzes, and descending buzzes. By combining these adjustable parameters, users can define vibrotactile patterns that mimic real textures. The application was developed using the Android Studio IDE and the Java programming language.

2.2 Interaction Devices

Using the coin vibration motor embedded in the MetamotionS Device, we conducted a design session to propose three interaction devices (a ring, a smartphone case, and a glove (see Figure 2). Each device was designed to communicate seamlessly with the Cactus App through Bluetooth, ensuring a smooth and reliable connection. By integrating the coin motor into these everyday objects, we aimed to explore diverse uses in tactile therapy for children with ASD.

Figure. 2. Shows different interaction devices (ring, smartphone case, glove) to test the sensations of the vibrotactile patterns.

The interaction devices receive the parameters of the coin motor from the Cactus App to generate a specific vibrotactile pattern, activated through user interaction such as tap or drag gestures. This interaction allows users to experience different sensations that mimic real textures.

2.3 Vibrotactile Pattern Design

A vibrotactile pattern refers to a specific arrangement of stimuli applied to the skin, typically through a tactile interface. According to Paul Strohmeier [5], a vibrotactile actuator generates textures by modifying the pulse's intensity, duration, and delay. To represent the textures of bumpy, smooth, rough, sharp, and adhesive surfaces. We conducted five design sessions after analyzing the coin motor embedded in the MetamotionS device and considering the tactile therapy texture book [9]. See Figure 3 for details.

Figure. 3. Example of a tangible texture book.

During the sessions, two Human-Computer Interaction experts and four subjects participated in defining the parameters to customize the vibrotactile pattern perceptions, mimicking the real textures, considering the following definitions of the textures: A smooth texture is when someone touches a soft uniform surface, without any roughness. In contrast, a rough sensation is when an irregular surface is touched. On the other hand, bumpiness is when it is possible to feel edge elevations while touching the surface, which creates a sensation of minor hits. Sharpness relies on how pointy you perceive the elevations. Finally, the adhesive texture can stick to other surfaces and not feel slippery. We used the following five vibrotactile pattern definitions to conduct a pilot study to evaluate the perception similarity and the tolerance between the vibrotactile patterns and the real textures. (see Table 1).

Table 1. A summary of the vibrotactile pattern parameters.

Vibrotactile Patterns	Intensity %	Duration of the pulse ms	Delay of the pulse ms
No perceptible	0-24	0-4	0-4
Bumpy	60	120	250
Smooth	25	1000	4
Rough	60	300	200
Sharp	100	40	90
Adhesive	70	10	5

Based on the design sessions, we control the vibrotactile pattern parameters for the pilot study. However, the Cactus APP can be manipulated by the users, who could be either researchers in haptic interfaces or therapists.

2.4 Pilot Study

We recruited 31 adults. Each participant signed a consentiment and answered a Sensory Profile Test [9] and the Adult Autism Spectrum Quotient – 10 items (AQ-10) [10]. These tests have been validated for screening purposes and can be used to refer adults to a specialist for further evaluation. The inclusion criteria were that the participant must obtain a score greater than five on the AQ-10 test and the Tactile Sensory profile as the majority. After analyzing the criteria, only 24 participants between 18 and 45 years old (28.63 mean, 4.93 standard deviation) continued with the pilot study. All the participants spoke Spanish.

The pilot study uses the Cactus App with the only vibration scenario and the ring interaction device to compare the participants' perception while experiencing real textures (bumpy, smooth, rough, sharp, and adhesive) versus vibrotactile patterns that represent those textures to compare the accuracy of the perceived sensation. To avoid audio confusion, the participants used headphones with white noise, and to avoid visual confusion, they were behind a curtain with an open space to introduce their arms to perceive the sensations.

During the study, participants first completed a sensitivity task. Then, they were exposed to five different haptic tasks. While randomly some participants started by exploring real textures from a texture book, others began by experiencing vibrotactile patterns. Specifically, participants explored three real textures and one vibrotactile pattern (Figure 4), followed by three vibrotactile patterns and one real texture (Figure 5) to minimize bias in the marching activity. In both cases, they were asked to match the similarity between the real textures and the vibrotactile patterns.

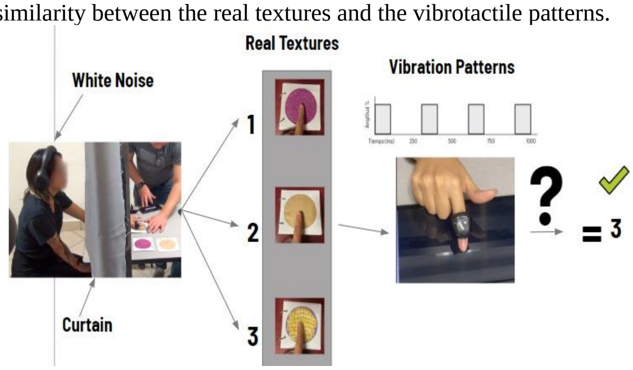

Figure. 4. Illustrates the experimental setup, exploring the first three real textures and one vibrotactile pattern.

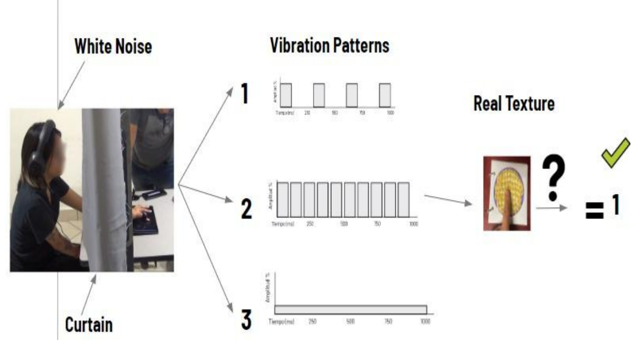

Figure. 5. Illustrates the experimental setup, exploring the first three vibrotactile patterns and one real texture.

Also, while perceiving the last sensation, the participants answered in one word the label that best describes the texture of that sensation and answered on a Likert scale of 5 points, how smooth, bumpy, rough, sharp, and adhesive they felt the last sensation and how was the tolerance of that sensation.

2.5 Results

Our results showed that the participants felt different sensations (see Figure 6) when interacting with each vibrotactile pattern and could tolerate most of them; however, the participants disagreed when classifying such patterns as a particular surface texture (see Figure 7). The preliminary results show that the Cactus App with the vibration only scenario and the interaction with the ring can provoke different haptic sensations and be used in similar studies to study perception and tolerance in distinct scenarios related to tactile sensory processing understanding.

From the pilot study results, we understood that some participants showed difficulties remembering the order of the stimuli during the tasks, which could challenge the participant to complete the activity. The labels of the textures were in Spanish (bumpy-bachoso, smooth-liso, rough-rugoso, sharp-filoso, adhesive-adhesivo); some of the labels, in particular bumpy-bachoso and sharp-filoso, the answers suggest that the translation was not accurate enough for the understanding of the participants.

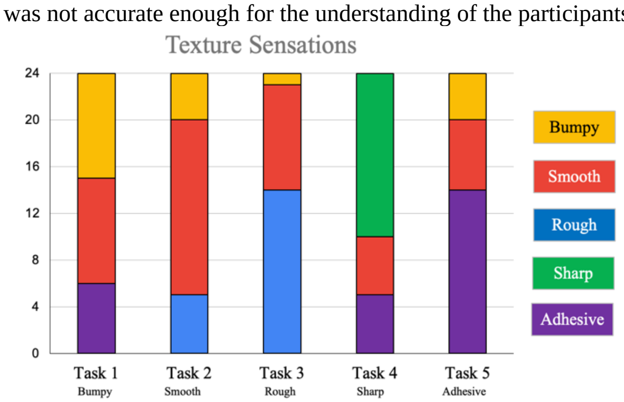

Figure. 6. Shows the responses for each haptic task.

We observed considerable confusion; the results showed 52.2% accuracy when the participants tried associating a specific vibrotactile sensation with the real texture (see Figure 7). The cognitive load of remembering the perceived sensation also contributed to these difficulties.

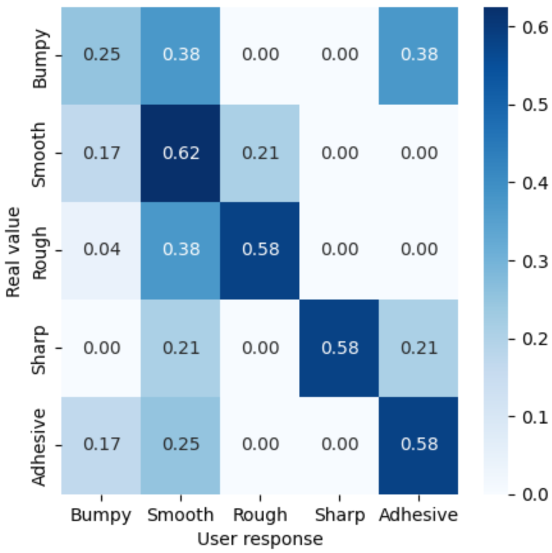

Figure. 7. Shows the confusion matrix of the participant's responses.

Using only the ring interaction device may have further diminished the sensation of the patterns. Moreover, the vibrotactile patterns were defined using only flat patterns, which could have limited the richness of the stimuli. These are aspects that could be improved in future studies.

3 Conclusion

This pilot study aimed at evaluating the design process of vibrotactile patterns, defining five patterns based on flat patterns to simulate various real textures and testing them to observe participants' tolerance and perception as they identified different textures using the Cactus App. Our observations revealed that the order in which participants experienced textures during the matching activity created cognitive load, leading to hesitation in their responses. To address this, we recommend allowing participants to re-experience the textures rather than relying solely on their memory. Additionally, we discovered issues with the translation of texture names such as "sharp" being translated as "filoso" which some participants interpreted as a cutting tool, highlighting the need for precise definitions.

We also noted that the position of the ring might diminish the sensory experience of the stimuli. Therefore, exploring alternative interaction devices like gloves, smartphone cases, thimbles, and pens could be advantageous. Further data exploration is necessary to gain insights for improving future design iterations. Finally, refining the design to include patterns beyond flat ones, such as ramps or buzzing patterns, could enhance the realism of texture simulations.

Considering that adults and children have comparable performance levels in task completion. As a formative study, this work provides valuable insights for improving the Cactus App. It advances our research towards developing interfaces tailored to the tactile sensory perception needs of children with autism spectrum disorder ASD.

4 References

[1] Naim Salkic, Zulfo Ahmetovic, Safet Velic, and Lara Krnojelac. Difficulties of the tactile sensory system Integration of children with autism. Technium Soc. Sci. J., 27:502, 2022, DOI: 10.47577/tssj.v27i1.5497

[2] Nicolaas A J Puts, Richard A E Edden, Ericka L Wodka, Stewart H Mostofsky, and Mark Tommerdahl. A vibrotactile behavioral battery for investigating somatosensory processing in children and adults. J Neurosci Methods, May 2013, DOI: 10.1016/j.jneumeth.2013.04.012.

[3] Shuhei Asano, Shogo Okamoto, Yoichiro Matsuura, Hikaru Nagano, and Yoji Yamada. Vibrotactile display approach that modifies roughness sensations of real textures. In 2012 IEEE RO-MAN: The 21st IEEE International Symposium on Robot and Human Interactive Communication, pages 1001–1006, 2012, DOI: 10.1109/ROMAN.2012.6343880

[4] Shuhei Asano, Shogo Okamoto, and Yoji Yamada. Vibrotactile stimulation to increase and decrease texture roughness. IEEE Transactions on Human-Machine Systems, 45(3):393–398, 2015. DOI: 10.1109/THMS.2014.2376519

[5] Paul Strohmeier and Kasper Hornbæk. Generating haptic textures with a vibrotactile actuator. In Proc. CHI '17, page 4994–5005, New York, NY, USA, 2017, ACM, DOI: 10.1145/3025453.3025812

[6] Yusuke Ujitoko, Yuki Ban, and Koichi Hirota. Modulating fine roughness perception of vibrotactile textured surface using pseudo-haptic effect. IEEE Transactions on Visualization and Computer Graphics, 25(5):1981–1990, 2019, DOI: 10.1109/TVCG.2019.2898820

[7] Jie Ying Gao, Leijing Zhou, Miaomiao Dong, and Fan Zhang. Expressive plant: A multisensory interactive system for sensory training of children with autism. Proc. UbiComp'18, DOI: 10.1145/3267305.3267588

[8] Metamotions device, mbientlab. 2021. Retrieved August 21, 2024 from https://mbientlab.com/metamotions

[9] Paths to Literacy, Texture Book, Retrieved August 21, 2024, from https://www.pathstoliteracy.org/texture-book/

[10] Brown, C., Tollefson, N., Dunn, W., Cromwell, R., & Filion, D. (2001). The Adult Sensory Profile: Measuring Patterns of Sensory Processing. The American Journal of Occupational Therapy, 55(1), 75–82. DOI:10.5014/AJOT.55.1.75

[11] Carrie Allison, Bonnie Auyeung, Simon Baron-Cohen, Toward Brief "Red Flags" for Autism Screening: The Short Autism Spectrum Quotient and the Short Quantitative Checklist in 1,000 Cases and 3,000 Controls, Journal of the American Academy of Child & Adolescent Psychiatry, Volume 51, Issue 2, 2012, Pages 202-212.e7, DOI: 10.1016/j.jaac.2011.11.003