Attention to the role of the body and bodily awareness in human–computer interaction is increasing. Broader availability of cost-effective motion sensors in mobile and gaming applications has prompted a shift to body-centered design methods. This article examines the relevance of embodied sketching activities drawn from soma-based and sonic interaction design to digital musical instrument (DMI) development. It focuses specifically on the Telechord, a novel motion-controlled system that promotes methods for exploring connections between movement and sound. By emphasizing the felt aspects of movement-based design and performance, this approach places performer experience at the forefront, complementing technical efforts to enhance nuance and coherence in current DMI design research.

This article examines the application of embodied and vocal sketching techniques in digital musical instrument (DMI) design. Embodied sketching refers to exploratory techniques that integrate physical activities in the early stages of design to generate and test new ideas [1]. These body-led practices feature in soma-based design [2] and embodied sonic interaction design, where vocalizations and gestures are used to sketch sonic representations [3]. Soma-based design is informed by the bodily engagement and aesthetic sensibilities of the designer, emphasizing the felt dimension of first-person experience [4]. It draws on somatics, a field of study that investigates the body from a first-person perspective and incorporates techniques for promoting self-awareness [5]. Somatic principles inform the development of the Telechord, a nontactile gestural system driven by whole-body movement. Reflecting recent trends in interaction design, the system is based on the premise that all human actions are embodied actions [6]. This notion from the “third wave” of human-computer interaction (HCI) [7] encourages individual ways of moving and feeling and leverages innate human abilities to promote mastery of movement-based interaction without training [8].

As an instrument that relies on remote sensing and cannot be seen or touched, the Telechord lacks inbuilt resistance and tactile feedback to guide performer movements. Kinesthesia and proprioception provide sensory feedback for motor control and posture, enabling the performer to regulate the position, speed and force of their body movements in real time [9]. As Maiken Hillerup Fogtmann, Jonas Fritsch and Karen Johanne Kortbek observe in relation to the felt dimension of interaction design: “The knowledge of whether movement has been performed accurately is not determined by how it looks, but more importantly, from how it feels” [10]. This sense of feel can be built up from a combination of muscle memory and visual imagery developed over many years of training and practice [11]. To master relatively new movement-based instruments, one's physical engagement forms a vital part of honing one's individual movement preferences, abilities and awareness.

A tendency to overlook the direct impressions of the user in favor of designs and frameworks based on the body as an observable presence often leads to the body awareness of the performer becoming externalized [12]. This attention to the artifacts or outcomes of design can exclude valuable, subtle information during the design process [13]. Current DMI design research focuses mainly on the functionality and implementation of instruments in singular works and performances [14]. Yet a focus on the lived experience and insights of a performer through first-person methods is also needed to foster skill development, physical abilities and individual movement approaches in movement-based interaction. This central aspect of soma-based design has relevance to DMI design, particularly in regard to systems that are controlled either by continuous whole-body movement or discrete gestures, which represent self-contained segments or units of action [15].

Garth Paine’s techno-somatic dimension encourages DMI designers to acknowledge the intermediate space between body and instrument when conceptualizing and evaluating novel instruments [16]. To access this felt dimension, I employ embodied design sketching techniques such as movement improvisations to develop design ideas for the...
Telechord [17]. I undertake vocal sketching, a fast prototyping method for imitating and generating nonspeech sounds [18]. As a vocalist accustomed to sketching melodic phrases and lyrics through recorded improvisations, I have learned that this design activity has become a natural extension of my musical practice. I refine initial sound-movement mappings through live performance and self-reflection, continuing in the tradition of artist-designed or inspired motion-controlled instruments, including Laetitia Sonami's Lady's Glove [19], Michel Waisvisz's the Hands [20], Atau Tanaka's Electromyographical (EMG) muscle movement sensing instruments [21], Donna Hewitt's eMic [22] and Imogen Heap's Mi.Mu gloves [23].

Interactive dance systems also offer a template for designing exploratory multimodal environments that encourage immersive bodily engagement. Palindrome's custom-built system EyeCon [24] utilizes qualities of dance movement to alter musical phrases and projected images, text and stage lighting. Dance company Troika Ranch incorporates movement sensing and multimedia technology, developing mapping software Isadora [25], a visual programming environment that allows users to control video effects through a variety of movement, MIDI and audio inputs. Building on this body-centered, practice-based research, the following sections explore how these ideas can be applied to DMI design that prioritizes the felt dimension.

**SYSTEM OVERVIEW**

The Telechord is an open system that promotes exploration of links between movement and sound. Performer actions are captured remotely using a three-dimensional Kinect camera (Fig. 1). Acceleration, positional and velocity data of whole-body movement and discrete gestures are processed using visual programming language Max/MSP. A combination of external sound sources, including the voice, blend with movement to excite percussive, tube, plate and string models within physical modeling synthesis environment Modalys [26]. I selected remote camera sensing to detect motion in order to minimize disruption of the performer's particular movement style and maintain communication with the audience, aspects that are particularly critical for conveying a persuasive vocal performance.

The interaction design and movement vocabulary are organized according to a string instrument metaphor. The aim of the metaphor is to support kinesthetic learning and the construction of internal imagery and cognitive maps during performance by drawing on physical associations between instrumental action and sound. Envisaging a string under tension provides a structure to guide the performer's movements and energy expenditure in the absence of tangible feedback and resistance.

Two system modes are available. One mode is a four-string version in which multiple virtual strings are stretched across
the apex joints of the skeleton. As the body moves, the shifting length of virtual resonating wires surrounding the body affect pitch changes of four separate tones, enabling the performer to construct four-part harmonies. The second mode is a single-string version that allows more detailed control of the timbre and envelope of each note through a range of string instrument gestures, including bowing, plucking and striking actions. Similar to the mapping strategy of the Gloves by Stefania Serafin et al. [27], the left hand controls fundamental frequency along a vertical continuum, while acceleration data from the right hand affects excitation parameters that alter the attack and length of a simulated physical sound object.

Links between performer motions and sound are reinforced by visual feedback that represents the virtual strings connecting key joints connected to the performer’s expressive movement style, including the head, arms, throat and torso. Motion data and the audio output level of the Telechord are visualized using the Open Graphics Library (OpenGL) (Fig. 2). Each pose is preserved for 300 frames before gradually fading away, highlighting the temporal evolution of each movement. Additionally, the amplitude of the instrument and positional movement data are visualized as a particle system layer, representing the amount of energy being injected into the system. The primary aim of portraying the connections between performer movement and sonic data is to aid audience comprehension of the metaphor-based system mapping by externalizing the hidden processes of the invisible instrument and drawing out the nuance and detail of the movement-based interaction. During embodied sketching sessions, visual feedback also supports exploration by amplifying relationships between performance actions and emerging sounds.

**EMBODIED DESIGN APPROACH**

Physical engagement was a central part of the Telechord design process. Soma-based and embodied sonic interaction design methods like embodied and vocal sketching offer direct ways to stimulate creativity, externalize half-formed conceptions, test ideas [28] and promote a sense of playfulness in the earliest design stages [29]. Embodied sketching during the Telechord's conceptualization phase involved a series of movement experiments. Improvisations with a set of preliminary Max/MSP motion processing and physically based sound synthesis software patches provided the basis for evaluating initial mapping ideas. Sketching activities included explorations of pace, movement dynamics and scale. These experiments encouraged me to become more consciously aware of individual movement tendencies and deliberately expand my usual movement range and style of execution to achieve more sonic variation.

I used vocal sketching to configure and refine the Telechord’s interaction design in intuitive and immediate ways [30]. Similar to the vocal prototyping explored by Ross Bencina, Danielle Wilde and Somaya Langley [31], vocal sketching provided a means to challenge prevailing ways of designing sounds and conceiving sound-movement relationships. I approached it both as a participatory and embodied design practice and aid to creativity [32]. Stefano Delle Monache et al. [33] recognize vocal sketching as an immediate and rapid prototyping technique for expressing nonspeech sounds compared to disembodied methods for manipulating sounds through software. Using the voice to imitate desired sounds, I vocalized sonic ideas that eluded verbal description [34], from sliding drones and guttural groans to stuttering phrases. This process allowed me to create a series of string and percussive sounds in Modalys that a performer could manipulate by altering the phrasing and intonation of the voice in public performance.

The use of a vocal input in conjunction with movement data produced more timbral and dynamic variation than more regulated electronic sound sources like white noise and oscillators. Surges in vocal level would periodically heighten the intensity of physically modeled sounds, leading to volume spikes illustrative of fluctuating energy expenditure during performance. These energetic bursts could then be amplified and extended with increasingly intense and energetic movements. At other times, monotonal, spoken phrases were transformed with percussive plate models that altered the voice with robotic, vocoder-like effects. While movement in the left hand can impose additional melodic contours on the voice, the right hand is often mapped to volume control of

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**Fig. 2.** Visual feedback for the Telechord. Left: virtual string representation. Right: smoke screen particle system. (© Mary Mainsbridge)
external sound sources, activating the vocal input only when movement is present. This interaction presents a new way for the performer to approach the coordination of movement and vocal phrasing.

**REFLECTION**

Without prior movement training, sketching refined with the body alerted me to preexisting movement preferences and patterns in performance. Experimentation with different combinations of movement parameters through improvisation increased sensitivity to felt sensations. This process encouraged me to produce and direct movement with increased subtlety and range [35]. Embodied sketching also shifted my performance focus to inner states manifested in varying emotions, movement qualities and spatial imagery. It contributed to a more robust and stable instrument suited to both solo and ensemble contexts. When repeated over a range of rehearsals and performances, including a recent artistic collaboration with vocalist, producer and gestural system designer Donna Hewitt [36], the technique also gradually trained me to recognize and work with the intricate nuances of sensory perception, moving closer to Thecla Schiphorst’s ideal of the “sonic connoisseur” [37]. This focus builds on a somatic-inspired design strategy that nurtures reflection and refinement of the skills of experience [38].

Solo public performances also extended the improvised sketching approach I employed in the design process. During a performance at the 2018 Sound and Music Computing Conference in Limassol, Cyprus, I embraced glissando with noise-based percussive plate models before gliding to a cylindrical air column model that constrained pitch transitions to incremental steps regulated by the left hand. The former sound encouraged free movement improvisation, while the latter featured more calibrated and restrained movements. Stuttering spoken-word phrases alternated with sustained bellowing, gradually transforming into a repetitive, meditative chant. I increased my movement range throughout the performance, stretching and lunging into the surrounding space as my comfort with the system, space and audience grew. The experience felt much like my previous somatic practice incorporating the vocal toning process of yoga, in which participants use rhythmic chants and motions to regulate breathing and direction of energy.

As I explore the intangible aspects of body-centered instruments, such as the kinesthetic feelings associated with gestural performance and associated vocal production, my research reiterates the importance of incorporating bodily experiences into cyclical DMI development. Somatic design methods can offer a useful extension to embodied sketching techniques currently employed in sonic interaction design. They also offer a framework for reflecting and incorporating performer experiences and embodied understandings in movement-based interaction.

In the design of the Telechord, vocal and embodied sketching facilitated the design of not only a more immediate and individualized instrument for the performer but also increased bodily awareness by providing an environment for observing, describing and analyzing felt sensations. In this way, embodied sketching has parallels with somatic practices that promote internal awareness of the moving, sensing body while embracing playful, exploratory and physically immersive approaches to movement-based design.

**References and Notes**


396 Mainsbridge, Soma-Based Nonphysical Instrument Design in Electronic Music Performance


33. Delle Monache et al. [18] p. 49.

34. Delle Monache et al. [18] p. 49.


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