Studying Performances with Digital Musical Instruments: A Case Study of *Ritual*, a Piece for Solo Karlax

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Abstract. This chapter discusses ways to study sonic design from the perspective of musical performances with Digital Musical Instruments (DMIs). We first review the specificities of DMIs in terms of their unique affordances and limitations and comment on instrument availability, longevity, and stability issues, which impact the use of DMIs in musical practice. We then focus on the Karlax, a commercial device used in several musical performances for over a decade. We present an analysis of excerpts from three performances of D. Andrew Stewart's piece *Ritual* for solo Karlax, discussing the variability of performers' gestures and the musical choices made. We conclude by suggesting practice exercises to develop performance techniques with the Karlax and discussing musical composition and performance issues with DMIs.

Keywords: Gestures · Digital Music Instruments (DMI) · Music Performance · Computer Music

1 Introduction

Gestures and sounds are tightly coupled in musical performances (Cadoz & Wanderley 2000, Wanderley 2002, Leman & Godøy 2010, Dahl et al. 2010). The sounds produced by a well-known acoustic musical instrument, such as the piano, immediately suggest the general characteristics of the gestures used to play it (Godøy, 2009). Indeed, research suggests that "even listeners with little or no formal musical training can have images of sound-producing movements that reproduce both the effort and the kinematics of the imagined sound-production actions" (Godøy & Jensenius 2009 p. 46). This is possible as there are unequivocal links between gestures and sounds in acoustic musical instruments, i.e., performing the same gestures will likely produce the same sounds.

Godøy and colleagues' observations on performer movements shed light on the richness and complexity of musical performances (Jensenius et al. 2010). Similarly, their work on sound-tracing gestures and the analysis of performances with air instruments (Godøy et al. 2006) show that gestures are embedded in musical ideas, even in the absence of the instrument itself. By tightly combining gesture and sound analysis, they

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propose novel ways to understand better the relationship between musicians and their (acoustic) instruments.

In acoustic musical instruments, gesture–sound relationships are given by the physical behaviors of vibrating structures (e.g., strings, membranes, bars, reeds, columns of air). These structures vibrate in specific ways described by their mechanical properties. In other words, though involving complex vibration patterns, strings, membranes, reeds, etc., can only vibrate in a finite number of ways. Performer gestures and resulting sounds are inextricably coupled by physical laws.

Digital musical instruments (DMIs) are typically composed of an input device connected to a sound-generating device, both linked by mapping strategies defining the relationship between performer actions and resulting sounds (Miranda & Wanderley 2006). In this text, when talking about a gestural controller, we mean the input device itself, with its physical properties, affordances, embedded sensing techniques, and (sensor) data generated. A DMI implies a complete instrument with defined sound characteristics, which might or not be generated in a separate device or embedded in the controller. Therefore, when mentioning the Karlax as a device, we will refer to it as a gestural controller, whereas the same device (Karlax), for instance, in the context of *Ritual*, will be considered a digital musical instrument, since mapping strategies and sound generation have been defined by D. Andrew Stewart. In DMIs, the sound generation algorithm determines the "vibrations" that the instrument produces. What the algorithm will do and how it will relate to the performer's actions is arbitrarily defined by the instrument designer, the composer, or the performer (or eventually by all of them in one person) (Wanderley 2017). In DMIs, there is no inherent or natural connection between the actions of a performer (performer gestures) and the sound resulting from them. Indeed, there is an infinite number of possibilities allowing for the relationship between gestures and resulting sounds. Performer gestures and resulting sounds need to be coupled by the instrument designer.

2 Digital Musical Instruments in Context

There is a large set of possibilities for a musical performance with a DMI, as DMIs do not need to be played similarly to acoustic instruments. In other words, they do not necessarily produce musical notes as a result of performer gestures. They can instead be used to manipulate pre-recorded note sequences as input devices in live-coding contexts or many other contexts (Malloch & Wanderley 2017).

As DMIs do not necessarily produce a unique sound with given intensity, frequency, and timbral characteristics when excited by a performer's gesture, hearing a sound produced by a DMI does not univocally bring up the image of a particular gesture.

Though several hundred gestural controllers and DMIs have been proposed in the literature, with more than a hundred controllers already known before the New Interfaces for Music Expression (NIME) conference in 2002 (Piringer 2001, Wanderley & Battier 2000), access to DMIs might be severely limited. There are few examples of gestural controllers and DMIs made in large quantities or readily available, for instance, in a musical instrument shop (with the exception of keyboard controllers and matrix-based controllers such as Ableton's Push). Obtaining DMIs, when possible, might imply substantial expenses compared to entry-level acoustic and electric musical instruments.

Furthermore, many new controllers and DMIs proposed commercially aim at beginners and are marketed as “enabling anyone to make music, regardless of experience” (McPherson et al. 2019, p.8), raising questions about how much expertise development they allow.

Finally, performances with DMIs are often geared toward novelty, where the performance of a new piece sometimes takes precedence over the choice of existing works in the repertoire. If multiple performers do not repeatedly perform pieces, analyzing invariants and the variability of gesture–sound relationships is impossible.

3 Implications for DMI Design and Performance

3.1 Improved Design

New instruments might not be ready (stable enough) for intensive performance use, with many of the interfaces and DMIs proposed in the literature remaining laboratory prototypes. The move from an initial prototype developed to test a concept to a full-fledged instrument, which is inherently responsive, stable, and robust, is far from evident (Miranda & Wanderley 2006). Though it has been claimed that “Musical interface construction proceeds as more art than science, and possibly this is the only way that it can be done” (Cook 2017, p. 4), in practice, a balance between design and engineering is essential, as DMIs “are meant for real-time performance, instrumentation techniques providing stable, robust, accurate, reproducible and fast response are essential” (Medeiros & Wanderley 2014, p. 14).

Another reason preventing widespread, long-term use of DMIs might be the lack of subtle control (Morreale & McPherson 2017) or fine details of instrument craft in many instruments (Armitage et al. 2017), as “most (new interfaces for musical expression) NIMEs are viewed as exploratory tools created by and for performers that they are constantly in development and almost in no occasions in a finite state” (Morreale et al. 2018, p. 168). The trade-off between craft and engineering is essential, with unhealthy results when one side is overly considered at the expense of the other.

This context calls for DMI designs that aim to produce instruments beyond laboratory prototypes and can become tools for long-term musical expression. Medium- and long-term research projects such as the McGill Digital Orchestra aimed to make such instruments: “In the Digital Orchestra, we hoped to develop a methodology for the process of creating DMIs that would increase the likelihood of their being adopted by performers other than the instrument’s designer” (Ferguson & Wanderley, 2010, p. 19). But design alone is not enough: “sophisticated musical expression requires not only a good control interface but also virtuosic mastery of the instrument it controls.” (Dobrian & Koppelman 2006, p. 277). A balance between improved design and musical performance is, therefore, essential.

3.2 Accessibility

The path can be rough for musicians interested in acquiring a DMI, learning to perform with it, and eventually developing “virtuosic mastery.” First, one needs to decide on an instrument. Typically, this would be done after watching a concert or a video of a performance. Then one needs to get a hold of the DMI (the physical controller, the sound synthesis software, and the mappings used). Alas, getting a copy of a DMI might be a significant limiting issue as controllers are not necessarily available in (physical or virtual) music shops. Only once this step is done can musical practice start. But where should it start?

3.3 Musical Practice

Contrary to acoustic instrument performance in classical music settings, the path to learning a DMI is not well charted, though a few works have tackled this issue, see, for instance, (Butler, 2008; Ferguson & Wanderley, 2010; Hochenbaum & Kapur, 2013; Marquez-Borbon, 2020; Tomás, 2020).

Learning to play DMIs typically relies on musicians watching live performances or through videos, similar to the context of popular, folk, or rock music. Yet, contrary to those, there are few in-person opportunities to make music with DMIs in groups, perhaps except for the control of live loops in club settings. Building communities of practice is crucial to creating the conditions for widespread DMI performance (de Laubier & Goudard, 2006; Fukuda et al., 2021).

3.4 Longevity

A critical issue in the NIME community is the number of interfaces and DMIs that attain some longevity from the total number of instruments proposed each year (Marquez-Borbon & Martinez-Avila, 2018). In NIME, several instruments are proposed that do not establish themselves as performance devices (Morreale & McPherson, 2017) or that might have a "performer base of one" (Ferguson & Wanderley, 2010), i.e., being only played by their inventors. Researchers have pointed out many reasons for this situation, including "the lack of a proper instrumental technique, the inadequacy of the traditional musical notation, and the non-existence of a repertoire dedicated to the instrument" (Mamedes et al. 2014).

3.5 Musical Novelty

Establishing a repertoire of pieces performed multiple times is essential to allow comparisons of expert performers' musical outcomes. As discussed above, this is far from the case with DMIs, somehow implied in the title of the main event on these instruments (*NEW* Interfaces for Musical Expression). Does playing an interface that was proposed several years ago count as NIME? How "new" should an interface be? How long can a performer keep the same instrument? Does one necessarily need to abandon "old" DMIs? (Masu et al., 2023) How can one foster the performance of existing pieces in the repertoire? In which contexts could this happen?

In the rest of this chapter, we will focus on one successful commercial interface that fulfills several of the above requirements, the Karlax.

4 The Karlax

The Karlax (www.dafact.com) is a gestural controller created by Rémi Dury, a well-known composer and performer active in the new music scene in France since the 1980s. At the time of the Karlax development in the early 2010s, Dury already had substantial experience performing with electronic instruments as part of Puce Muse/Espace Musical, an association created together with Roland Caen, Serge de Laubier, and Philippe Leroux (Couprie 2018), most notably performing the Méta-Instrument (de Laubier & Goudard, 2006) in a duo with Serge de Laubier.

The Karlax concept is a device both hands hold, like a clarinet or soprano saxophone. It includes various sensors: 10 continuous keys and 8 pistons, an inertial measurement unit, and several switches. It also includes a rotary axis with bends at each end, allowing the performer to rotate the controller's axis, an action earlier explored in Cook's Hirn Controller (Cook 2017). In its original form, the Karlax is a gestural controller that generates control messages from the various sensors' outputs, not sounds. To become an instrument, i.e., to play sounds with the Karlax, such control messages must be mapped to sound synthesis parameters, and combining a Karlax and its mappings to a synthesizer becomes a DMI.

The Karlax received substantial funding from the industry. This funding allowed for the development of a series of prototypes by professional designers and engineers, an exceptional situation in the context of new interfaces for musical expression. Around seventy Karlax units have been produced, costing several thousand euros each, putting it at the expensive end of the electronic musical instrument's cost range.

Given the confluence of the above, the Karlax has a special place in music technology history. It was developed by an experienced musician who had a clear goal in mind, with substantial financial and technical support over several years, yielding a high-quality commercial product manufactured in multiple (several dozen) copies and performed by dozens of musicians over more than a decade (Lavastre & Wanderley, 2021). These numbers are very far from the situation with traditional acoustic musical instruments played by thousands or millions of people over hundreds of years. Yet, the Karlax is pretty unique in digital musical instruments. Musical performances with the Karlax include solo and mixed pieces, including acoustic instruments, in composition and improvisation settings. The confluence of these unique facts makes it an ideal candidate for evaluating DMI performances.

5 A Comparative Analysis of Interpretations of *Ritual* for Solo Karlax

Comparative music performance studies have developed considerably with the rise of audio and video recording. They have allowed the renewal of the musicological approach towards a multi-disciplinary field, including psychology, music history, analysis, and music theory (Donin, 2005, Lerch et al., 2021). However, comparative studies of interpretations with digital instruments are still marginal. Though musical performance with digital musical instruments can take different forms, from improvisations to imitations of performances with acoustic musical instruments, only a few devices have aroused genuine interest among performers and composers and allowed the development of original approaches to composition, notation, and performance as did the Karlax (Mays & Faber, 2014, Stewart, 2016).

Composer D. Andrew Stewart's piece *Ritual* for Karlax solo from 2015 features detailed notation and developed playing techniques based on a gestural repertoire. The composer has made a significant effort to ensure that the piece can be performed again (notation, explanation, software versions, video recordings). On the other hand, it is one of the only pieces for this instrument in which different filmed versions exist.

This section examines the musical and gestural expressive variations in three interpretations of the piece. We have identified three excerpts at the beginning of the piece, each requiring different instrumental techniques and containing different levels of control. By comparing the different interpretations of the same piece, we aim to highlight the expressive strategies chosen by performers, better understand the aspects of the piece that performers focus on, and how they decide to interpret specific musical gestures in the score.

5.1 *Ritual* for Solo Karlax

Ritual uses physical model synthesis (*Sculpture*, in *Logic Pro*), a type of sound synthesis that emulates the physical properties of acoustic instruments to create sound waves. The piece is based on a specific gestural vocabulary and original mapping strategies developed by the composer. MIDI data from the Karlax are processed and used in algorithms to identify particular gestures (e.g., *shake* or *thrust* as named by the composer). The mappings are created in Cycling '74's *Max,* thanks partly to the *Digital Orchestra Toolbox* library (Malloch et al. 2018). The mapping that associates the raw and conditioned data to the sound synthesis parameters is realized thanks to *libmapper/Webmapper* (Wang et al., 2019). Thus, to perform the piece, the interpreter must combine the appropriate versions of three programs: *Max*, *Logic,* and *Webmapper*.

The score is presented in detail in (Stewart, 2016, p. 3) and describes the required physical gestures, notational symbols, information related to traditional forms of music notation, audible output, and any necessary technical details.

6 Analysis

We analyzed video recordings of three performances (available here: https://youtube.com/playlist?list=PLyCL8KtgnNS-eEdFAhBhg9gylbGKj1YTP):

- V1, performed by the composer in 2015 at the University of Lethbridge
- V2, performed by the composer at the 2018 Crossing Boundaries Symposium / Interactive Art, Science, and Technology (IAST) at the University of Lethbridge
- V3, played by Vlad Baran in 2021 at McGill University

The piece lasts 10 to 15 min and contains six parts. We focused on the introduction, the first page of the score, annotated as "ceremonious awakening." In this relatively free part, we have identified three excerpts corresponding to typical sound morphologies considering musical phrasing, dynamic envelope, and spectral content.

1. Attack/resonance with resonance control
2. Melodic play with control of resonance and timbre
3. Crescendo followed by a terminal accent with control of amplitude and timbre

We used the piece's score notation as a reference. The composer comments on creating the score in great detail in the description, adopting a prescriptive approach (Kanno, 2007). Although, the score contains essential descriptive elements such as durations, rhythms, tempi, nuances, or density. The score is conceived as a succession of specific gestures represented by original symbols associated with sounds. Sometimes traditional symbols are used in different ways: the notes in the staves indicate fingerings, or the numbers at the beginning of the staff indicate octaviation. Furthermore, the sounds are described literarily in the description.

In the case of *Ritual*, the performer has the score and video recordings available on the internet to recreate the piece. The composer's website also provides information on sound synthesis, mapping, and gesture programming stages.

We chose three excerpts from *Ritual* with varying "levels of control." By level of control, we imply the number and complexity of the gesture–sound associations related to the mapping strategies chosen by the composer.

- In A, a low level of control, with a sound activation followed by the control of the sound resonance.
- In B, a more complex control, with the activation of the pistons and the control of timbre and amplitude by the coordinated action of several gestures.
- In C, a moderate control, with a sequence of gestures that modifies the timbre (distortion, modulation). In this last case, the response to the *shake* gesture (notated by *stir* in the score) seems less direct. This is an example of a convergent or many-to-one mapping, where the amplitude is controlled by both the tilt of the Karlax and the rotation of its axis.

For each excerpt, we investigate "expressive variations" made by the performers, the diversity of the interpretation of musical qualities such as dynamics, timbral variations, phrasing, note accuracy, and gestures (Cadoz & Wanderley, 2000) or the performance of the gesture-sound link (i.e., *transparency*) (Fels, 2002).

In the following, first, we describe the different sound morphologies defined by the composer and compare the three interpretations. Then, we discuss the results by looking at the expressive variations according to the levels of control.

6.1 Attack/Resonance

The first musical gesture of the piece is a kind of gong strike (a *thrust* gesture), with control of the resonance by shaking the instrument (a *shake* gesture). We will use the gestural terminology determined by the composer hereafter (Fig. 1).

The *thrust* gesture is described as follows in the score:

> "This technique requires a coordination of gestures: (1) holding down a single piston and (2) thrusting the Karlax in the direction of the right hand (...) A thrust onset generates a realistic bell tone in this composition."

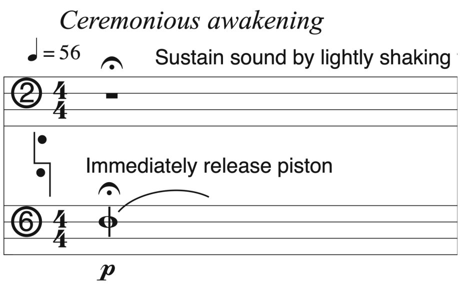

Fig. 1. The top four-line staff notates actions made with the left hand (e.g., pressing a key or a piston), while the bottom staff notates those with the right hand (Measure 1). Further details on the notation are presented in (Stewart 2015).

The *thrust* gesture triggers a complex gong-type sound with a dominant pitch. The shaking of the instrument controls the sustain of the resonance. The more the device is agitated, the more sustain there is.

This introductory gesture, quasi-theatrical, presents no specific difficulty and involves a basic level of control with the initial triggering of the sound and continuous management of the resonance (Fig. 2).

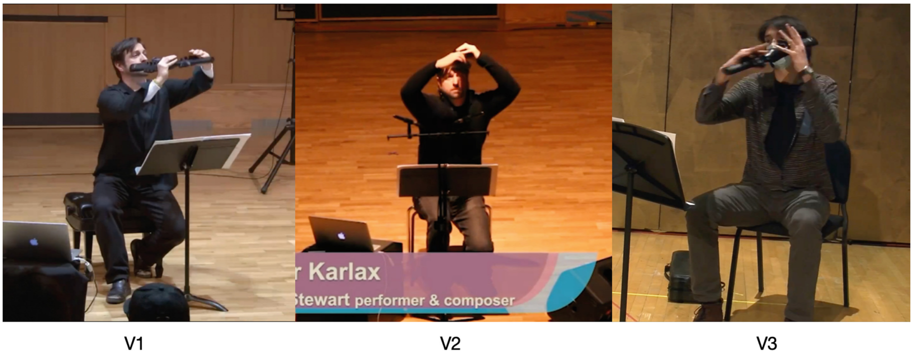

Fig. 2. Introductory gesture for the three versions

By comparing the three versions, we note significant differences in duration, which correspond to the interpretation of the fermata. V3 differs from the two other versions: the pitch of the gong sound is a half-tone higher (D#2 instead of D2), and ancillary bell sounds accompany the resonance. Though these bell sounds appear later in the two other versions, they are absent at this moment in V1 and V2. We also note that the performer in V3 performs rotational movements, which may have triggered the ancillary bell sounds as they appear later, whereas, in the first two versions, this gesture does not occur.

6.2 Melodic Play

The second excerpt is a descending melody in the high register composed of three notes, interpreted by fingering combinations on the continuous keys “The Karlax keys are used similarly to the keys of a piano keyboard in this composition. They are treated as discrete on and off signals." (Stewart 2016). The notes in the staves do not indicate pitches but keys to be pressed (Fig. 3).

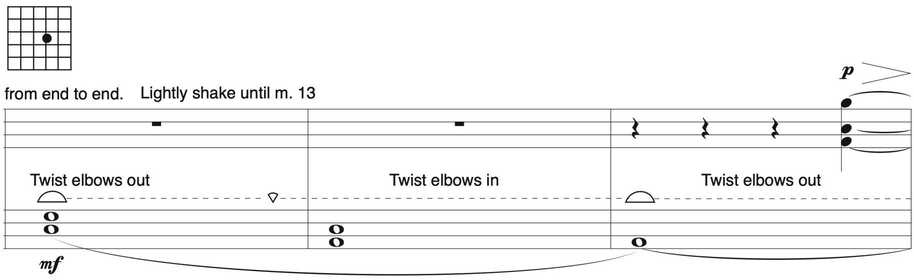

Fig. 3. Melodic play. Whole notes represent keys to be pressed. Timbre is controlled by rotating the axis and by tilting and rolling the Karlax. The grid with the dot indicates the Karlax inclination. Measures 2–4.

Bar 2 corresponds to simultaneously pressing keys 2 and 3 of the right hand until the end. Like in a standard MIDI keyboard, the keys are processed discretely, i.e., pressing the key until the end is necessary to get a signal.

Regarding the actual notes generated, in V1 and V2, we have the sequence Bb6, Ab6, and G6 (descending major second, then a minor second). In contrast, in V3, we have sequences A6, Ab6, and Gb6 (descending minor second, then a major second). This excerpt demands a higher level of control. A first gesture consists of playing pitches using specific fingerings, with control of timbre achieved by the rotation of the Karlax axis in combination with tilting and *rolling* (named by the author) (the roll angle also affects note sustain) and the shaking of the device (which produces a tremolo). Sound intensity is controlled by tilting and rolling the Karlax and rotating the instrument axis (Fig. 4).

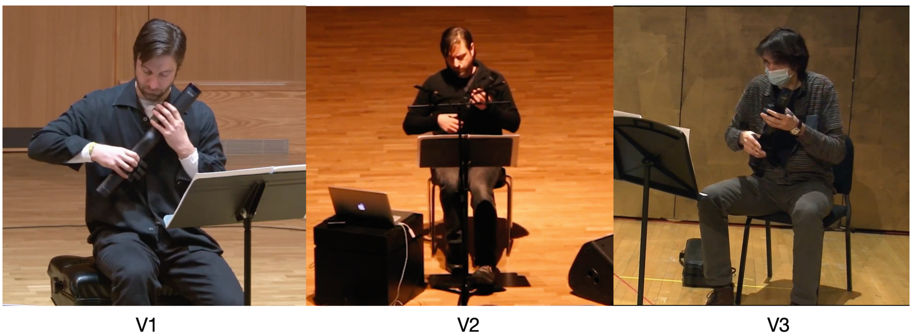

Fig. 4. Gestural posture for the three versions during melodic play (Measures 2–4)

This melody is played differently in the three versions: V1 is clearly articulated, with regular tremolo. V2 contains volume accents; in V3, sound intensity is lower, without tremolo. The indications "Lightly shake" and "Twist elbows in (or out)," the latter corresponding to the rotation of the device's axis, are freely interpreted. As before, there is a variation in pitch for V3 and the presence of extraneous bells.

6.3 Crescendo Followed by a Terminal Accent

The third excerpt consists of a progressive crescendo followed by an accent. This gesture is made up of several phases: first, the agitation of the instrument (named in the score *stir*) causes distortion, then the rotation of the axis initiates a crescendo amplified and modulated by the activation of the bend (maximum torque on the spring-like sensors at the end of each stroke of the Karlax axis), allowing to saturate the instrument's timbre (Fig. 5).

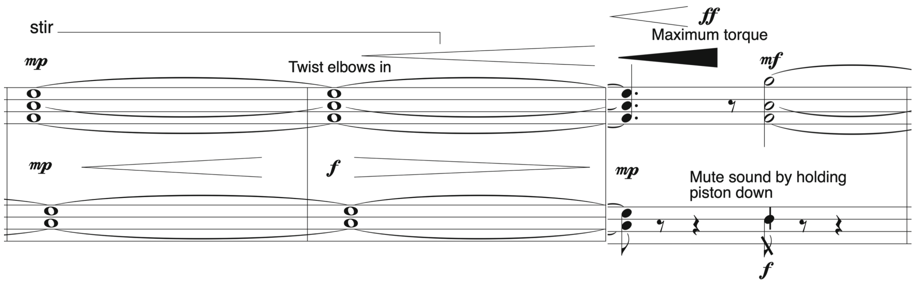

Fig. 5. Crescendo with a terminal accent (Measures 17–19). Whole notes correspond to the keys to be pressed. Amplitude and timbre are controlled by stirring the Karlax and turning the axis. The terminal accent is achieved by rotating the bend at the end of the axis rotation (Fig. 6).

In the score, the composer details these techniques as follows:

> "Stirring produces a dramatic sound color distortion of any sustained bell tones."
>
> "(...) the resistive twist space is referred to as "maximum torque" and is notated in the score as an opaque triangle, resembling a traditional crescendo symbol that has been filled in. (...) The result is increased loudness and a timbre modulation of the sound."

The three performance versions present a very different gestural expression with a large amplitude for V2, resulting in an important distortion effect. At the same time, V3 is much more contained, with little change in timbre.

7 Discussion

The analysis of the three excerpts shows a variety of musical and gestural expressions. Though these excerpts do not require virtuoso techniques, they contain subtleties in the control of timbre and the sequence of instrumental techniques that contribute to the richness of the sonic result. For the first part of extract A (the gong thrust), one can hear similar sound results even though the gestures are very different.

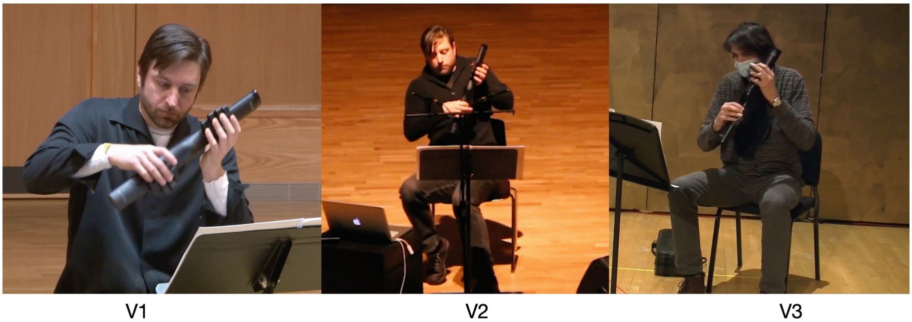

Fig. 6. Gestural posture for the terminal accent for all three versions (Measure 19).

Regarding body expression, the first two versions are more concentrated, and the gestures are slower, especially when moving from the attack to the control of the resonance. In contrast, V3 is more abrupt and shorter. There is a difference in the grip of the instrument for the attack in the two versions of the composer. In the 2015 version, the composer holds the Karlax by the center at the axis, facilitating the gong stroke. The performer in the V3 version rotates the instrument to control the resonance (likely to have triggered the ancillary bell sounds), whereas the composer moves the device longitudinally in the V1 version.

Furthermore, it would be interesting to investigate, in this specific case, to what extent the visual component of this gesture influences the perception of sound duration (Schutz & Lipscomb 2006). In other words, would one perceive the sound rendering in V3 as louder because the performer's gesture is more abrupt?

In the second part of extract A (the resonance), one notices that the link between gesture and sound is not evident because of the important latency between the gesture (agitation of the instrument) and the sound rendering (tremolo or sustain). In terms of control, the signal generated by the agitation of the device based on the algorithm for effort recognition is somewhat approximate because it seems difficult to obtain and maintain intermediate values of the signal accurately. These distortions between the visual and auditory parts complicate the identification of a specific character for each version. It is then challenging to determine expressive variations on a standard basis.

However, there are several solutions to this latency problem. The first and most obvious is to practice. By repeating the same gesture, the performer will get closer to the desired musicality, resulting in more confidence. Also, a calibration stage of the sensors may be necessary. Finally, a solution could be to adjust the effort recognition algorithm (scale, leak speed, and smoothing parameters) to be more responsive, so the gesture more closely matches the sound results. Moreover, it is interesting to note that the same phenomenon of latency can be observed in the acoustic instrumental world, especially with percussion instruments such as the tam-tam or the spring drum.

In excerpt B, one can perceive a more substantial similarity between the performances and more explicit interpretation choices, such as the calmer and more peaceful character of V1 and V3, compared to V2. However, the gestures are relatively different between the composer's version and V3. In V1 and V2, there is a longitudinal movement of agitation of the instrument, whereas, in V3, the instrumentalist makes almost no agitation.

In excerpt C, there are important gestural and musical amplitude variations across the three versions. The interpretation of V3 is more economical than the composer's intentions described in the score, especially in terms of nuances and distortion of the sound. If we focus on gestures, there are significant differences. The first two versions offer similar gestures even though the musical phrasing is different, with the instrument waving longitudinally and the device being raised and then leaning back during the accents. In the V3 version, the performer realizes rotations/gyrations, a sort of paddle stroke. Also, the link between gesture and music is unclear for the same reasons as in excerpt A.

Some gestures allow for limited control, such as the gong strike. Other gestures require the performer to listen to sound results to adjust the gesture, for example, during the sound saturation at the end of the third excerpt.

It turns out that the version that seems to possess the maximum expressive variation is the one that we identified as containing the highest level of control (V2). But one can easily imagine versions with a high level of control but low gesture/music legibility or transparency. So, what if we only focused our comparisons on the musical content? Would one have found the same differences?

The differences in the three performances highlight the rehearsal work needed to incorporate and control the different types of sound morphologies, but also possible technical issues with the particular interface used. Some of the differences in V3 are likely due to technical problems in the device used, the performer having reported issues with that Karlax, including piston malfunction. The many subtleties of the piece allow for a great deal of progression, developing expertise and providing both a sense of control and freedom that are the foundation of the pleasure of instrumental playing.

7.1 Suggestions for Practice Exercises Based on Gestures in *Ritual*

Let us return to the first gesture of the piece, the "gong strike" in excerpt A. The gesture *following* the activation of the sound ("sound-producing" (Jensenius et al. 2010)) could also be considered to have a communicative side. As already observed, this gesture contains an important theatrical aspect.

Can we imagine other types of control? For example, the indications of the Karlax's inclination (on the x and y axes, according to the dot on the tablature above the staves) could differentiate the note attack by favoring specific components (transients). Then it would be necessary to map the tilt data to the characteristics of the sound attack (e.g., distortion, sustain, resonators, etc.).

One could imagine that the stroke acceleration controls another parameter or that its combination with another gesture further differentiates the sound rendering. For example, the speed of a piston pressing could control the sound amplitude. In this case, if the performer activates a piston with more or less speed, this gesture could condition the amplitude of the resulting sound when the impulse is triggered. Some such features have been implemented in *Ritual*. For instance, the rotation speed is associated with the decay structure: a slow rotation produces a longer sound, while a fast/abrupt rotation produces a very short sound (Stewart, 2023).

Generally speaking, with more control complexity, the performer would approach this introductory gesture with a more precise "idea" of the resulting sound. Presumably, this could result in more significant expressive variation between each version. But is increased control complexity the composer's goal? In this musical context, the gong stroke seems to represent a kind of entry into the ritual like Claude Vivier's *Et je reverrai cette ville étrange*. It delimits the time of the ritual with a signal that does not require any particular change in the sound result. In any case, such suggestions could constitute the basis of a series of extended performance exercises with increased complexity, providing performers with material to develop dexterity and musicianship with the Karlax.

7.2 A Few Thoughts on the Use of Digital Instruments and Contemporary Music Creation

The use of digital musical instruments constitutes an opportunity for composers and performers to develop original approaches and to invest in a new field of musical creation (Ferguson and Wanderley 2010). The challenges related to DMI concerning sound synthesis, mapping, the link between gesture and music, and interaction strategies (Lavastre & Wanderley 2021) lead to rethinking the writing and interpretation practices.

Furthermore, instrumental identity has constantly evolved and adapted to musicians' and composers' needs and requirements. Moreover, listeners/viewers/audiences/experiencers also have an essential role in this evolution because composers and performers *play* with the audience's expectations. The cultures of playing, composing, and listening are interconnected and generative. In composing, it is with the development of *musique concrète instrumentale*, notably with the composer Helmut Lachenmann (2009), that the expansion of the notion of instrumental identity is one of the most spectacular. *Pression* for solo cello, *Guero* for solo piano, or *Salut für Caudwell* for two guitars are examples of this composer's extensive exploration of unusual playing techniques that question instrument identity. Therefore, it may be interesting to ask in what sense these playing techniques have or will have consequences for future instrument making. On the other hand, mixed pieces with an electronic part—or augmented instruments equipped with sensors—redefine and blur the instrumental identity.

In this context, digital musical instruments like the Karlax offer new perspectives. For this instrument, the cultures of composing, performing, and listening are still in their infancy, limited by the number of available instruments and a restricted repertoire. Consequently, this leads composers and performers to develop a trajectory—which seems to be the reverse of Lachenmann's—reinforcing the instrument's identity, notably by providing gesture–sound legibility during a phase of "acclimation" (Stewart, 2023). This phase is to convince the audience of the gesture-to-sound relationships within the context of a composition. Also, it seems that composers and performers need to develop a set of rules by developing original techniques and strategies, mapping, signal processing, sound synthesis, notation (Faber & Mays, 2014), (Stewart, 2015) and interaction with other instruments if applicable (Lavastre & Wanderley, 2021).

If we look at the compositional level, one of the challenges of writing with DMI will be to explore how the instrument "responds" to the composer's musical ideas and how it inspires them. Take the example of polyphonic writing with two voices with the Karlax. Two continuous keys control the amplitudes of these two voices, and the axis rotation and the sensors of the inertial unit control the timbre features. The independence of the timbre of each voice will not be perceptible because the same sensors are used for both voices. Therefore, the performer must find other ways to clearly render this musical idea.

The simplest way to achieve a polyphonic type of composition with the Karlax is to assign different sensors to each voice. But that supposes limited levels of control because the Karlax is made for holistic control of simple gestures. However, the many keys and pistons allow the performer to play a variety of key-activation techniques for polyphonic playing. The composer can also consider gate-type many-to-one strategies. In this case, some sensors are activated only when combined with other sensors. This allows differentiation of the control level for the same gesture but requires alternating the control for each voice. By adjusting each of the triggers and varying the control levels of each voice, the instrumentalist can create the illusion of polyphonic writing with independent control.

With this example, we show how limitations linked to the interface are circumvented to achieve musical intentions. The composition process is deeply dynamic, and the choices made by the composer result from balancing between the domains of performance, programming, musical composition, notation, etc., that transcend the mere idea of sound–gesture associations.

On the other hand, reinterpreting a piece with a digital musical instrument or gestural controller such as the Karlax can be much more demanding technologically than a piece for an established acoustic instrument. Among other things, the interface, the computer running the sound synthesis, the conditioning of Karlax's data, and the mapping must be brought together. Similarly, fitting typically in the context of contemporary/experimental music, performances with DMIs might also suffer from the newness aesthetics in performances where the reproducibility of existing repertoire might not necessarily be the first objective of composers, performers, or ensembles.

Paradoxically, an ensemble composed of acoustic instruments and a Karlax, the Fabrique Nomade, has performed and recorded many times the pieces in their repertoire, some of the pieces more than 30 times since 2013 (Faber, 2022). This is a unique situation, many pieces composed for contemporary music ensembles are rarely reperformed after their creation. In that case, the questions of longevity and reproducibility are intrinsic to their performance by Fabrique Nomade and are addressed very early on by the ensemble. Furthermore, collaborations with composers are often longer than average in similar situations; an average collaboration lasts two years with the ensemble Fabrique Nomade.

8 Conclusion and Future Work

Acquiring, learning to play, and keeping a medium- to long-term performance practice with DMIs can be challenging, though examples show they are possible. In this study, we performed a comparative performance analysis focusing on a piece written for a particular gestural controller. The analysis was based on Rolf Inge Godøy's notion of sound–gesture relationships, focusing on the importance and diversity of gestural activity in instrumental performance. In this context, the piece *Ritual* by D. Andrew Stewart for solo Karlax offers an exciting study object as gestures constitute the source of the writing. We compared different interpretations of some excerpts of the piece from sound morphologies and identifiable musical phrasings. Though these excerpts do not present specific technical difficulties, they contain subtleties in the timbral control that allow for variations in interpretation.

In future work, a closer examination of existing analytical tools for a comparative study of interpretations with video seems particularly important in our approach. Furthermore, it would be interesting to compare different interpretations of pieces where the Karlax interacts with acoustic and digital instruments. By allowing a differentiated level of control for each part of the piece, the composer also gives the performer and the listener something to conceive, organize, and perceive musical ideas. Rather than a "virtualization" seeking the precision of the control of an acoustic musical instrument, it seems that it is in the interplay of the relations between the composer, the performer, and the listener that the challenges and the richness of the interpretation with a gestural controller lie.

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