Audiovisual Perception of Musical Interactions in Mixed Pieces with the Karlax

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Abstract. Digital Musical Instruments (DMIs) add new layers of complexity to musical performance by physically embodying electronic sound control. Despite growing studies on the design of DMIs, little research has investigated how DMIs are understood in real musical contexts by listeners. Inspired by the interactive potential between DMIs and acoustic instruments, this study investigates the perception of interactions between Karlax (a model DMI) and acoustic instruments. Six duo pieces were composed by student composers for Karlax and various acoustic instruments. An eight-category taxonomy of interaction types was proposed by the authors based on the pieces. Thirty-six musicians participated in a free-sorting task, grouping 32 selected excerpts according to perceived interaction types and providing descriptions for each group. Hierarchical cluster analysis revealed that some predefined interaction categories were successfully identified by participants. Moreover, "dialogue-like" interactions were distinguished from "non-dialogue" interactions. The results also suggest a perceptual framework of musical interaction with three musically relevant dimensions: *temporality*, *synergy*, and *prominence*. This study highlights the embodied potential of DMIs to function as fully interactive partners alongside acoustic instruments. The results offer empirical evidence of how complex musical interactions involving novel digital instruments might be mentally organized by listeners.

Keywords: Embodied musical interaction · Digital Musical Instrument (DMI) · Karlax · Multimodal perception · Motion and gesture.

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1 Introduction

A Digital Musical Instrument (DMI) is commonly defined by three parts: the interface, the sound synthesis and the mapping, which associates the sensor data from the interface with the sound synthesis parameters [13]. This means that for a DMI, unlike an acoustic instrument, the body of the instrument with which the performer interacts is separated from the sound-generating device (e.g. computer and loudspeakers), entailing an infinite number of possibilities in the sound-gesture relationship. For acoustic instruments, this relationship is determined by the physical behavior of vibrating structures (air column, reeds, membranes, etc.). For DMIs, on the other hand, this relationship must be staged by composers/performers implying new elements of language with audiovisual aspects [9]. Furthermore, an interface equipped with sensors has no sound identity. Its identity can evolve over time, similar to a digital synthesizer with several pre-defined timbres. In this sense, mixed music involving DMIs offers challenging perspectives. It brings together instruments whose sound identity and playing techniques are generally well-known with instruments whose identity is more fluid.

Among existing DMIs, the Karlax is an interesting candidate. This clarinet-shaped gestural controller was developed in the early 2010s and has an active user community with numerous creations. Its main sensors are 10 continuous keys, 8 velocity pistons, a rotating axis, and an inertial measurement unit (IMU) with 3 axes of accelerometers and gyroscopes. Its ability to detect subtle and larger gestures, its robustness, portability, reliability, continuous and event based control, low latency and high bandwidth wireless system have been praised [11]. In addition, there exists a substantial literature around this interface on notational strategies [11, 16] and analyses focusing on either Karlax itself [9] or its interaction strategies with other acoustic instruments [8] used in real-world music. The latter article is of particular interest to this study in that it proposes several interaction strategies between DMIs and acoustic instruments based on perceptual criteria.

Given the rich possibilities of writing for DMIs and acoustic instruments in the context of mixed music, we decided to specifically investigate the relationship between the Karlax and one acoustic instrument through the lens of interaction. By doing so, we explored the theoretical and perceptual notion of musical interaction in general. Another impetus behind the current study is to examine the relationship between compositional strategies around musical interaction and their reception by the audience.

1.1 General Background

The current study forms part of a larger research-creation project that explores the writing for Karlax in interaction with acoustic instruments. The creative part of this project proposes an initial set of interaction strategies [8] that inform a corpus of six pieces involving the Karlax and various formations of acoustic instruments by the third author.

The research part of this project is concerned with listeners' perception of the role of Karlax in various mixed music contexts and the interactive dynamics between Karlax and the acoustic instrument, using various musical outputs from the creative part of the project as experimental stimuli. An earlier experiment was conducted prior to the current study where the real-time perception of the prominence of Karlax was measured on a piece written for Karlax and an ensemble of 13 musicians (*Instrumental Interaction I* composed by the third author in 2022). The primary takeaway from the first experiment is consistent with those from earlier studies [4, 2], that visual cues contribute significantly to the perception of gestural expression in music, which are crucial components of music for DMIs [5]. It was observed that a stronger identity was perceived on Karlax when the underlying sound synthesis produced more electronic-like sounds that are well differentiated from those of acoustic instruments. Despite these preliminary findings, the limitation of this earlier experiment is clear: the measure of perceived prominence is too generic to allow substantial inferences to be made about any specificity of interaction between Karlax and other instruments. The current study was thus proposed to address the problem of the perception of musical interaction directly.

1.2 Current Experiment

This study investigates the perceptual categorization of musical interactions between the Karlax and acoustic instruments through a free-classification experiment, inspired by [12] and [7].[1] It follows a creative phase involving the composition of six duet pieces for Karlax and one acoustic instrument, from which audiovisual excerpts were selected as experimental stimuli. One piece, *Instrumental Interaction II* (for Karlax and tenor saxophone), was composed by the third author. Five other works were composed by undergraduate students enrolled in a course on mixed music at McGill University (winter 2023 and winter 2024). The main objective of this course is to write a piece with an acoustic instrument and a fixed electronic part. Students had the opportunity to compose for an acoustic instrument and a DMI, instead, as part of a workshop.

A presentation of the workshop and a demonstration of the Karlax and the T-Stick [10] took place during the first class. Two students were interested to write for Karlax in the first year (2023), and three in the following year, all of whom had composed at least one electroacoustic piece during the previous semester. The workshop consisted of approximately 12 sessions. During the first session, the use of interfaces, the functioning of sensors, and data behaviors were presented. Next, basic data conditioning techniques (scaling, smoothing, etc.)

[1] In [12], the authors looked at a contemporary chamber piece and investigated how listeners classify sub-thematic materials drawn from different thematic sections in the piece according to their resemblance. In [7], the authors investigated the perceptual validity of the Temporal Semiotic Units (TSUs) model by asking participants to freely group musical excerpts corresponding to different TSUs based on how much they sounded alike.

and basic mapping, diffusion, and spatialization strategies were presented. They were shown how to use the software interface designed for ease of use. Discussions were held on the main issues in the composition, performance, or perception of pieces involving DMIs, such as the importance of gesture and movements, and parametric writing. There was also a brief exchange on composition strategies with acoustic instruments. Finally, notation strategies for the Karlax were introduced [11, 16]. The acoustic instruments featured in these five pieces were double bass (*Echoic Interference*), percussion (*Effervescence*), viola (*Rise of the Virusheads*), alto saxophone (*Amorphous*), and guitar (*Pink Engine*).

2 Method

2.1 Participants

For the experiment, 39 participants with normal hearing were recruited who identified themselves as musicians. Three participants' data were not included in the subsequent data analyses after a preliminary screening of their verbal data (see Procedure section below). Thus, 36 participants were included in the data analyses (male = 20, female = 15, non-binary = 1) with an average age of 25 years (SD = 6.2) and an average of 15 years of musical training and practice (SD = 4.0). Participants were paid for their participation. The experiment was certified for ethical compliance by McGill University's Research Ethics Board II.

2.2 Stimuli

The stimulus set consisted of 32 audiovisual excerpts selected from six original duet compositions for Karlax and acoustic instrument.[2] The full compositions were recorded in the Multimedia Room (MMR) at McGill University, using fixed-camera frontal framing to ensure consistent visibility of the performers. From these six works, the first three authors collaboratively selected short excerpts ranging from 4 to 23 seconds in duration, chosen to exemplify salient interaction behaviors between the performers. Excerpt selection followed a multi-stage procedure: (1) a preliminary review of all six works to define an initial set of potential interaction categories, freely inspired by the interaction strategies introduced in [8] and grounded in observable performative and musical behaviors; (2) individual annotation of four pieces per author, with time-coding of candidate interaction passages; (3) the development of an eight-category interaction taxonomy (see Fig. 1) and a preliminary selection of excerpts mapped to those categories; (4) internal rating of each excerpt's clarity and salience according to the taxonomy on a 3-point pertinence scale—only excerpts receiving average ratings at or above 2 were retained (see Table 1).

Fig. 1 displays the interaction taxonomy created for the experiment. The eight predefined categories were grouped into two meta-categories: "Dialogue" and "Non-dialogue." The categories were: *Mirror dialogue* (MD, the Karlax fully

[2] Excerpts can be viewed here: https://figshare.com/s/69bb4d67d2357ae86009

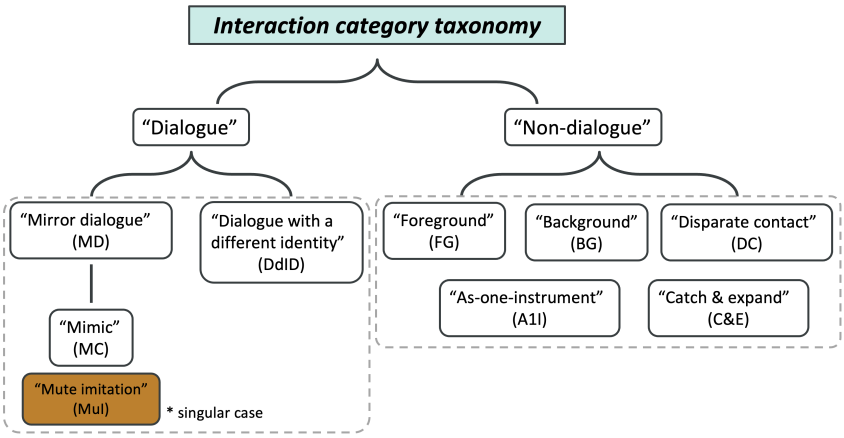

Fig. 1. The predefined eight-category interaction taxonomy that was used to label the 32 excerpts. The eight categories are organized under two meta-categories ("Dialogue" and "Non-dialogue"). Abbreviations of the categories are shown in parentheses and are used throughout the paper when appropriate.

adopts the identity of the acoustic instrument while playing potentially distinct material), *Mimic* (MC, the Karlax imitates local gestures from the acoustic instrument without full identity fusion), *Dialogue with a different identity* (DdID, both instruments maintain distinct sonic identities but actively engage with one another), *Foreground* (FG, the Karlax is supported by the other instrument), *Background* (BG, the Karlax provides a supporting ambient or harmonic layer), *Disparate contact* (DC, both instruments act independently, with no apparent engagement or response between them), *As-one-instrument* (A1I, the Karlax fuses with the acoustic instrument to create a unified hybrid voice), and *Catch & expand* (C&E, the Karlax captures a gesture from the acoustic instrument and develops it into something new). A special case, *MuI, Mute imitation*—in which the Karlax player mimics the physical gestures of the other performer without producing sound—was also included to label one particularly salient excerpt, though it was kept outside the main taxonomy.

2.3 Apparatus

Participants were seated in an IAC model 120act-3 double-walled audiometric booth (IAC Acoustics, Bronx, NY). The experiment was run with the PsiExp computer environment [15]. Video excerpts were displayed on a computer screen. The audio was amplified through a Grace Design m904 monitor (Grace Digital Audio, San Diego, CA) and presented over Sennheiser HD280 Pro earphones (Sennheiser Electronic GmbH, Wedemark, Germany). Participants performed all the experimental tasks with a mouse and a keyboard.

Table 1. Summary of excerpt selection showing the number of excerpts for each piece and each predefined interaction category.

	Interaction Types									
Titles	**BG**	**FG**	**DC**	**A1I**	**C&E**	**MD**	**MC**	**DdID**	**MuI**	
Amorphous	1	0	0	2	1	0	0	1	0	**5**
Echoic Interference	0	1	1	1	0	1	1	1	0	**6**
Effervescence	0	1	0	2	1	1	1	0	0	**6**
Instrumental Interaction II	1	0	0	0	0	0	1	2	1	**5**
Pink Engine	0	1	2	0	0	1	0	0	0	**4**
Rise of the Virusheads	3	0	0	2	0	1	0	0	0	**6**
	5	**3**	**3**	**7**	**2**	**4**	**3**	**4**	**1**	**32**

2.4 Procedure

The experiment is composed of three parts. First, participants were required to watch and listen through all 32 excerpts for familiarization. Then, they were asked to sort the excerpts into as many groups as they want according to the similarity in terms of the perceived interaction between the Karlax player and the acoustic instrument player. The working definition of "interaction" was introduced to participants as two-way communication where each party is aware of (and possibly influencing) the other. Participants could re-watch each excerpt as many times as they wanted. For the third part, participants reviewed each group they created by re-watching each excerpt again. They rated each group on how strongly the grouped excerpts belong to one clearly defined group by placing a freely movable cursor on a scale from *Very weak (poorly defined group)* to *Very strong (Clearly defined group)*. Additionally, participants provided verbal descriptions for each group in terms of the interaction they perceived. A preliminary check on participants' verbal descriptions showed that three participants described mostly surface level features (e.g., texture and timbre of the sounds) within each group rather than interactive behaviors between the two players. As these participants clearly misunderstood the task, their data were not included in the following data analyses.

3 Results

3.1 Hierarchical Cluster Analysis

A 32-by-32 weighted co-occurrence matrix was calculated, which summarized how often each pair of excerpts was placed in the same group by participants (weighted by the "belongingness" rating of each group). For the hierarchical cluster analysis, the co-occurrence rate was treated as a measure of similarity between excerpts, i.e., excerpts which were grouped together more often were more similar in terms of perceived interaction. Fig. 2 shows the hierarchical tree structure resulting from the cluster analysis. Excerpts that are joined lower on the tree share greater similarity than those joining higher up on the tree. To interpret the tree structure in terms of discrete classes of excerpts that could reflect

the average categorization choices of all participants, a dissimilarity threshold of .88 was chosen which gave rise to seven classes of excerpts.[3]

As can be seen in Fig. 2, only Class 7 is entirely composed of excerpts coming from a single interaction category ("Background"). Two other classes also have an almost one-to-one mapping with single predefined categories: Class 3—"As-one-instrument", and Class 5—"Disparate contact". Notably, all excerpts that fall under the meta-category "Dialogue" (except Excerpt 21 labeled singularly as "Mute imitation") are contained in Classes 1 & 2, which almost exclusively differentiate themselves from the rest of the classes.

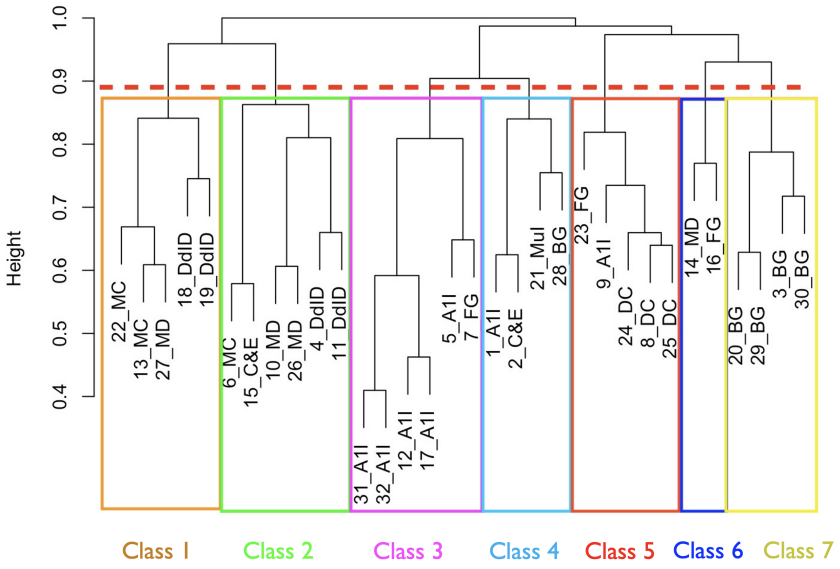

Fig. 2. Hierarchical tree structure of the 32 excerpts. A cutoff threshold at .88 yields seven classes as annotated in the figure. Each excerpt is labeled by a number followed by its categorical label according to the predefined interaction taxonomy.

3.2 Verbalization Analysis

In order to interpret the seven perceptual classes of excerpts, participants' verbal descriptions of groupings were processed and assigned to each of the classes. If a participant-generated group contains at least 60% of the excerpts in a specific

[3] The decision of this dissimilarity cutoff point was made so that the resulting number of classes was as close as possible to the number of predefined interaction categories (8) while also aiming for a parsimonious model.

class, and the class also contains at least 60% of the excerpts in that group, then the verbal description of that group is assigned to the class. Afterwards, key words and phrases that explicitly described interactive behaviors were singled out as lower-level codes, from which emerging higher-level themes were then extracted. The extracted themes are presented below. Numbers in parentheses indicate the number of participants contributing to the class or theme. Overall, all classes of excerpts are associated with distinct themes except Classes 4 & 6, for which no consistent themes were found.

- **Class 1** (8): *Togetherness/Agreeing*(5); *Conversation*(4);
- **Class 2** (7): *Call & response*(6); *"Polyphony"*(2)
- **Class 3** (11): *Synergy*(11)
- **Class 4** (3): (No themes extracted)
- **Class 5** (15): *Opposition*(8); *Simultaneity*(6); *Unbalance*(5); *Independence*(4);
- **Class 6** (3): (No themes extracted)
- **Class 7** (8): *Accompaniment/Subordination*(7)

Participants' descriptions associated with Classes 3, 5, and 7 align rather well with the authors' definitions of the corresponding predefined categories, which parallels observations from the cluster analysis. Classes 1 and 2 combined suggest the idea of dialogue and conversation, which aligns with the fact that excerpts contained in these two classes are mostly from the meta-category "Dialogue".

3.3 Multidimensional Scaling

To visualize and better examine the relationship between different excerpts and the seven interaction classes, the dissimilarity matrix was also subjected to ordinal multidimensional scaling (MDS), a technique frequently used to visualize proximity data and uncover latent psychological dimensions of judgment [1]. For ease of visualization, a two-dimensional model was calculated.

Fig. 3 shows the MDS configuration with the seven classes identified in hierarchical cluster analysis annotated additionally. The closer two excerpts are to each other, the more often they were put into the same interaction category by participants (i.e., the more similar they are in terms of the perceived interaction). All seven classes are reasonably well differentiated from each other with distinct boundaries (with the exception of Excerpt 20 which lies outside of the main class to which it belongs).

4 Discussion

4.1 Perceptual Data

A deeper insight into the perception of musical interaction displayed by these excerpts can be gained by interpreting the two dimensions underlying the "interaction space" given by MDS analysis. After viewing all excerpts in relation to their positions on the MDS space, the two geometrical dimensions were found to

bear significant correspondence to independent musical features: referring back to Fig. 3, the horizontal dimension was interpreted as relating to the temporal nature of the two players' playing (*simultaneous* [left end] vs. *separated* [right end]), and the vertical dimension was interpreted as relating to the degree of sonic and physical synergy between the two players (*agreeing/match* [lower end] vs. *disagreeing/mismatch* [upper end]).

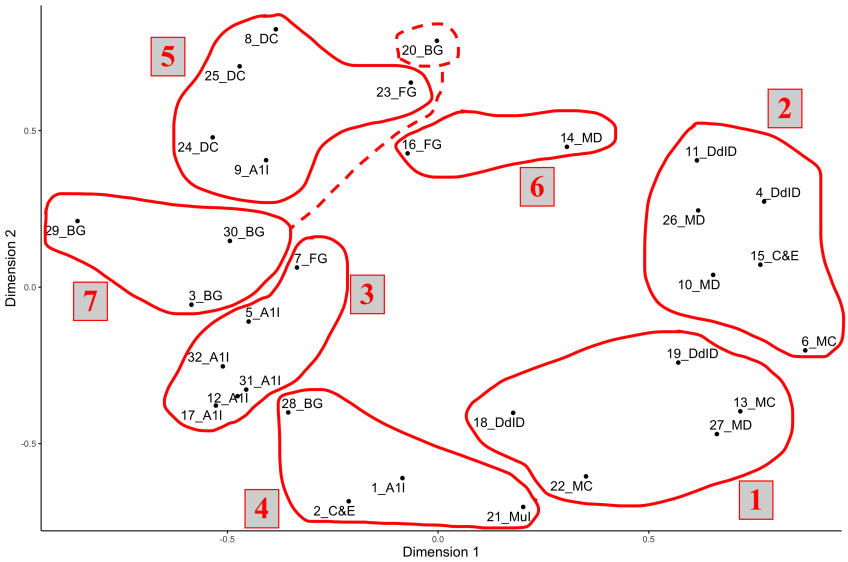

Fig. 3. MDS configuration of the 32 excerpts based on the dissimilarity matrix. The seven classes obtained from the hierarchical cluster analysis are drawn on top of the MDS space.

Focusing on the horizontal dimension, classes that are situated on the opposite ends clearly exhibit the supposed dichotomy in term of temporal features: as shown by participants' verbal descriptions, Class 1 on the right end is characterized by alternating playing, whereas Classes 3, 5, and 7 involve a much higher degree of simultaneity between the two players. Notably, the temporal aspect suggested by this dimension seems to be a dividing factor between "dialogue-like" interactions (Classes 1 & 2) and "non-dialogue" (the other classes). The idea of "dialogue" seems to come across more readily when the two players' parts are somewhat (or even completely) separated in time, as opposed to playing simultaneously.

Zooming in on the synergy dimension, Classes 5 and 3 exemplify opposite kinds of synergy between the two interacting parties. Importantly, the concept of synergy defined on this dimension is multimodal, meaning that both sonic and

visual cues are involved in the perception of degree of "matchingness". As an example, Excerpt 20 is situated at the upper end of the synergy dimension. In this case, the "disagreeing" nature between the two players is primarily delivered through the sonic cues, where Karlax's electronic drone sound is timbrally contrasting to that of the saxophone. On the other hand, for Excerpt 21, which is situated on the "agreeing" end of the dimension, the visual cues are the ones suggesting inter-player synergy: while Karlax is practically not making any sound, the Karlax player mimics the physical movements of the other player almost in synchrony.

4.2 Music Analysis

Despite the limitations of the experiment—particularly the short duration of the excerpts—the MDS model presented above still offers valuable insights for both music analysis and composition. The synergy axis, in particular, is especially relevant for mixed music involving DMIs. Commenting on their works, several composers emphasized the Karlax's dual role as both a complementary and transformative agent, often describing it as an extension of the acoustic instrument's capabilities. In *Amorphous*, for instance, the composer designed interactions where the Karlax processes and transforms acoustic material such as key clicks, growls, and trills. Other works explored possibilities that exceed human physical technique—for example, in *Effervescence*, the composer wrote a tremolo that would be unplayable by a human performer, using the Karlax's granulator effect applied to recorded temple block samples. A key affordance of the Karlax, which distinguishes it from traditional acoustic instruments in generating different musical interactions, lies exactly in its ability to navigate flexibly across a wide sonic identity spectrum.

Another important finding emerges when looking at cases in which the Karlax and the acoustic instrument perform simultaneously but with contrasting material. Participants' interpretations in such cases varied depending on the Karlax's role (as reflected in verbal descriptions in Class 5). When the Karlax played drone-like, textural, or background material, it was generally perceived as supporting or accompanying the acoustic instrument. Conversely, when it produced more prominent or active gestures, it tended to be perceived as competing with or overpowering the acoustic part. This observation suggests the emergence of a third perceptual dimension—*prominence*—which reflects the relative salience or dominance of one instrument over the other. Prominence could serve as a useful complement to the existing two-dimensional framework. While acoustic instruments typically achieve prominence through parameters like register, dynamics, or textural density, the Karlax introduces new means such as spatialization, filtering, or occupying a broader or narrower portion of the frequency spectrum.

An area that remains relatively underexplored—but is essential for a deeper understanding of DMIs—is the role of gesture in shaping perceived interaction. In this study, gesture was especially salient in the "As-one-instrument" category, notably mapped in Class 3. In many excerpts, perceptual fusion was reinforced

by visual mirroring between the performers—such as bow-like gestures on the Karlax imitating string movements in *Rise of the Virusheads*.

5 Conclusion

In this article, we presented a perceptual experiment on the perceptual categorization of musical interactions in duet pieces between the DMI Karlax and an acoustic instrument. The results overall indicate that listeners were able to differentiate a diverse range of abstract interactions into meaningful categories. This suggests that the part played by the Karlax was largely perceived as an entity capable of interacting with other parts. Analyses of the perceptual data and music also suggest a useful three-dimensional perceptual model—emphasizing on temporality, synergy, and prominence—that can be used as a compositional and analytical tool regarding musical interaction.

It is important at this point to outline and re-state the prerequisites of the experiment, which at the end delimits the scope of the current project: we focused on a particular DMI, the Karlax, which resembles an acoustic instrument in its physical appearance. Furthermore, five of the six pieces chosen for the experiment were composed as part of the previously mentioned workshops. The technical setup behind these pieces was clearly specified during the workshops. Students had to compose using a quadriphonic system for the first year and an octophonic system for the second year. The patch provided to students contained sampling, granulation, and spatialization modules (ICST Ambisonics [14]). For the second year, they could also control the level and parameters of DSP modules such as delays (Valhalla FreqEcho), reverberation emulator (Valhalla Supermassive), and guitar amp simulator (Amped Roots). In terms of the stimuli selected for the experiment, it is necessary to note that the experimenters determined the most relevant excerpts from the pieces and decided on their length. All in all, one can imagine that the audiovisual conditions experienced by the participants in the experiment could be quite different from those in a real concert.

Mixed pieces with DMIs such as the Karlax form a particular genre in that they involve an instrumentalist embodying an electroacoustic part on stage. The mechanisms of multimodal perception induced by the sound/gesture relationship represent interesting constraints for composers and performers [6]. In addition, the use of a DMI offers the possibility of gestural and sonic interactions conducive to the invention of new elements of language and instrumental techniques. In this sense, the study of perceptual mechanisms is crucial to understanding the most idiomatic situations for this type of piece and enabling compositional techniques to evolve. For future work, it would be interesting to investigate other DMIs in the same context, in particular instruments that feature an original design and allow both sound and gestural interaction with acoustic instruments, such as the T-Stick [10] or the Meta-Instrument [3]. Furthermore, an in-depth study of the relationship between sound (or other media) and gesture at the perceptual level seems of particular importance.

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