Understanding User-Defined Mapping Design in Mid-Air Musical Performance

Dom Brown
University of the West of England
Coldharbour Lane
Bristol, UK BS16 1QY
dom.brown@uwe.ac.uk

Chris Nash
University of the West of England
Coldharbour Lane
Bristol, UK BS16 1QY
chris.nash@uwe.ac.uk

Tom Mitchell
University of the West of England
Coldharbour Lane
Bristol, UK BS16 1QY
tom.mitchell@uwe.ac.uk

ABSTRACT

Modern gestural interaction and motion capture technology is frequently incorporated into Digital Musical Instruments (DMIs) to enable new methods of musical expression. A major topic of interest in this domain concerns how a performer's actions are linked to the production of sound. Some DMI developers choose to design these mapping strategies themselves, while others expose this design space to performers. This work explores the latter of these scenarios, studying the user-defined mapping strategies of a group of experienced mid-air musicians chosen from a rare community of DMI practitioners. Participants are asked to design mappings for a piece of music to determine what factors influence their choices. The findings reveal novice performers spend little time reviewing mapping choices, more time practising, and design mappings that adhere to musical metaphors. Experienced performers edit mappings continuously and focus on the ergonomics of their mapping designs.

CCS CONCEPTS

• **Human-centered computing → Sound-based input / output**; **Gestural input**; **Empirical studies in HCI**;

KEYWORDS

Digital Musical Instruments; Mid-air Interaction; Mapping; User-Defined Interaction.

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Figure 1: The data glove instrument.

1 INTRODUCTION

The introduction of computational systems to musical instrument design has enabled movement away from traditional musical interfaces, such as chromatic keyboards, towards novel interaction methods, typically those prominent in HCI [15], including mid-air motion capture technologies [8, 28, 29]. With no established guidelines on how these novel interfaces should be utilised for musical expression, the connection between a performer's actions upon an interface and the sound that it produces, or the instrument's *mapping strategy* [16, 27], has become a new creative domain for instrument designers [18] as well as end-users [12].

DMIs often have only one practitioner, who is usually also the instrument's designer [23]. However, a small community of practitioners has grown around a pair of data gloves used for musical performance (Figure 1). Many of these practitioners are musicians having committed their professional practice to learning, practising and performing with the gloves. These dedicated glove musicians are a rare resource in the field, and understanding their creative practice can allow us to better understand how to facilitate interactions that engage musicians and performers, and to create better tools for musical expression.

In this study, the mapping design practices of these glove musicians is explored. Previous research has examined the perspective of composers in mapping design [10]; the focus in this research is on the performer's perspective, with participants tasked with designing performance mappings for pre-determined musical material. The research contributes new findings into the mapping practice of novice and experienced DMI performers.

2 BACKGROUND

2.1 Mid-Air Interaction

Mid-air interaction is an interaction method that does not rely on a user physically manipulating an interface, but instead relies on the direct detection of a user's bodily movements; thus a user interacts with the space, or in the air, around them. Mid-air interaction has

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been used previously for controlling music [25, 29], and is a popular interaction method for music systems, most notably Michel Waisvisz's "The Hands" [30] and the Theremin.

Mid-air interaction is hailed as a natural and intuitive interaction style, which provides an unmediated form of control with no constraints on human movement [14, 33]. However, the interaction style does have a series of issues: users often report "gorilla arm" [14] after spending long periods of time using mid-air systems, and their propensity for error-proneness causes frustration and confusion among users [3].

2.2 User-Defined Mapping

Previous research in computer music has used user-defined mapping techniques to explore the cognitive link between sound and gesture, asking participants to perform gestures for short pieces of musical stimuli, which are then used to train machine learning algorithms [12], as well as being used to elicit user-defined gestures for a set of musical interaction metaphors: shuffling, shaking, fishing and shaping [6].

While user-defined mappings almost always guarantees an interaction that is meaningful and engaging for the specific performer who created it, it does not necessarily lead to mappings that provide the same level of engagement and enjoyment for other stakeholders, such as spectators or other performers.

2.3 The Mapping Problem

Connections between action and sound in DMIs can be changed on-the-fly and are nearly unlimited in possibilities, presenting a new challenge for designers that is not present in acoustic instruments: with no physical laws defining how actions are expressed as sound, what should influence the design of DMI mappings?

Much of the literature agrees that a DMI mapping strategy should provide an engaging interaction for performers and audiences alike [18, 27], and that mappings should allow novice players to achieve some musicality with little investment and allow experienced players to achieve highly expressive and virtuosic performances [31].

It has been argued that using metaphor in DMI mapping design helps to provide an engaging interaction with a "low entry fee with no ceiling on virtuosity" [31], and that metaphor creates "transparent" mappings for both performers and audiences [9].

2.4 The Importance of Experienced Users

To examine virtuosic and expressive performance with a DMI it is important to study the interaction of experienced performers. However, DMIs often suffer from an issue of a lack of practitioning musicians beyond the initial designer [23]. This issue is compounded further in the case of mid-air instruments, as unlike other studies, such as [22], in which an existing body of expert pianists can be called upon for evaluation, mid-air instruments have no such acoustic counterpart, and require virtuosos of their own.

3 THE GLOVES

The instrument used in this study is a pair of data gloves (Figure 1) that use bend sensors along the back of each finger and an Inertial Measurement Unit (IMU), to provide an accurate representation of the wearer's hand posture and orientation in space.

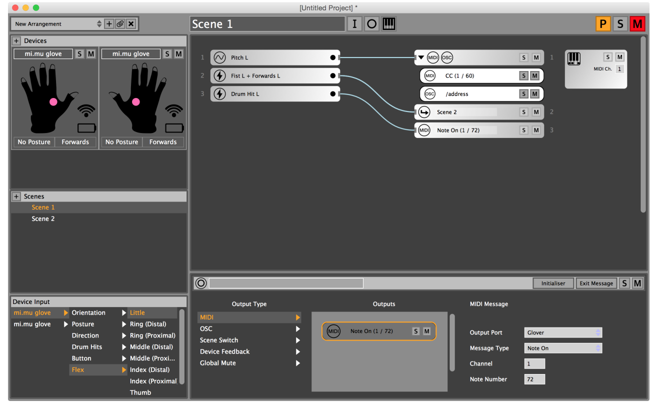


Figure 2: The Glover mapping software.

The gloves are used alongside a dedicated piece of software called Glover (Figure 2) which has been designed for end-users to create mapping strategies. The software converts the raw sensor data provided by the gloves to a variety of input parameters: for example, orientation data provides yaw, pitch and roll parameters, while flex sensor readings provide joint angle parameters and posture parameters via a classification algorithm. These control parameters can be mapped to auditory controls via MIDI or OSC using one-to-one, one-to-many, and many-to-one methods [16, 27]. The software gives users direct and creative control over how their movements and gestures are mapped to sound output.

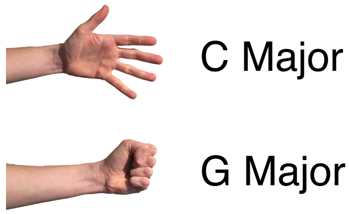
The mapping software categorises the glove data into three types:

- *Movements* Continuous controls derived from body movements, such as the pitch, yaw and roll of the wrist, and the amount of flex of each finger.
- *Events* Controls that notify that a specific action has occurred, such as drum hits.
- *Qualifiers* Controls that can either be occurring or not, such as specific hand postures (such as fist, open hand, one finger point) and current arm orientation (up, down, left, right etc.).

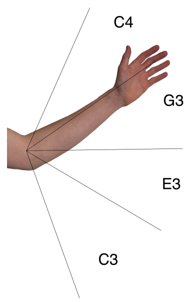
Mapping connections are made using a patch cord and object metaphor, with gestural input objects on the left being connected to MIDI/OSC output objects on the right (Figure 3). The software organises mappings into *scenes*, which can be switched between on-the-fly. This allows musicians to *scene switch*, which is generally used to perform more musical material than would be cognitively or physically possible using one scene. For example, one scene may be used to map events to trigger drum samples, while another may map movements to synthesiser parameters.

Figure 3: The patchcord connection metaphor.

The software also includes two built in "instruments" for controlling multiple notes (Figure 4).



(a) An example of the Chord Machine being used to map open and closed hand postures to chords.



(b) An example of how the Note Matrix splits an axis into thresholds for note triggering.

Figure 4: Mapping Instruments' Behaviour.

- *Note Matrix* This splits a movement parameter (such as the pitch of the wrist) into a series of thresholds, which, when crossed, trigger successive notes in a chosen scale.
- *Chord Machine* This allows for multiple notes to be played at once, triggered by selected qualifiers or events.

3.1 The Glove Community

The gloves have been developed over several years and have appeared in previous research [24, 28]. Like most DMIs the gloves started with a single practitioner, but over time have amassed a small but active group of dedicated users. Many of these users have adopted the gloves into their professional performance practices, superseding other instruments as their main mode of musical expression.

4 METHOD

The study involved a five-person focus group of mid-air instrument musicians, who regularly design their own action–sound mappings. The group were asked to individually complete a mapping exercise before participating in a group discussion.

4.1 Mapping Design Task

Participants were given 1 hour to develop mappings that would enable them to perform a piece of monophonic piano music. The mapping needed to incorporate control of multiple notes and three expressive parameters: vibrato (pitchbend); dynamics (volume control); and timbre (a low pass filter). While the note order and timing were fixed, participants were given the freedom to incorporate the expressive parameters as they wished. Pitch, time, timbre and dynamics are fundamental dimensions of music [26], and the articulation of notes, which covers pitch and time, is an important part of music making and warrants study in gestural interaction.

The piece of music used in this study was written in A minor, with three main sections (Figure 5), arranged in a Rondo structure (AABBAACCAA):

A: a slow melody with small intervals between notes;
B: a slow melody with large intervals between notes;
C: a fast melody with small intervals between notes.

This music was chosen as it can be easily expressed using the MIDI protocol, to which participants were mapping their gestures. MIDI remains the most widely supported and popular choice for control in music production systems, and so findings from this study will be more applicable to further studies of MIDI supporting systems than more niche control methods such as OSC.

The participants were provided with the necessary auditory output parameters in MIDI, which were used to trigger the MINI 3OSC preset of the Simpler synthesiser in Ableton Live, a piece of music production software familiar to all of the participants. Participants were also provided with a score, annotated with the corresponding MIDI note values, and a piano-sequenced audio example.

Figure 5: The sections of the score.

4.2 Time Spent

During the task, the interactions that each participant had with the mapping software was recorded. These recordings were then analysed to study how each participant used their time during the task (Figure 6), measuring how long each participant spent in the mapping software, Ableton Live and on reference material (audio example and musical score), as well as the amount of time each participant spent: practising their performance; editing, either note selection mappings, expressive mappings, auditioning these mappings or editing settings in Ableton Live; or calibrating and setting up the gloves. Periods of inactivity or time spent on unrelated activities were marked as N/A (Not Applicable).

4.3 Group Discussion

After the mapping exercise, participants performed with their mapping strategy to the group and discussed their designs. The group was encouraged to contribute their own feelings towards each performer's mapping. The participants' discussion was analysed using thematic analysis [4].

4.4 Participants

Five participants took part in the study. While all but one of the participants have been using the gloves for several years, the focus of this research is on the perspective of DMI performance. As such, only two participants were experienced performers (C and D), while the majority of the other participant's experience with the gloves was composition (B) or development (A and E). Details of each participant's background with the gloves are as follows:

A: User for over two years. Has experience playing piano and guitar. Uses the gloves sometimes for composition and live performance. Regular use includes controlling synthesis, manipulating effects and controlling visuals. Typically uses the chord machine.

B: User for under three months. Has experience playing the violin, viola and keyboards. Uses the gloves for composition, and has never used them for live performance, but intends to. Regular use includes developing new composition strategies and "investigating new textures and musical objects". Typically uses OSC and MIDI CC messages to control inputs to self-developed Max/MSP and SuperCollider software.

C: User for between one and two years. Has experience playing the piano. Uses the gloves for live performance regularly and composes using them some of the time. Regular use includes solo musical performance, controlling visual effects and outboard synthesisers. Typically uses the chord machine, seven postures per hand, scene switching and button for calibration.

D: User for over two years. Has experience playing piano, oboe, bass, flute, violin, cello and synths. Uses the gloves for composition and performance often. Regular use includes standalone musical performance and use with other instruments and controllers. Typically uses "all" features.

E: User for over two years. Has no experience playing other instruments, and never uses them for live performance or composition. Regularly uses the gloves for development purposes.

5 RESULTS

5.1 Time Spent During Exercise

Participants A and E (who perform with the gloves the least) spent the majority of their time practising their performances (49% and 52% respectively). In contrast, the regular performers (C and D) spent less time practising (19% and 9% respectively) and the majority of their time editing (53% and 61%). Participant B, who mainly composes with the gloves, spent an approximately equal amount of time editing (43.4%) and practising (43.6%).

Regarding the time spent in applications (Figure 6b), each participant spent the majority of their time in the mapping application. Interestingly, the two most experienced performers spent both the least amount of time (C: 47.7%) and greatest amount of time (D: 84.8%) in the mapping application. These two participants also spent the greatest (C: 39%) and least (D: 6.5%) amount of time on reference material. Four of the five participants spent a notable amount of time in the Ableton Live application, which was spent either editing Ableton parameters or practising their performances.

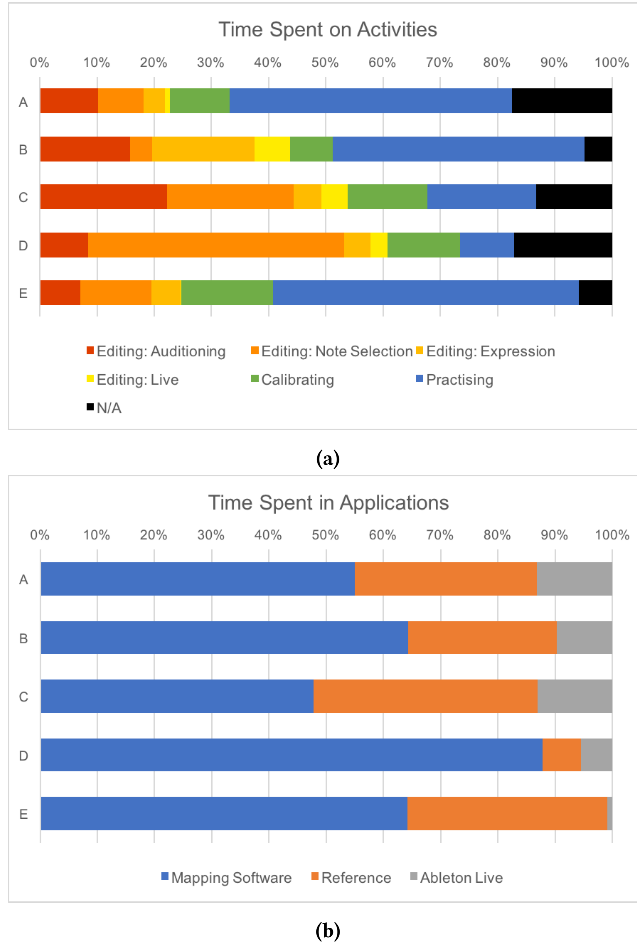


Figure 6: Time spent during the exercise.

5.1.1 Calibration. Each participant spent an average of 12% of their time conducting calibration tasks. This reveals the lengthy setup time required to use the gloves. Also, all of the participants returned to recalibrate the gloves throughout the exercise. This included retraining the posture recogniser with fresh training data, setting minimum and maximum values for movement data, and refreshing WiFi connections to their gloves.

5.1.2 Note Selection. Participants A, C and D trialled multiple solutions for note selection mappings. Participant A swapped a Note Matrix for a Chord Machine for sections A and B of the piece, keeping a Note Matrix for section C.

Participant A spent most of their time practising their second note selection solution instead of continuing to make further edits. In contrast, participants C and D exhibited a continuous editing, auditioning, and practising cycle throughout the exercise. Participant C began by using a Note Matrix to perform section C of the piece, before switching to a chord machine; while participant D

User	*Note Selection*	*Expression*	*Comments*
A	All on RH. Qualifiers: postures and direction (A and B sections). Movement: Note matrix on pitch axis (C section).	All on LH. Timbre: pitch axis. Vibrato: roll axis. Dynamics: no mapping.	Vertical spatial relation between direction qualifiers and notes. Specific postures used for specific phrases.
B	All on LH. Movement: Note matrix on pitch axis. Movement: Octave intervals on yaw axis. No qualifiers used.	Split between hands. Timbre: LH average finger flex. Vibrato: RH pitch axis. Dynamics: no mapping.	Spatial grid-like representation of notes used.
C	All on LH Qualifiers: postures and directions.	All on RH Timbre: average finger flex. Vibrato: roll axis. Dynamics: pitch axis.	Circular motion for performing C section. Focus on ergonomics and being visually appealing for performance.
D	All on LH. Qualifiers: postures and directions. Scene Switching: button to click through musical sequence (C section).	All on RH. Timbre: average finger flex. Vibrato: roll axis. Dynamics: pitch axis.	Focus on ergonomics. No relation between directions and notes.
E	Split between hands. Movement: note matrix for pitch selection (mirrored on both hands). Qualifiers: open hand posture for triggering.	All on RH. Timbre: roll axis. Vibrato: no mapping. Dynamics: no mapping.	Vertical representation of notes. Open hand "letting go" of the notes.

Table 1: Description of each participant's final mapping strategy.

also began by using a note matrix for section C, but switched to a button and scene switch solution, clicking through the notes of the section.

5.1.3 Expression. All but one participant spent <5% of their time editing the expressive mappings. Participant B spent 18% of their time on this task, and was the only participant to audition and trial multiple expressive mapping solutions. All of the other participants left the expressive mapping part of the task to the end of the hour, and did not experiment with more than one mapping solution for each expressive parameter. This suggests that the lack of expressive experimentation could be due to the time limitation of one hour, more time could have allowed participants to explore more solutions.

5.1.4 Ableton Live. Although an Ableton Live project with all the necessary MIDI and synthesiser settings was provided for the participants, all of the participants spent time editing the Ableton Live project. Participant A added extra effects processing to their project, while other participants edited synthesiser parameters such as the synthesiser's ADSR amplitude envelope.

5.2 Mapping Designs

A description of each participant's final mapping design can be found in Table 1.

5.2.1 Technical Mappings. Four of the five participants set up the same series of mappings for resetting the gloves orientation, referred to as "set forwards". Each participant used either a button or unusual posture (such as "pinky point") to trigger this orientation reset procedure, accompanying it with a pulse of the glove's vibration motor for feedback (Figure 7). This seems to have become a common procedure for glove performers. Participants noted that drifting from one's starting point while performing with the gloves happens regularly, and that this reset procedure has been adopted by many members of the glove community.

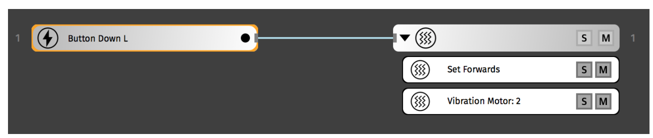


Figure 7: An example of the "set forwards" mapping.

5.2.2 Bimanual Control. Three participants (A, C and D) split note selection and expressive control between the two hands. This was done seemingly for cognitive purposes and a desire for "independent control" of notes and expression.

> "I don't have to worry about this [expressive] hand once I've got the muscle memory for this [note selection] hand."

Of the other two, Participant E mapped controls symmetrically, providing both hands the ability to select and trigger notes. However, this participant only mapped one expressive parameter, timbre, citing that mapping the others was too cognitively challenging.

> "I tried volume control, but I found it hard to control it consciously while controlling the notes."

Participant B mapped both note selection and expressive parameters to a single hand, claiming that it is "quite interesting" to map as much as you can on one hand. They also found difficulties controlling expression.

> "I tried mapping [average finger flex] to volume ... but it gets a bit uncontrollable."

5.2.3 Mapping Expression. There was slight trend of participants making similar mapping choices for expressive parameters, with three participants mapping vibrato to the roll axis (A, C and D), three mapping timbre to their average finger flex (B, C and D) although often no mapping was provided for expressive parameters, particularly dynamics, where three participants (A, B and E) did not provide mappings.

When participants did create expressive mappings, a hand's average finger flex was the most popular control for timbral expression. One participant (C) commented that it "looks cool", suggesting that aesthetic considerations were an important factor. Another (B) commented that "there's a sort of symbiotic relationship between opening [their hand] equalling the filter", suggesting a metaphorical relationship, with the opening and closing of their fingers representing the opening and closing of the low pass filter.

Meanwhile, the roll axis was the most popular for vibrato control, with one participant commenting that "it seemed like a natural choice" and another that "it was sort of incidental".

5.2.4 Metaphors. In an explanation of their mappings, we found that four of the five participants expressed musical metaphors. During the discussion, the participants expressed a connection between spatial terms and musical pitch, supporting the idea that pitch has a strong schematic relation to space [5, 20].

> "It makes sense that C is physically the highest note."
> "Next octave is here [on the right], as I wanted some relation between where my hand is on the lateral plane and the [musical] pitch."
> "There is a kind of height relation for some of the notes."
> "Low notes low, high notes high."
> "You kind of want to play [the notes] like this [participant gestures up and down]."
> "Naturally it seems good to go up and down a scale."
> "The G obviously needs to come down [from the A]."

Also present were examples of dynamic control reflecting the UP–DOWN metaphor of dynamics [32].

> "I often do volume up and down."
> "I made it so it got louder and brighter as I raised my hand."

The participants who expressed the strongest representation of metaphors in their mappings were those who performed with the gloves the least (A, B and E).

5.2.5 Ergonomics. Although most of the participants used musical metaphors when discussing their mappings, the experienced performers (C and D) focused on designing mappings that mitigated performance error. These participants were focused on the ergonomics of their control, particularly on how their transitions between notes, emphasising a need to be able to easily switch between them without accidentally triggering other notes.

> "I like how [other participants] thought about the musicality behind the notes, I didn't do that at all, I just put the postures where I saw them fit more for performance."
> "I did try with a Note Matrix, but you just don't have enough control."
> "I move from postures that use more unbent fingers to postures with bent fingers for reliable note triggering. For example, from one finger point to a fist. Then I change direction without changing posture so as not to accidentally trigger other notes."

This is reflected in the time spent by both participants auditioning and editing note selection mappings against practising their performances: if a particular musical section took too long to master with one mapping, these participants changed the mapping to something more playable, to the extreme case of exploiting unseen affordances of the mapping software to perform a musical section with the touch of a button.

> "It's annoying to do quick melodies so I used scene changing and just set each scene to [trigger each note in the sequence]. I used the easy, simple format of the song to program that sequence of notes as a sequence of scene changes."

6 DISCUSSION

We have found evidence of contrasting mapping design behaviour between novice and experienced glove performers. Participants A and E (with little glove performing experience) first designed their mappings, spending little time experimenting with solutions, and then devoted the majority of their time to mastering the mappings they had defined. In contrast, the regular performers C and D took advantage of the dynamic nature of the gloves interaction, constantly updating their mappings to aid their performance instead of dedicating time to practise.

The participants who adhered most strongly to musical metaphors commented that they did so as it was "natural", it "made sense" and was "obvious". This supports the notion that using metaphor leads to an intuitive interaction [2], however, by adhering to metaphor too strongly and spending less time iterating their mapping designs, these participants overlook the ergonomics of their choices and require increased practise time.

In contrast, the participants with the most performing experience expressed very few or no metaphors at all in their mapping. These users instead focused on pragmatic, ergonomic solutions, reflecting the desire in live performance to minimise mistakes. This highlights an interesting feature regarding user-defined control mappings in musical performance, in that, unlike acoustic instruments, in which the performer must master the movements necessary to play the instrument, the control mapping can be customised to suit the movements of the performer. This also reflects recent findings that performers find the most convenient ways of playing DMIs, optimising gestures to be maximally efficient [19].

We also found that many of the participants mapped note selection to one hand and expressive parameters to the other. This reflects Guiard's theory of bimanual action, where skilled manual tasks are divided asymmetrically between the two hands [13], and has been observed in previous user-defined mid-air interaction research [1]. The two participants who chose not to do this (B and E) had the most trouble controlling expressive parameters and note selection, suggesting that dividing different types of musical tasks between the hands could make control of multiple musical parameters cognitively less challenging.

Many of the participants used the chord machine (Figure 4a), designed to give glove users control over chords, to play single notes. This suggests that the affordances present in the chord machine tool provides a preferred mapping tool to glove musicians than the patch cord mapping tools. As well as this, three of the participants used the note matrix (Figure 4b), which also does not use the patch cord metaphor, instead using a very technical interface that relies on users editing numbers to create musical scales. In all, very few note mappings were made using the patch cord interface. This suggests that the traditional left-to-right conceptualisation of mapping that is prevalent across the mapping literature [17, 18, 27] may not be the most appropriate method of presenting mapping options to end-users. This presents an avenue for future research looking at users' preferences between different methods of presenting input and output mapping options.

For many expressive parameters the participants made no mapping choice at all, and from the exercise interaction data we observed that four of the five participants spent very little time mapping expression. The lack of concentration on expressive parameters is perhaps down to the nature of the task: the participants were explicitly instructed to provide mappings for specific note selection (the target piece), while given freedom over their use of expressive parameters. The fact that participants were only given one hour to complete the task may have also had an effect. For instance, participant B spent a considerable amount of time auditioning and editing their expressive mappings, but they stressed that they "hadn't had time to really explore" their choice to map vibrato to the pitch axis of their right hand. Given more time, other participants may have experimented further with different expressive solutions.

The amount of exercise time taken up by calibration tasks reveals that the gloves require a considerable amount of adjustment throughout a user's interaction. Breaks in the participants' time designing mappings would have disrupted their creative processes and any periods of flow [7]. This suggests that calibration tasks should be removed from the users direct control to help them focus on mapping design, however, there is a balance to be achieved between abstracting such complexity away, which may benefit novice users, while still providing control over the precise workings of the gloves for expert users like participant D, who customised details such as their gloves' IP addresses and UDP send/receive ports.

Although the focus of the task was to create performance mappings, it is interesting how many of the participants edited sound features of the Ableton Live synthesiser used in the exercise. This is likely down to each participant's desire for the sound output to more closely match their own aesthetic taste: one participant commented "Ah, that's better" after adding extra audio processing to the Ableton Live synthesiser. Future work may give participants freedom over the sound output, allowing for a better reflection of their personal performances.

Four of the five participants implemented a "set forwards" mapping that, triggered by a button press or specific posture, resets the yaw orientation and sends a pulse to the gloves' vibration motors. While this does not directly relate to a musical use of the gloves and is a calibration task necessary to use the gloves effectively, the way that all of the participants made similar decisions regarding input parameter choice and feedback modality suggests that it has become a part of standard glove practice, shared between glove musicians.

While the less experienced performers (A, B and E) were influenced by adhering to musical metaphor, their final mapping solutions were diverse, with varied expressive parameter mapping and a mixture of movement and qualifier parameter types being used for note selection. In contrast, the experienced performers (C and D) used similar mapping choices, using the same gestural parameters for each expressive parameter, and using posture and direction qualifiers for most of the musical material. With their main motivation being the minimisation of performance error and the efficiency of their movements, this suggests that these parameters are the most efficient choice for note selection.

6.1 Limitations

While this study has revealed some interesting insights into the mapping design processes of mid-air interaction musicians, there are important lessons learnt from this study to apply to future research. The length of time given (one hour) may not have provided some of the participants, particularly the more inexperienced ones, with enough time to fully explore and experiment with possible mapping solutions. As well as this, participants commented that the target piece of the task did not reflect music they would choose to perform. This may have influenced how the participants approached the task, focusing on completing their mappings and giving a satisfactory performance instead of experimenting with mapping solutions.

7 CONCLUSIONS

Five mid-air DMI musicians took part in a mapping design task to investigate what factors influence end-user design of action–sound mappings for musical performance. Below are the theoretical findings of this research regarding end-user mapping musicians:

(1) Experienced performers focus on designing efficient mapping solutions that minimise performance error.
(2) Less experienced performers design mappings that adhere to musical metaphors.
(3) Experienced end-user mapping performers iterate on their mapping design in rapid feedback cycles.
(4) Less experienced performers spend less time editing mappings and focus on mastering the mappings they have implemented.

This research has explored the mapping processes of experienced users, which novel DMIs and mid-air interfaces and often lack. The findings from this study may also apply to other user-defined digital musical instruments, such as the D-Box [21] and Wekinator [11], as well as the wider domain of user-defined control mapping.

The main limitation of this study was the nature of the musical task. Participants focused on the note selection element far more than the expressive parameter element. Future work could examine factors that affect end-user mapping of expressive parameters and note selection using separate tasks. Similarly, the participants noted that the musical task did not reflect their personal creative practice, which may have had an influence on how the musicians approached the task. Future work could examine what factors influence mapping design in the context of the musicians' personal creative practice. The main findings from this study highlight the contrast in mapping practice between novice and experienced glove performers, future research could examine this contrast in greater detail, investigating how mapping practice develops as musicians transition from novice to experienced end-user mapping musicians.

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