Surface Haptics for Music Education: Evaluating TanvasTouch as an Interactive Learning Interface

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Abstract: Touchscreen-based music education tools typically rely on audio and visual feedback, despite the inherently sensorimotor nature of musical learning. Recent advances in surface haptics enable programmable tactile feedback on flat displays, opening new possibilities for multisensory interaction. This paper explores the use of *TanvasTouch* technology in music education, focusing on design patterns, pedagogical applications, and accessibility. We developed interactive activities using tactile textures to represent musical shapes and conducted an exploratory study with primary school students (ages 6–11). Participants engaged in guided touch tasks to recognize simple musical symbols and instrument shapes, allowing us to assess recognition, engagement, and usability. Results show that surface haptics can support exploratory learning experiences, enhancing traditional audio-visual approaches. However, blind shape recognition was largely unsuccessful, indicating that the technology cannot yet function as a standalone modality for visually impaired users. Instead, *TanvasTouch* is better suited as a complementary multisensory tool in inclusive educational settings.

1 INTRODUCTION

Music education relies on the integration of perception and action, where auditory, visual, and motor processes interact continuously. While digital technologies have expanded access to music learning tools, most touchscreen-based systems remain constrained to audiovisual feedback. This limitation is particularly evident when teaching concepts related to timing, coordination, and expressive gesture.

Surface haptic technologies such as *TanvasTouch* [1] enable localized, programmable tactile sensations to be rendered directly on a touchscreen (Basdogan et al., 2020). These systems modulate friction between the user's finger and the display surface, allowing textures and contours to be perceived without mechanical actuators.

This work aims to explore how such technologies can support music learning and foster multisensory educational experiences in primary school contexts. Based on this general goal, we designed an experiment to investigate the educational potential of surface-haptic interaction in early music learning. More specifically, the following research questions guided the study:

- RQ1. To what extent can primary school students recognize simple music-related shapes (such as basic musical notation symbols and stylized instrument images) through tactile exploration on a friction-based surface haptic display?
- RQ2. How does the design and structural complexity of tactile stimuli influence recognition performance and exploration strategies when children interact with surface-haptic representations of musical elements?
- RQ3. How do young learners perceive and engage with surface-haptic interaction in a music-education context, and what usability or pedagogical implications emerge from their experience?

In order to answer these research questions, the rest of the paper is structured as follows. Section 2 reviews related work on haptic interaction and tactile interfaces in music education and digital musical instruments. Section 3 provides a set of potential application scenarios for surface haptics in music learn-

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ing contexts, highlighting pedagogical opportunities and technological constraints. Section 4 presents the features of *TanvasTouch*, the device we used for our tests, and explains our implementation choices. Section 5 describes the experimental study conducted in a primary school using *TanvasTouch*, including participants, stimuli, and experimental protocol. Section 6 reports the quantitative and qualitative observations and preliminary findings emerging from the study. Finally, Section 7 discusses the implications of the results for music education and outlines directions for future research.

2 STATE OF THE ART

Recent advances in music education research have increasingly emphasized the importance of multisensory learning processes, particularly in early educational contexts. In order to situate the present study within the current scholarly landscape, this section reviews a selection of contributions published between 2019 and 2026, with a specific focus on digital technologies, multimodal interaction, and haptic feedback in music learning environments.

Music learning is acknowledged as an inherently multisensory and embodied process, involving the continuous interaction between auditory perception, visual representation, and motor activity. Recent studies highlight how digital technologies can enhance such processes by enabling interactive and sensorimotor forms of engagement. For instance, Lee and Liu show that the integration of sensor-based digital systems in early childhood music education can foster the development of motor coordination, sensory integration, and creative behaviors, particularly when learners engage with interactive environments that extend beyond purely screen-based interaction (Lee and Liu, 2025). These findings reinforce the pedagogical value of multimodal approaches in supporting the acquisition of foundational musical skills.

Nevertheless, despite the proliferation of digital tools in music education, recent literature points to a persistent dominance of audiovisual interaction paradigms. A comprehensive scoping review by Behzadaval et al., analyzing 63 studies on digital music learning tools, reveals that most systems rely primarily on visual feedback and individual performance-oriented tasks, while dimensions such as embodied interaction, creativity, and collaborative learning remain comparatively underdeveloped (Behzadaval et al., 2026). This imbalance suggests that current technological solutions only partially address the multisensory nature of musical cognition.

Within this context, haptic technologies have emerged as a promising avenue for extending musical interaction beyond vision and hearing. A substantial body of recent work has focused on vibrotactile feedback as a means of conveying musical information through touch. Lu et al. explore the use of vibrotactile wearable devices for blind and low-vision learners, showing that tactile feedback can support music reading, technical guidance, and practice through structured vibration patterns (Lu et al., 2023).

In parallel, research in accessible and inclusive music technologies has further highlighted the relevance of haptic interaction. Frid et al. emphasize the importance of multimodal feedback in the design of accessible digital musical instruments, demonstrating how diverse tactile interaction strategies can support participation in music-making for users with complex needs (Frid et al., 2022). Likewise, May et al. show that haptic interaction can function not only as an assistive modality but also as an autonomous expressive medium, particularly in the context of Deaf and Hard-of-Hearing users (May et al., 2024). These findings point toward a broader reconceptualization of touch as an integral component of musical experience rather than a supplementary channel.

Beyond accessibility, haptic feedback has also been investigated in relation to motor learning and performance training. The “Haptic Tutor” system proposed by Tom et al. demonstrates that vibrotactile cues can improve temporal accuracy and coordination in drumming tasks, particularly for novice learners, by reinforcing sensorimotor synchronization processes (Tom et al., 2020). Such results support the role of haptics in facilitating the acquisition of motor skills through embodied interaction.

More broadly, the integration of multisensory and interactive technologies (including augmented reality, tangible interfaces, and hybrid physical-digital systems) has been shown to enhance engagement and learning outcomes in music education. For instance, Ho et al. report high levels of user engagement and learning effectiveness in a multisensory system combining augmented reality, auditory content, and tactile interaction for children (Ho et al., 2023). Similarly, tangible and game-based interfaces have been demonstrated to support the acquisition of musical knowledge through embodied and exploratory interaction paradigms (Baratè et al., 2013; Baratè and Ludovico, 2024; Micheloni et al., 2019).

Despite these advances, several critical gaps remain in the current state of the art. First, the majority of existing studies focus on vibrotactile feedback, while friction-based surface haptics, such as those employed in the present work, have received comparatively limited attention. Second, prior research has predominantly targeted adult users, expert performers, or accessibility contexts, with relatively few investigations addressing primary school learners in mainstream educational environments. Third, most contributions emphasize performance-related outcomes, such as timing accuracy or motor coordination, whereas the role of haptic interaction in early music literacy, particularly in relation to the perception and recognition of symbolic representations, remains insufficiently explored.

Furthermore, while performance metrics are commonly used to evaluate haptic systems, less attention has been devoted to experiential and perceptual dimensions such as usability, confidence, engagement, and exploratory behavior. These aspects are particularly relevant in early educational settings, where affective and motivational factors play a crucial role in the learning process.

Recent analyses of haptic technologies in music learning contexts highlight both the growing interest in the field and its current fragmentation, underscoring the need for more systematic and pedagogically grounded investigations.

3 APPLICATION SCENARIOS

In this section, we outline a range of music education scenarios enabled by surface haptics. Most of them can be supported by devices with capabilities similar to *TanvasTouch*, while others require alternative technological approaches. This survey guided our formulation of research questions and the design of the experiment described in Section 5.

One of the most immediate applications of programmable tactile feedback concerns the design of guided touchscreen instruments. Many digital musical interfaces, e.g., those involving tablets and smartphones, adopt flat glass surfaces that lack the physical affordances traditionally provided by mechanical keyboards, strings, or buttons. This absence of tactile landmarks can hinder motor learning, particularly for beginners who rely on proprioceptive cues to develop spatial accuracy. Tactile technologies such as *TanvasTouch* can partially restore these cues by dynamically rendering localized friction patterns that correspond to musical structures. For instance, virtual keyboard instruments may present tactile boundaries between keys, allowing users to perceive their limits through touch. Similarly, continuous controllers (e.g., pitch ribbons, modulation strips, virtual faders, etc.) can incorporate regions with different tactile characteristics that correspond to musically meaningful zones (e.g., pitch classes, scale degrees, or control thresholds). From a pedagogical perspective, these tactile cues may support motor learning and spatial orientation, enabling performers to develop muscle memory even on glass surfaces. Over time, learners could internalize the spatial layout of the instrument while gradually relying less on visual guidance, thus approaching the embodied interaction typical of physical instruments.

Another promising scenario concerns the use of tactile feedback to support rhythm perception and timing practice. Traditional rhythm training is frequently based on auditory metronomes or click tracks. While effective, these auditory cues may interfere with listening tasks or mask subtle aspects of the musical material being practiced. Programmable tactile feedback offers an alternative by delivering localized haptic pulses synchronized with a temporal grid. In this configuration, the touchscreen itself becomes a silent metronome: pulses can mark beats, subdivisions, or other temporal landmarks without introducing additional sounds into the acoustic environment. This approach can be particularly useful when practicing in ensemble contexts or when working on passages that require careful auditory attention. Unfortunately, *TanvasTouch*'s technology is not intended to actively produce vibrations; consequently, this kind of experience cannot be reproduced with such a device.

However, in the context of rhythm encoding, beat marking is not the only possible application. Tactile patterns could also encode metrical hierarchies. For instance, stronger friction peaks might correspond to downbeats, while lighter pulses represent subdivisions. Such differentiation may help learners internalize the structure of rhythmic cycles and improve their temporal precision. Moreover, tactile timing cues can be experienced through direct contact with the performing surface, potentially reinforcing sensorimotor coupling between gesture and rhythm. Two examples are shown in Fig. 1: a sort of tactile metronome can be experienced in the upper and lower areas of the image, whereas the central part provides a rhythmic pattern to discover. Unlike the mentioned rhythm perception and timing practice activity, this scenario can be experienced on *TanvasTouch*.

Tactile rendering also opens interesting possibilities in the domain of music notation and literacy, particularly in educational contexts. Digital scores displayed on touchscreens typically rely on visual interaction alone, which may pose challenges for young learners or users with serious visual impairments. By aligning tactile patterns with elements of the notation displayed on screen, it becomes possible to create multisensory overlays that complement visual read-

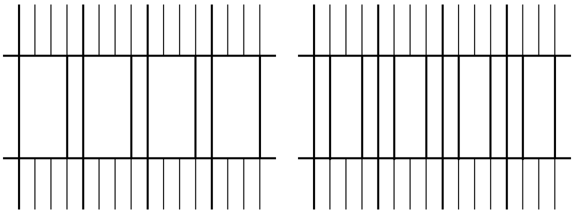

Figure 1: Examples of rhythmic patterns: ♩. ♪ (left) and ♪ ♩ ♪ (right). The images are rendered by *TanvasTouch* in terms of haptic feedback.

ing. For instance, tactile ridges or friction zones could correspond to staff lines, measure boundaries, or note positions. When users slide their fingers along the score, they might perceive the spatial organization of pitch and rhythm through touch, reinforcing their understanding of the notation. In early music education, such tactile scaffolding could help learners associate symbolic representations with physical interaction, bridging the gap between abstract notation and concrete musical gestures. In addition, tactile guidance may facilitate score navigation, enabling users to track musical structures such as measures or phrases without relying exclusively on visual attention. This capability could also support accessibility oriented applications aimed at inclusive music education.

A further application area concerns the use of tactile feedback as a channel for expressive information during musical practice. Musical expression often involves subtle variations in parameters such as dynamics, articulation, vibrato, and timing. These aspects are typically communicated through auditory feedback, but additional sensory channels may enrich the learning process. Through programmable friction modulation, a touchscreen interface could convey real-time haptic cues related to expressive performance parameters. For example, vibrato might be represented through oscillating tactile patterns that mirror pitch modulation, while dynamic shaping could correspond to gradual changes in friction intensity. Similarly, different tactile textures could signal articulation styles, such as legato versus staccato. Such feedback mechanisms may serve both didactic and assistive purposes. During practice, learners could receive immediate tactile indications of how closely their performance aligns with a target expressive profile. Alternatively, tactile feedback might guide performers toward desired expressive gestures by providing continuous sensory reinforcement. This multimodal feedback loop could strengthen the connection between motor action, expressive intention, and perceptual outcome.

While friction-based tactile displays such as *TanvasTouch* open several potential applications in music interaction and education, two constraints significantly shape the design space considered in this work. First, the technology provides passive friction modulation rather than active vibrotactile stimulation, meaning that tactile information is perceived primarily through finger-based exploration of the surface. Second, in this context, our target audience consists of primary school children without prior formal musical training, which suggests focusing on intuitive and easily recognizable representations rather than complex musical structures. Taken together, these considerations motivated us to concentrate on a specific application domain, namely the development of early music literacy through the tactile exploration of simple musical symbols and instrument shapes, as better explained in the following.

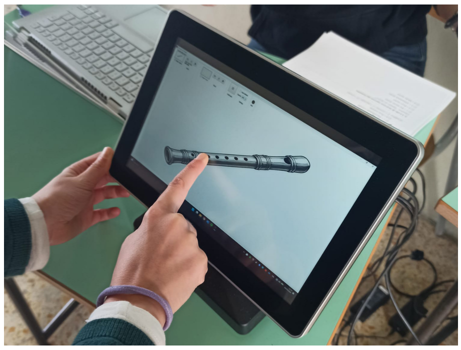

Figure 2: The *TanvasTouch* haptic interface.

4 THE DEVICE

TanvasTouch is a programmable surface haptic technology that enables users to perceive tactile textures and physical interaction effects on otherwise smooth touch-sensitive surfaces. The device functions as a standard external touchscreen display connected to a computer, capable of showing graphical content like any conventional monitor through screen duplication or screen extension. At the same time, it can render tactile feedback on the display surface, allowing users to perceive textures and interaction cues directly through their fingers while exploring the screen. Such tactile feedback is potentially independent of the image displayed. The device is shown in Figure 2.

Unlike conventional haptic feedback systems based on vibrotactile actuators (e.g., the vibration used in smartphones), *TanvasTouch* renders tactile sensations directly on the surface by dynamically modulating friction between the user's finger and the touchscreen. This allows the system to simulate edges, switches, bumps, and textures ranging from smooth to rough while the user moves their finger across the display.

From a technical perspective, *TanvasTouch* combines multi-touch sensing with friction-based haptic rendering on the same interactive surface. Finger position is detected through an integrated 10-point multi-touch sensor similar to those used in capacitive touchscreens. At the same time, the system modifies the friction locally using a phenomenon known as *electroadhesion*. By applying controlled electric fields to the surface, the device increases or decreases the attractive forces between the finger and the screen, producing perceivable variations in friction as the finger slides across it. Because the effect relies on electrostatic forces rather than mechanical actuation, the device has no moving parts and can generate spatially localized tactile effects across the display.

The *TanvasTouch* development kit is typically used as an external touch-enabled display connected to a standard computer. The device receives the video signal through an HDMI connection, while touch sensing and haptic rendering are managed via a USB data connection. An additional power connection supplies the device electronics. Once connected, the display behaves like a conventional touchscreen from the operating system's perspective, allowing the user to interact with applications through direct touch input. Haptic effects are generated through dedicated software components, including the *TanvasTouch Engine*, which communicates with applications through an API and renders programmable textures on the screen in real time.

The characteristics of *TanvasTouch* make it particularly suitable for experimental interaction studies involving children. First, the interaction modality is direct and intuitive, relying on simple finger gestures such as tapping or swiping rather than complex devices or controllers. Second, the ability to render tactile cues on the surface supports multimodal interaction by combining visual and tactile feedback, which can facilitate exploration and learning. Finally, the absence of moving mechanical parts and the use of a flat touchscreen interface result in a robust and safe device that can be comfortably used in educational or laboratory settings involving young participants. These properties are expected to make *TanvasTouch* an effective platform for studying tactile perception, exploratory interaction, and multisensory learning in child-centered experimental scenarios.

5 THE EXPERIMENT

Within primary music education, the introduction of musical notation and instrument recognition often relies heavily on visual representations that may initially appear abstract to young learners. Friction-based tactile feedback technologies such as *Tanvas-Touch* offer an opportunity to complement visual materials by enabling active tactile exploration of simplified musical symbols and instrument shapes directly on a touchscreen surface.

In this scenario, children interact with graphical elements displayed on the screen by moving their fingers across the surface, while localized friction patterns render the contours and internal regions of selected images perceptible through touch. Because the technology does not generate active vibrations but instead modulates friction under the exploring finger, the interaction naturally encourages exploratory scanning gestures, similar to the way children trace shapes with their fingers while learning letters or drawings.

This multisensory interaction may support early stages of music literacy development, helping learners associate graphical representations with musical concepts through a combination of visual and tactile cues. For instance, tracing the shape of a note symbol could reinforce the recognition of its graphical structure, while exploring the outline of an instrument may facilitate discussions about its sound and role in music. By integrating tactile exploration into familiar touchscreen interactions, the approach seeks to make introductory musical concepts more engaging, discoverable, and accessible for young learners.

5.1 Participants

The experiment involved all classes of the primary school, from the first to the fifth grade. Participants were between 6 and 11 years old and had no prior experience with surface haptic technologies. The distribution of students enrolled in the experiment was as follows:

- Grade 1 – 18 students (11 males, 7 females);
- Grade 2 – 14 students (5 males, 9 females);
- Grade 3 – 16 students (6 males, 10 females);
- Grade 4 – 18 students (12 males, 6 females);
- Grade 5 – 17 students (9 males, 8 females).

The sample showed near-equal gender representation, with a slight male predominance: 43 males (51.8%), 40 females (48.2%). Participants were predominantly right-handed ($n = 74$, 89.2%), with 8 left-handed students (9.6%) and 1 ambidextrous individual (1.2%).

The sample also included several students with specific educational needs, including pupils with certified disabilities, specific learning disorders, and other special educational needs.

Written informed consent was obtained from the parents or legal guardians of all students participating in the study, along with an information sheet explaining the purpose of the research. No sensitive data were collected or disclosed.

5.2 Stimuli

The stimuli prepared for the experiments belong to two categories: musical instruments and music notation. In both cases, considering the target, we focused on simple shapes, distinguishable from one another, rather than complex musical instruments and advanced notation. In each recognition instance, *TanvasTouch* displayed only one stimulus at a time.

Musical instruments included: guitar, maracas, tambourine with jingles, triangle, saxophone, recorder, and xylophone. Musical notation symbols included: whole note, quarter note, eighth note, half rest, quarter rest, and eighth rest.

The images used on the tablet were developed through an iterative design process. Initially, simple two-dimensional stylized drawings were created. However, these images produced limited tactile feedback. Subsequently, three-dimensional versions with shading and surface variations were developed. The final versions used in the experiment consisted of grayscale three-dimensional illustrations with differentiated textures. In the case of musical notes, a very dense internal texture resembling fabric proved particularly effective for tactile perception.

5.3 Experimental Protocol

The experiment was conducted in several class sessions, one for each participating class. During each session, children completed the experiment individually. Each individual session consisted of two phases: a familiarization phase, collectively conducted with the class, during which the procedure was explained and children performed preliminary activities without the device, and an experimental phase, in which they interacted with the haptic interface. In fact, our goal was to make students gradually approach the sensory aspects of the experience before interacting with the technological device. In the experimental phase, participants completed two trials. In each trial, a shape had to be recognized through *TanvasTouch*. The two trials were separated by a short inter-trial interval. Now, we will provide further details on each of the mentioned steps.

Each class participated in a two-hour session, whose duration was accurately planned to allow both shared and individual activities. Each participant was granted a time to interact individually with *TanvasTouch*. Due to the cost of the haptic interface and the unavailability of other devices, individual trials had to be conducted in sequence. Specifically, class sessions were organized into two main phases: 1. A *familiarization phase*, characterized by preparatory multisensory activities; 2. An *experimental phase*, using the haptic interface.

The *familiarization phase* lasting approximately 30 minutes, was designed to raise students' awareness of the different sensory channels involved in the perception of objects and sounds. The activities progressively involved vision, imagination, hearing, and language. The first activity focused on visual perception. Students took part in visual memory games and "odd-one-out" tasks in which they had to identify the element that did not belong to a group of similar objects. This activity aimed to stimulate the skills of observation and visual discrimination. The second activity involved auditory perception. The students listened to the sounds of different musical instruments and were asked to recognize the instrument only on the basis of its timbre. After listening activity, they were asked to associate each sound with the corresponding visual representation of the instrument. A third activity involved tactile and representational skills. Each student received an A4 sheet divided into two halves and was asked to draw one of the musical instruments previously heard during the listening activity. The drawing was first performed with eyes closed on the left half of the sheet, encouraging students to rely on their mental representation of the instrument. The same drawing was then repeated with eyes open on the right half of the sheet. (see Figure 3a). Finally, a language-based activity was proposed. Students worked in pairs and described a musical instrument verbally while their partner attempted to guess which instrument was being described. This activity aimed to stimulate verbal description and conceptual representation of musical objects. This preparatory phase aimed to introduce the concept of multisensory perception, preparing students for the subsequent haptic exploration experience.

The *experimental phase* focused on individual trials with *TanvasTouch*. Before using the device, students were given ten minutes to wash and dry their hands carefully to avoid fingerprints or moisture that might affect tactile perception on the screen. In addition, the surface of the *TanvasTouch* display was cleaned before each individual interaction in order to ensure consistent performance of the device for all participants.

Following the familiarization phase, a brief technology introduction lasting approximately five min-

(a) Student draws with eyes closed. (b) Shapes on the whiteboard. (c) *TanvasTouch* in use.

Figure 3: Experimental setup and interaction phases.

utes was conducted. During this moment, the researcher explained the functioning of the *TanvasTouch* device and introduced the concept of a haptic tablet capable of producing tactile sensations through friction modulation on the touchscreen surface.

The second phase was structured in two trials separated by a short inter-trial interval and lasted one hour. Each child interacted with the tablet individually, exploring one stimulus at a time using a single finger, typically the index finger of the dominant hand. When children slide their fingers across the image, friction variations highlight relevant contours and boundaries, allowing them to perceive a shape while simultaneously observing it on the screen.

The order of the trials was the same for all classes: first the instrument exploration task and then the music notation task. This progression was designed to begin with more concrete and visually familiar shapes (musical instruments) before introducing more abstract symbolic representations (musical notation).

During the trials, the visual content on the *TanvasTouch* display was intentionally hidden. The screen was configured to appear completely gray, so that students could not see the shapes they were exploring. This design choice ensured that the task relied primarily on tactile exploration rather than visual recognition.

To support the activity while maintaining the tactile focus of the task, the visual representations of the stimuli were projected onto the interactive whiteboard (see Figure 3b). Coherently with the trial sequence, during the first trial, images of the musical instruments were projected, allowing students to become familiar with their visual appearance; during the second trial, the whiteboard showed images of musical notation symbols.

Students therefore explored the tactile shapes on the tablet while simultaneously referring to the projected images (see Figure 3c), encouraging the integration of tactile and visual information during the learning process. To ensure uniformity across participants, each child was given no more than 30 seconds per trial. At the end of each exploration, students were asked to immediately report the type of image they believed they had perceived, or to indicate whether they had not perceived any recognizable shape. Overall, each individual interaction with the device lasted approximately 2 to 3 minutes per student.

Data were collected through an observer protocol that recorded exploration strategies, recognition time, and response accuracy. In addition, students completed a short self-assessment questionnaire about their interaction experience.

6 RESULTS

6.1 Quantitative Analysis

The quantitative results of the haptic recognition task are summarized in Fig. 4, which reports the outcomes for two consecutive trials. Each trial was characterized by one out of four possible outcomes:

1. Correct, meaning that the shape was identified;
2. Partially correct, implying that the recognition tasks was not successful, but the chosen shape was somehow close to the right one. In particular, this happened with some musical instruments presenting a similar aspect;
3. Incorrect, indicating a wrong result;
4. Time expired, i.e. the participant was unable to give an answer at the end of the 30 s slot.

In the first trial, the number of correct responses was significantly low ($n = 15$) with respect to wrong ones ($n = 63$); a limited number of partially correct responses was also observed ($n = 2$). These results suggest that, in their first trial, participants were generally unable to grasp the aspects of the haptic stimuli.

In the second trial, performance improved substantially. The number of correct responses increased

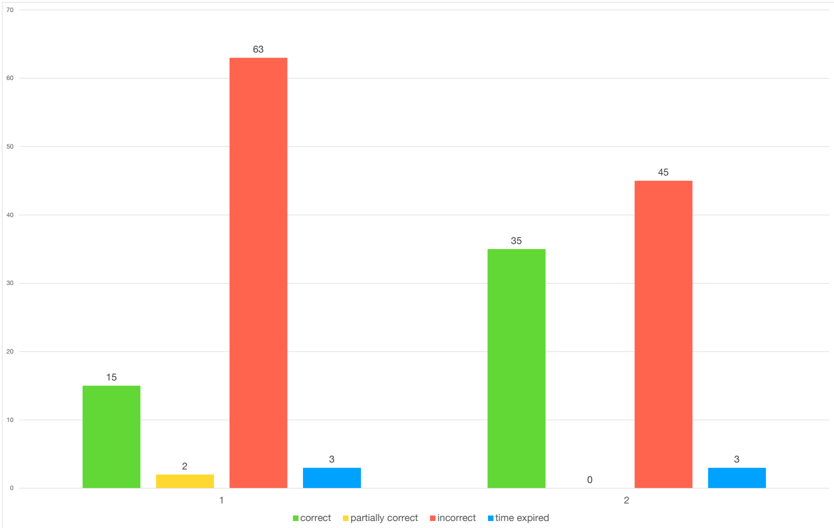

Figure 4: Test results by trial. The first trial is reported on the left, the second trial on the right.

markedly ($n = 35$), and the number of incorrect answers decreased accordingly ($n = 45$). We identified two possible reasons: on one side, this indicates a clear learning effect, with participants benefiting from prior exposure to the stimuli; on the other side, the distinctive features of the second stimulus, focusing on musical notation instead of musical instruments, could also have helped. In fact, the note and rest symbols chosen for the experiment were clearly distinguishable, with fewer possibilities to be misinterpreted. The absence of partially correct responses in the second trial seems to confirm this observation.

In both trials, three timeouts were recorded, all attributable to the same participants, who presented Special Educational Needs associated with cognitive impairments.

Overall, the quantitative data highlight two main aspects: (i) a strong learning effect between consecutive trials, and (ii) a moderate level of recognition accuracy, indicating that haptic feedback alone may not be sufficient to support fully reliable identification.

To investigate whether haptic recognition abilities improve with age, results from the extreme ends of the considered age range were compared, namely first-grade and fifth-grade participants. For this purpose, the outcomes of the two trials were aggregated. In the first grade, performance was markedly low. Only 3 correct responses were recorded overall (8.3%), while the majority of responses were incorrect (29, 80.6%). Additionally, 4 timeouts were observed (11.1%). These data indicate substantial difficulty in completing the recognition task at this educational level. In contrast, fifth-grade participants exhibited a considerably higher level of performance. The number of correct responses increased to 20 (58.8%), while incorrect responses decreased to 14 (41.2%). No timeouts were recorded in this group.

To statistically assess the association between school grade (first vs. fifth) and task performance, a χ-square test of independence was conducted on the aggregated outcomes (correct, incorrect, time expired). The analysis revealed a statistically significant association between grade level and performance, $\chi^2(2, N = 70) = 21.75$, $p < 0.001$. The effect size, measured using Cramér's V, was $V = 0.56$, indicating a large association according to conventional benchmarks.

In general terms, recognition performance varied across grade levels. All students in the fifth grade were able to correctly recognize the tactile representation of the musical note or rest presented during the task. In the fourth grade, approximately half of the students successfully identified the symbol. In the third grade, several students were able to recognize the notation symbols, although the recognition rate was lower than in the older classes. For the first and second grades, the task proved more difficult. This result is consistent with the students' musical background, as these younger children had not yet formally studied or practiced writing this type of musical notation in their curriculum. These findings quantitatively support the observation that haptic recognition abilities improve with age. Nevertheless, the proportion of incorrect responses in the fifth grade remains non-negligible, suggesting that the task retains a certain degree of difficulty even for more advanced age groups.

6.2 Qualitative Analysis

An expert conducted a classroom observation during the experimental sessions, qualitatively assessing participants' interaction with the device. In particular, the observer subjectively rated the level of confidence shown by each participant when using the system on a four-point scale: 1 = Not confident (0 participants); 2 = Slightly confident (4 participants); 3 = Fairly confident (28 participants); 4 = Very confident (51 participants).

Students showed high levels of curiosity and engagement while interacting with the device. Many children spontaneously adopted different exploration strategies, such as tracing image contours or searching for distinctive tactile details. The distribution of confidence levels indicates a generally positive user experience with the device. No participants was considered not confident, while the majority of participants scored medium to high confidence. Overall, these results suggest that the interaction with the system was perceived as accessible and intuitive by most users. The predominance of high confidence levels is particularly noteworthy given the relatively challenging nature of the haptic recognition task observed in the quantitative results. This apparent discrepancy may indicate that, although recognition accuracy was not optimal, participants felt comfortable exploring and interacting with the device. From an interpretative perspective, confidence appears to be more closely related to usability and engagement than to task performance. This supports the idea that surface haptics can provide a positive and motivating user experience, even when used in tasks that remain cognitively demanding.

Additionally, the observer annotated the predominant haptic exploration strategies adopted by the participants, using the following categories: Global Exploration, Analytical Exploration, Sequential Exploration, Repetitive Movements, and Other/None. In Fig. 5, results have been weighted when more than one behavior was observed for the same participant. Students in the third, fourth, and fifth grades tended to adopt more structured exploration strategies, often following the contours of the shapes or systematically scanning different parts of the image. In contrast, students in the first and second grades generally interacted with the screen in a more exploratory and less organized manner, moving their fingers more freely across the surface.

An interesting difference emerged between the tactile perception of musical instrument images and musical notation symbols. In general, students reported that the tactile representations of notes and

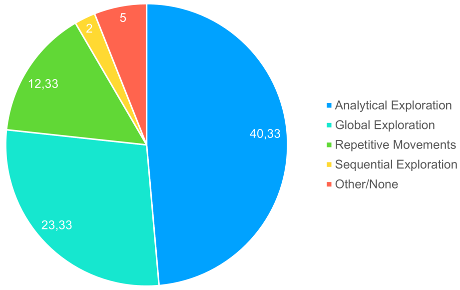

Figure 5: Haptic exploration strategies adopted by the participants.

rests were easier to perceive than the images of musical instruments. This result is likely related to the design of the stimuli, since the musical notation symbols included a denser internal texture that produced stronger friction variations and therefore clearer tactile feedback.

Despite these differences in recognition performance and exploration strategies, all students reported a clearer tactile perception when interacting with the musical notation symbols compared to the instrument images. The activity was generally perceived as enjoyable and stimulating, suggesting that surface haptics may enrich traditional audiovisual approaches to music learning and support exploratory, multisensory experiences in early music education.

7 CONCLUSIONS

This study aimed to investigate the potential of friction-based surface haptics as a support for early music education, focusing on tactile recognition, stimulus design, and user experience. The findings of the experiments conducted with *TanvasTouch* allow us to provide partial answers to the research questions introduced in Section 1.

With respect to RQ1, the results indicate that primary school students are generally not able to reliably recognize music-related shapes through tactile exploration alone. Recognition performance remained moderate overall and was particularly limited in younger participants. Although some improvement was observed after initial exposure, tactile-only identification of shapes cannot be considered robust in the current technological and experimental conditions.

Regarding RQ2, the design and structural properties of tactile stimuli emerged as a critical factor influencing recognition performance. Simple, well-defined symbolic representations with clear and consistent textures proved more effective than complex or highly detailed shapes. This suggests that tactile interfaces for music education should prioritize perceptual clarity and structural simplicity over visual realism, adopting design strategies specifically tailored to haptic perception rather than visual fidelity. This finding is consistent with established practices in accessible museum design, where visual artworks (e.g., paintings or photographs) are translated into tactile representations by emphasizing salient contours and reducing visual complexity. For instance, institutions such as the *Museo Nazionale del Cinema* in Turin adopt simplified tactile renderings that highlight essential structural features, enabling visitors to explore visual content through touch (Girotto and Pisu, 2015). In such contexts, tactile perception is understood as a sequential and time-dependent process, requiring active exploration and gradual construction of a mental representation. Similarly, our results suggest that effective haptic stimulus design should account for the exploratory nature of touch, privileging clarity, hierarchy, and discriminability of tactile features over detailed visual correspondence.

Concerning RQ3, the study highlights a positive user experience associated with surface-haptic interaction. Despite the limited recognition accuracy, participants showed high levels of engagement, curiosity, and confidence while interacting with the system. This indicates that usability and motivational aspects are not necessarily correlated with task performance, and that surface haptics can provide accessible and enjoyable interaction models in educational contexts.

Taken together, these findings suggest that surface haptics should be considered as a complementary modality within a multisensory learning framework, rather than as a standalone channel for information transmission. In particular, the integration of tactile and visual feedback appears essential to support learning processes in early music education.

From a pedagogical perspective, friction-based haptic interfaces such as *TanvasTouch* show potential in fostering exploratory interaction and reinforcing the association between physical gestures and abstract musical representations. However, their effectiveness depends on careful stimulus design and on their integration within multimodal learning activities.

Future work will focus on refining tactile stimulus design, exploring longer-term learning effects, and investigating how different combinations of sensory modalities can enhance the acquisition of musical concepts across diverse learner profiles. In addition, we acknowledge that some of the observed results may be influenced by the specific characteristics of the *TanvasTouch* device; therefore, further studies will involve comparative experiments with alternative surface-haptic technologies to assess the generalizability of the findings.

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