

# Haptic Technology in Digital Music Learning Context: A State-of-the-Art Analysis

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**Abstract:** Digital media have become increasingly established in learning contexts in recent decades, and it seems impossible to imagine education without them, especially in recent years. Various technological advances can be observed, such as developments in virtual reality and augmented reality. To give learners a realistic impression of the virtual world, as many sensory impressions as possible should be addressed. However, current developments have mainly addressed the visual and auditory modalities, which make up two of the five human senses. Research and developments for the use of the other senses are being made but at this stage they are not yet ready for mass use. Especially the sense of touch based on skin as the largest human sensory organ or tactile and haptic perception seem to be of interest. Particularly in manual or medical areas where motor skills are required, haptic technologies are declared to be supportive and beneficial. One area that has hardly focused on digital learning so far is the music sector. Learning a musical instrument in this context seems to be an interesting field of research, as it not only promotes motor skills, but also cognitive development in both children and adults. To give an update on the technical developments in the field of digital teaching and learning in music, and especially to highlight the use of haptic technologies, we will briefly review the state of the art in this paper. It begins with a brief overview of the basics of digital learning and haptics, as well as previous work in this field. Using the method of a scoping review, the topic of haptic technologies in the field of music education will be researched, analysed, and summarised according to defined criteria to give a condensed overview of it. The selected database and appropriate search strings will be used to achieve the aim of the paper. The results help to shed light on current research gaps and give indications for future developments of haptic technology in the music learning context.

**Keywords:** haptic, technology, digital learning, music, scoping review

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## 1. Introduction

An increase in the use of digital media like web-based trainings, collaborative platforms, mobile applications and learning videos can be observed in various educational settings, be it in schools, vocational training, or further education. Current studies investigate how digital media can influence and enhance learning (Tamim et al., 2011). Moreover, there has been progress in the development of technologies used in the learning context. Particularly noteworthy are emerging technologies such as virtual reality (VR), augmented reality (AR), or mixed reality (MR), which can be summarised by the term extended reality (XR). VR is used, for example, in medical training (Ruthenbeck & Reynolds, 2015) or in automotive mechatronics training (Kamińska et al., 2021).

Particularly regarding these examples, which involve learning motor skills such as certain motion sequences, pressure or palpation, not only visual and auditory perception is important, but also tactile and haptic perception. In the virtual world, mainly the two senses vision and audition have been focused on so far. To give learners an impression of XR that is as realistic as possible and thus enable a sustainable transfer of learning, addressing as many senses as possible is seen as beneficial (Dörner et al., 2019). There are initial approaches in research and development to address additional senses such as the sense of smell or taste (e.g., Cheok et al., 2018), but these are not yet mature enough to be disseminated.

A further promising area for incorporating tactile and haptic perception with the aim of learning motor skills and support learning with technologies is music. For learning in the field of music, research results from the perspective of music education and music psychology are of particular interest. Previous research on motor skills or haptics has focused on how impaired people can be supported either in music lessons, playing instruments or through music. Exemplary impairment contexts are Braille (Park, 2015), hearing aid implants (Fletcher, 2021) or rehabilitation measures (Cheng et al., 2016).

However, previous studies seem to have investigated less the use of digital media and technologies in the context of music learning. For this reason, the aim of this paper is to provide an overview of the current state of technological developments in the field of digital haptic teaching and learning in music and to identify existing research gaps. To achieve this goal, haptics and its role in technologically induced learning will first be explained before the previous work and the used method of a scoping review will be presented. Finally, a presentation of the results and a summary of the paper with an outlook and limitations. The contribution of this paper consists in answering the following two research questions:

- What haptic technologies are currently used in the context of music learning?
- What are advantages and challenges of using haptic technologies in the context of music?

## **2. Definition of 'Haptic'**

The word 'Haptic' refers to the sense of touch. Everyone is familiar with the sense of touch in real life, but what haptic technology offers is an interaction between users and a device via touching and manipulating objects, that are often presented virtually. By simulating or enriching what humans feel in real life when touching objects, haptic technology allows for a tactile experience while interacting with a digital system. Haptic technology enables various kinds of interactions with computer-generated objects and information.

Distinct levels of interaction can be integrated in systems using haptic technology (Dörr et al., 2022). Some systems work with high level of interaction which means user and system interact mutually, while in some other systems equipped with haptic technology, only middle or low level of interaction between the system and a user is needed, meaning that there is less feedback and manipulation from user and/or system side. Another characteristic of haptic devices is the way that a user is supposed to interact with them, i.e., the type of feedback provided by a specific device. To create a believable illusion of touch via technology, several types of haptic feedback can be implemented in haptic devices. This is because the receptors on the skin of the human body are sensitive to diverse types of haptic cues such as pressure, vibration, temperature, etc. (Sallnäs et al., 2000). Tactile feedback and force feedback are two types of haptic feedback which can often be found implemented in a haptic device. As Burdea (1999) describes, tactile feedback intends to simulate some characteristics such as smoothness, surface contact geometry, and temperature of objects, while force feedback aims at reproducing other attributes such as hardness and weight of the objects. Campos et al. (2011) who studied the effect of haptic feedback in a game-based context explained that when there is an obvious link between the context that users experience and the haptic feedback that they receive, immersion is improved. To keep the immersion at a high level, these haptic feedbacks should be consistent.

Haptic feedback can be provided by a device as the only kind of the feedback, or it can be accompanied by other types of feedback such as visual or auditory feedback. To implement haptic feedback in a system, various kinds of visual environments such as AR, VR, or a display screen can be used. Although, it is not obligatory to provide a visual environment whenever it comes to haptic feedback (Norouzinia et al., 2022).

Taking motor learning process as an example, haptic interactions play a significant role for different age groups and particularly for newborns and kids (Rochat & Senders, 1991). Findings revealed that giving the students the opportunity to explore objects by touching may help them to better conceptualize them and when it comes to objects which are not available in daily life, such as orbits, haptic technology can be helpful by providing learners a haptic experience in a virtual environment. Using haptic technology, learners get the chance to be actively involved in learning and this can make the learning processes more advantageous (Barfield, 2010).

## **3. Previous work on technology-enhanced music learning**

Numerous studies have explored the impact of using technology in learning. Although the use of technology can lead to positive effects on learning outcomes and motivation (Lin & Chen, 2017), Remillard et al. (2021) found out that it is important to first understand teachers' goals, needs, and their current methods before expecting them to use digital instructional resources. This is because their findings reveal that teachers are much more likely to use digital instructional resources when these are in line with their goals.

Considering the field of digital music learning, Camlin and Lisboa (2021) explain that digital learning and online learning is not something new. However, the need to use technology in music learning was increased by the pandemic.

Waddell and Williamon (2019) conducted a study regarding the use of technology in music learning to investigate to what extent music learners can use different technologies and how likely they are to use technology. The study investigated not only learners’ behaviour in a music classroom, but also situations in which they want to practice music on their own. Results revealed that musicians prefer smartphones, laptops, and desktop computers more than audio and video recording devices, and playback equipment. Moreover, new technology is considered to have the potential to enhance music learning “through advanced and interactive systems”.

In addition to these various devices, different other technologies play an important role in digital music learning, e.g., for musicians. Applying XR in musical contexts by integrating music sound can lead to a particularly enriched as well as highly interactive and controllable experience (Turchet et al., 2021).

Furthermore, there are studies in which haptic devices have been developed to improve music instrument playing. These vary between the instruments focused on (e.g., flute, Zhang et al., 2019), the systems developed (e.g., haptic gloves, Pala & Türker, 2019) and the type of learning (e.g., motor learning, Zhang et al., 2019).

Zhang et al. (2019) for example developed a haptic interface to assist in learning to play the flute, with a clutch mechanism attached directly to the instrument. They emphasize the relevance of multimodality in learning to play instruments and argue in their study that adaptive learning overrides static, traditional learning. They see their system as promising, which focuses on adaptive, interactive, and haptic-supported learning.

#### **4. Methodology**

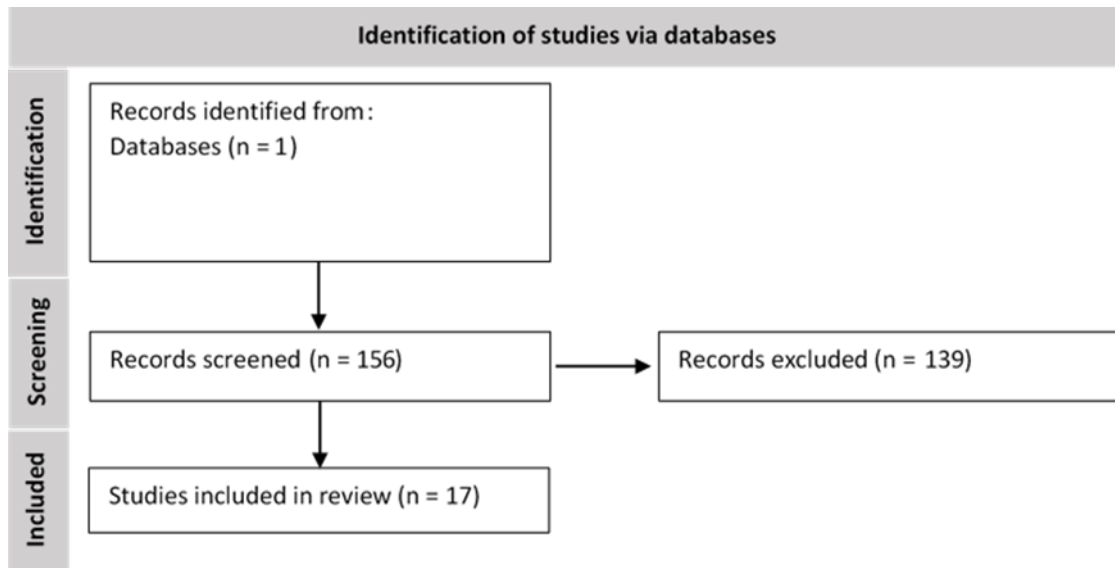
To achieve the goal of this paper to receive a broad overview and to identify research gaps concerning haptic technologies in digital music learning, a scoping review based on Arksey and O’Malley’s (2005) methodological framework was conducted. Following the first of five stages of their framework, we started with the identification of research questions. The resulting two research questions are listed in the Introduction and represent the main focus of the paper.

To identify relevant studies as stage two of the Arksey and O’Malley’s (2005) framework, the search was carried out by using the database Web of Science being considered as relevant in the field of educational research (Newman & Gough, 2020). For this purpose, the three categories haptic technology, learning and music were formed with representative search terms per category. An iterative process of initial literature reviews was then used to adapt the final search string, which can also be seen in Table 1. This was entered on 2 May 2022 in the selected database Web of Science, which was searched for hits in title, abstract or keywords and exclusively considered studies in English language.

**Table 1:** Search string and -results

<b>Search String:</b> (haptic* OR tact*) AND (educ* OR learn* OR train* OR teach*) AND (music*) NOT (braille OR medic*)			
<b>Database</b>	<b>Search field</b>	<b>Hits</b>	<b>Initial Selection</b>
Web of Science	Title, Abstract, Key words	156	17

For stage three, the selection of articles matching the research questions, all abstracts of the found articles (n = 156) were first read and analysed based on the inclusion and exclusion criteria (see also Figure 1 for visualisation). The criteria were developed post hoc according to the methodology of scoping studies (Arksey & O’Malley, 2005) after becoming more familiar with the literature. Thus, no restriction was made in publication years as it would have limited the selection too much. In addition, studies that focused on medical aspects or Braille were excluded because the terms in first search trials provided an incorrect focus for this paper. In contrast, papers were included that were aimed at the research project, contained search terms in the above-mentioned categories and were in English language. Thus, of the n = 156 search results, n = 17 abstracts were selected, and then the respective full studies were read, which were assumed to fit the present research questions.



**Figure 1:** Visualisation of used databases and included records (based on PRISMA Statement, 2020)

According to the described stage four of the scoping method, the selected studies were analysed twice by reviewing, recording, and sorting the material according to important key questions and topics. The data examined from the selected studies were sample, music learning context, haptic experience, and technology. The results of the analysis are broken down in the results chapter, although it should be noted that some studies did not provide all the data just mentioned. In the following chapter, the results are also compiled, summarised, and reported in line with stage five of Arksey and O’Malley’s (2005) framework.

## 5. Results

The information extracted from the 17 selected and analysed studies were sorted into four categories: sample, music learning context, haptic experience, and technology. Table 2 shows detailed information on the studies.

**Table 2:** Summarised results

Authors (Year)	Sample	Music (Learning) context	Haptic Experience	Technology
Ho et al. (2022)	Kindergarten and school children	Music culture in Taiwan	(Pop-up) book with tangible elements of different texture	Application for AR with Tablet
Senecal et al. (2020)	Adults: regular and non-dancers	Salsa dance skills	Haptic feedback through controller	VR with Headset, Controller, Markers
Walzer (2021)	Educators for music production	Ideas for learning environments for sonic practitioners	Playing musical instruments	Digital Audio workstation
Bremmer et al. (2021)	Music teachers for special education	Multimodal approaches of music teachers for a specific method	Different materials varying in shape, texture, usability, ...	/
Wallmark & Allen (2020)	Children from preschool and day-care facilities; adults: musician and non-musician	Patterns of crossmodal mappings of timbre, age, sensory modality	Smooth and rough sandpaper	/
Fontana et al. (2020)	Community and developers for digital/virtual instruments	Development of digital/virtual instruments in Unity3D	Force and tactile feedback through robotic arm	Desktop, Phantom Robotic Arm, Keyboard
Ludovico et al. (2017)	Children and adults of all ages	Experiential learning by a sound installation	Touching a metal plate	Laptop, audio power amplifier
Nanayakkara et al. (2013)	Hearing-impaired people	Enhancing musical experience for deaf	Haptic chair	Vibrating haptic chair, computer display

<b>Authors (Year)</b>	<b>Sample</b>	<b>Music (Learning) context</b>	<b>Haptic Experience</b>	<b>Technology</b>
Gunther & O'Modhrain (2003)	/	Facilitating the composition and perception of musically structured patterns of vibration on the body	Transducers to transfer vibrotactile response	A vibrotactile stimulator comprised of 13 transducers worn against the body
Nunes-Silva et al. (2021)	/	Focusing on interaction between musician and instrument & role of sensory feedback on music performance	Interaction of fingers and instruments	/
Huovinen & Rautanen (2020)	Primary school students	Creative music-making in groups	Traditional musical instruments	iPad tablet computers
Debevc et al. (2020)	School students	Supporting & motivating learners and teachers to achieve mastery in solfeggio	Rhythm tapping on a mobile display	Mobile application with AR
Cheng et al. (2016)	Professional pianists: healthy or suffering from Musician's Dystonia	Reducing Musician's Dystonia during piano playing	Tactile variation through wearing latex gloves	Metronomic click sound of a computer, EEG
Zappi et al. (2012)	Electronic musician	Using a robotic arm to control and create music	Force feedback by touching a robotic arm	Generic controller, robotic arm, display wall
Luciani et al. (2009)	Adults: musicians and non-professional musicians	Meaning of ergotic audio-haptic situations for performing musical tasks	Friction sensation variation of a virtual bowed string	Model of a virtual bowed string, ERGOS haptic devices, audio-haptic simulator
Rose (2008)	/	Overview of Australian music history	/	/
Lage et al. (2007)	Musicians	Using visual, tactile and auditory information for intonation control in the double bass	Tactile feedback variation via foam cushions on the instrument	Pick-up attached to double basses, mixer to amplify signals, computer

In 14 of 17 studies the sample was named. In five studies, children were named as the sample, which can be summarised in the range from kindergarten to approximately primary school. In two of these studies, adults were also mentioned. In five other studies, the sample could be summarised as musicians, and in two additional studies the sample consisted of music teachers or educators. In two studies, no specific classification could be made, but impaired people and developers were represented individually.

All the studies dealt with various forms and fields of music learning, which are summarised here under the heading music learning context. There were eight studies that can be grouped under music performance. Five studies dealt with music education and three with experiencing music. One of the studies was assigned to the topic effects of musical training.

Haptic manipulation was mentioned in 16 studies. In nine of these, no technologies, but various other materials and musical instruments were used to evoke tactile perception. Seven of the studies used different technologies for haptic manipulation.

Of the 17 studies, 13 reported using technology. They always referred to hardware, either used individually, combined, or used as a supplement. Three studies reported XR, two as an AR application and the other as a VR learning scenario. One of the studies with XR also used vibrating technology, which was also used in two other studies. Another study dealt with an AR-supported software for mobile devices that required learners to tap rhythms, being a form of tactile interaction. In six studies, additional music equipment was explicitly used, e.g.,

in the form of a metronome or a keyboard, or hardware which was attached to a real instrument. In two of the studies, only hardware was mentioned that had no direct connection to music, vibrating technology or XR.

## **6. Discussion and conclusion**

The present scoping review tried to compile and analyse prior research on the use of haptic technologies in the context of music learning. It found that haptic sensation plays an important role in investigations on musical experiences and music performance and that haptic manipulation is realized in various ways, including innovative digital devices and simple tools like foam cushions. However, the current review indicates that experimental research on the impact of haptic feedback in music education is still scarce. Nevertheless, several included studies emphasize the potential of haptic technology for the field of music learning for different targets groups (e.g., Nanayakkara et al., 2013)

Regarding the first research question of this review, haptic technologies used in the context of music learning were investigated concerning the included papers. Results showed that haptic manipulation was realized by means of technology in only about 44% of the papers analysed for the present review. While two papers used technology-based vibrating full-body stimulators, the most prevalent forms of haptic technologies concerned the hands (e.g., controllers, robotic arms, and experimental musical instrument). Moreover, a few of the technology-enhanced and non-technological haptic musical interfaces showed to be combined with innovative digital applications, e.g., in AR or VR (Ho et al., 2022; Senecal et al., 2020). A wider dissemination of haptic technologies in the field of music would facilitate the interconnection to such upcoming XR-technologies that showed to be advantageous, especially for music (e.g., Turchet et al., 2021). For example, wearable devices as haptic gloves could be used to create a smooth and effective (learning) experience in a XR (see Dangxiao et al., 2019 for an overview of haptic displays). They might be especially useful for learning and playing musical instruments since most instruments need interaction with one or both hands and provide a kind of tactile feedback.

Concerning the second research question on advantages and challenges of using haptic technologies in the context of music, we found that while only few of the papers of the current scoping review concentrated on the effects of haptic feedback for musical learning processes or learning gains, some of them still highlighted the (future) potential of haptic stimulation in music education. For example, Nanayakkara et al. (2013) stated that their prototype namely the haptic chair can serve as a help for deaf people to learn playing an instrument or singing. Moreover, even though Luciani et al. (2009) did not explicitly address learning goals in their study on the role of ergotic sounds for music creation with (virtual) bowed string instruments, they found that using haptic feedback to create an adapted and well-tuned ergotic sound situation can improve instrumental learning. To sum up, since the benefit of haptic feedback for the music domain seems to be undoubted, a further development and a broader use of technology-based haptic feedback holds a lot of potential. Compared to non-technological haptic manipulation, technology-based haptics can be applied more implicitly and less intrusively and integrated nearly invisibly into a musical set-up. Thus, technology can contribute to a more realistic, multimodal, and effective musical (learning) experience with less distraction for musicians and a more fine-grained, individually tuned, and adaptive haptic feedback. Still, haptic devices can be expensive and may need technical expertise to apply, which may make them not accessible for all users yet.

The present review faces some limitations. To ensure a high standard of included studies and to primarily focus on education, we used the database Web of Science. Nevertheless, we thus neglected studies of different or rather distant fields that could not be found via the mentioned source (e.g., Papetti & Saitis, 2018). This review also faces a publication bias as it does not include non-published studies. However, first trials to expand the search in other databases like Google Scholar or in other fields like Human Computer Interaction support the conclusion that haptic feedback in music learning is an emerging topic, and results suggest that haptic feedback can be beneficial for learning (e.g., Tom et al., 2020). A further limitation concerns the definition of a musical learning context. For our review, we also included studies on dancing (Senecal et al., 2020) and sound production (Ludovico et al., 2017) since we considered these subjects to be inextricably linked with music. Nevertheless, it should be mentioned that the typical haptic feedback given while playing an instrument might not be easily comparable to these previously named musical contexts.

Overall, the results of the present scoping review show that haptic feedback is a widespread and current topic in research on music performance, music experience and music learning. However, our search results indicate

that the investigation of concrete learning environments including technologically realized haptic stimulation is scarce. Future research should on the one hand develop affordable technological devices enabling adaptive and individually tuned haptic feedback for different fields of music learning as well as evaluate their effectiveness and learning gains compared to traditional musical learning set-ups.

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