Evaluation of the Learnability and Playability of Pitch Layouts in New Musical Instruments

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ABSTRACT

Certain properties of isomorphic layouts are proposed to offer benefits to learning and performances on a new musical instrument. However, there is little empirical investigation of the effects of these properties. This paper details an experiment that examines the effect of pitch adjacency and shear on the performances of simple melodies by 24 musically-trained participants after a short training period. In the adjacent layouts, pitches a major second apart are adjacent. In the unsheared layouts, major seconds are horizontally aligned but the pitch axis is slanted; in the sheared layouts, the pitch axis is vertical but major seconds are slanted. Qualitative user evaluations of each layout are collected post-experiment. Preliminary results are outlined in this paper, focusing on the themes of learnability and playability. Users show strong preferences towards layouts with adjacent major seconds, focusing on the potential for learning new pitch patterns. Users confirm advantages of both unsheared and sheared layouts, one in terms of similarity to traditional instrument settings, and the other to ergonomic benefits. A model of participants' performance accuracy shows that sheared layouts are learned significantly faster. Results from this study will inform new music instrument/interface design in terms of features that increase user accessibility.

1. INTRODUCTION

Designers of new or extended musical instruments are often concerned with ensuring accessibility for users either with no previous musical experience, or for those who already have training in another instrument, so that they can easily alter/learn new techniques. Several claims regarding the optimal pitch layout of new electronic instruments/interfaces have been made, but as yet there is little empirical investigation of the factors that may enhance or disturb learning and performance on these devices.

1.1 Isomorphic Layout Properties

Since the nineteenth century, numerous music theorists and instrument builders have conjectured that *isomorphic pitch layouts* provide important advantages over the conventional pitch layouts of traditional musical instruments [1–4]. Indeed, a number of new musical interfaces have used isomorphic layouts (e.g., Array Mbira [5], Thummer [6], Soundplane [7], AXiS-49 [8], Musix Pro [9], LinnStrument [10], Lightpad Block [11], Terspstra [12]).

An isomorphic layout is one where the spatial arrangement of any set of pitches (a chord, a scale, a melody, or a complete piece) is invariant with respect to musical transposition. This contrasts with conventional pitch layouts on traditional musical instruments; for example, on the piano keyboard, playing a given chord or melody in a different transposition (e.g., in a different key) typically requires changing fingering to negotiate the differing combinations of vertically offset black and white keys.

Isomorphic layouts also have elegant properties for microtonal scales, which contain pitches and intervals "between the cracks" of the piano keyboard [13]. Although strict twelve-tone equal temperament (12-TET) is almost ubiquitous in contemporary Western music, different tunings are found in historical Western and in non-Western traditions. Isomorphic layouts may, therefore, facilitate the performance of music both within and beyond conventional contemporary Western traditions.

In this paper, we do not compare isomorphic and non-isomorphic layouts. Instead, we focus on how different isomorphic layouts impact on learnability and playability. This is because there are an infinite number of unique isomorphic layouts: they all share the property of transpositional invariance (by definition) but they differ in a number of other ways that may plausibly impact their usability. For example, successive scale pitches, like C, D, and E, are spatially adjacent in some isomorphic layouts while in others they are not; additionally, in some isomorphic layouts, pitches are perfectly correlated to a horizontal or vertical axis while in others they are not [14]. In some layouts, octaves may be vertically or horizontally aligned; in others, they are slanted. [1]

Properties such as these are typically non-independent: improving one (e.g., pitch axis orientation) may worsen another (e.g., octave axis orientation). Choosing an optimal layout thus becomes a non-trivial task that requires knowledge of the relative importance of the different properties.

To shed light on this, the experiment presented in this paper explores how two independent spatial transformations

[1] With respect to the instrumentalist, the "horizontal" axis runs from left to right, the "vertical" axis from bottom to top or from near to far.

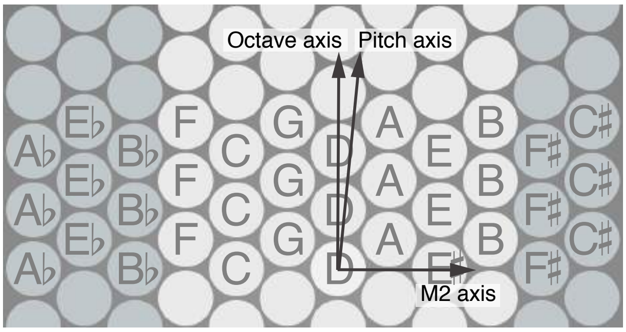

Figure 1. Layout $A'S'$.

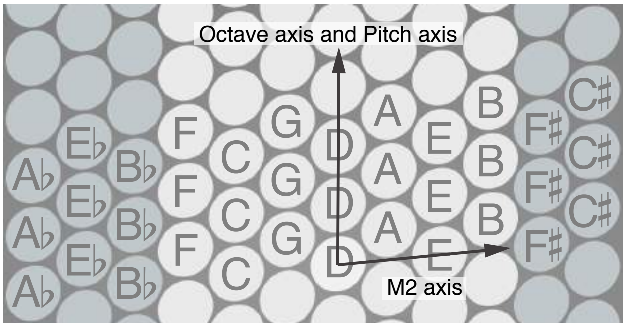

Figure 2. Layout $A'S$.

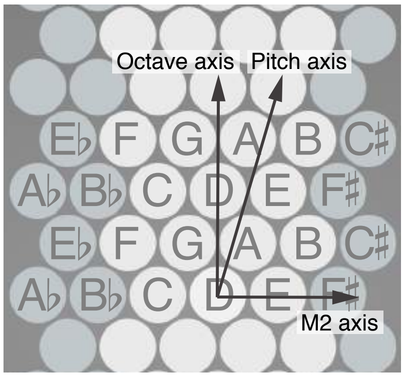

Figure 3. Layout AS' (the Wicki layout [3]).

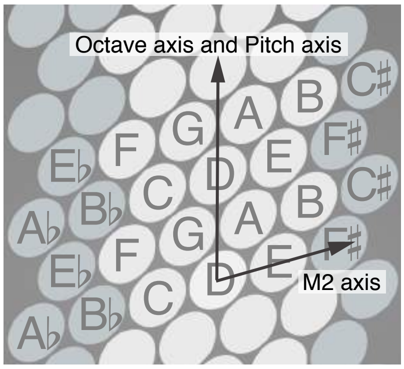

Figure 4. Layout AS.

of isomorphic layouts – adjacency and shear – impact on their learnability and playability for melodies. The four resulting layouts are illustrated in Figures 1–4. Each figure shows how pitches are positioned, and the orientation of three axes that we hypothesize will impact on the layout's usability. Each label indicates whether the layout has adjacent major seconds or not (A and A', respectively) and whether it is sheared or not (S and S', respectively). The three axes are the *pitch axis*, the *octave axis*, and the *major second axis*, as now defined (the implications of these three axes, and why they may be important, are detailed in 1.1.2).

- The *pitch axis* is any axis onto which the orthogonal (perpendicular) projections of all button centres are proportional to their pitch; for any given isomorphic layout, all such axes are parallel [15].
- The *octave axis* is here defined as any axis that passes through the closest button centres that are an octave apart.
- The *major second axis* (*M2 axis*, for short) is here defined as any axis that passes through the closest button centres that are a major second apart. [2]

1.1.1 Adjacent (A) or Non-Adjacent (A') Seconds

Scale steps (i.e., major and minor seconds) are, across cultures, the commonest intervals in melodies [16]. It makes sense for such musically privileged intervals also to be spatially privileged. An obvious way of spatially privileging intervals is to make their pitches adjacent: this makes transitioning between them physically easy, and makes them visually salient. However, when considering bass or harmony parts, scale steps may play a less important role. This suggests that differing layouts might be optimal for differing musical uses.

The focus of this experiment is on melody so, for any given layout, we tested one version where all major seconds are adjacent and an adapted version where they are nonadjacent (minor seconds were non-adjacent in both versions). Both types of layouts have been used in new musical interfaces; for example, the Thummer (which used the Wicki layout (Fig. 3)) had adjacent major seconds, while the AXiS-49 (which uses a Tonnetz-like layout) [17]) has non-adjacent seconds but adjacent thirds and fifths.

1.1.2 Sheared (S) or Unsheared (S')

We conjecture that having any of the above-mentioned axes (pitch, octave, and M2) perfectly horizontal or perfectly vertical makes the layout more comprehensible: if the pitch axis is vertical or horizontal (rather than slanted), it allows for the pitch of buttons to be more easily estimated by sight, thereby enhancing processing fluency. Similar advantages hold for the octave and M2 axes: scales typically repeat at the octave, while the major second is the commonest scale step in both the diatonic and pentatonic scales that form the backbone of most Western music.

However, changing the angle of one of these axes typically requires changing the angle of one or both of the

[2] When considering tunings different to 12-TET (e.g., meantone or Pythagorean), alternative – but more complex – definitions for the octave and M2 axes become useful.

others, so their independent effects can be hard to disambiguate.

A way to gain partial independence of axis angles is to shear the layout parallel with one of the axes – the angle of the parallel-to-shear axis will not change while the angles of the other two will. [3] As shown by comparing Figure 1 with Figure 2, or by comparing Figure 3 with Figure 4, we used a shear parallel with the octave axis to create two versions of the non-adjacent layout and two versions of the adjacent layout: each unsheared version ($A'S'$ or AS') has a perfectly horizontal M2 axis but a slanted (non-vertical) pitch axis; each sheared version version ($A'S$ or AS) has a slanted (non-horizontal) M2 axis but a vertical pitch axis. In both cases the octave axis was vertical.

In this investigation, therefore, we remove any possible impact of the octave axis orientation; we cannot, however, quantitatively disambiguate between the effects of the pitch axis and the M2 axis, although qualitative information can provide some insight into their independent effects (see Sec. 3.1).

Sheared and unsheared layouts are found in new musical interfaces – the Thummer and AXiS-49 both have unsheared layouts; the crowdfunded Terpstra keyboard uses a sheared layout.

1.2 Motor Skill Acquisition

Learning a new musical instrument requires a number gross and fine motor skills (in order to physically play a note), and sensory processing (of feedback from the body and of auditory features, e.g., melody, rhythm, timbre) [18]. For trained musicians adapting to a new instrument, they may be required to learn a new pitch mapping, which means they must adjust their previously learned motor-pitch associations [19]. In learning a motor skill there are three general stages [20]:

- a *cognitive stage*, encompassing the processing of information and detecting patterns. Here, various motor solutions are tried out, and the performer finds out which solutions are most effective.
- a *fixation stage*, when the general motor solution has been selected, and a period commences where the patterns of movement are perfected. This stage can last months, or even years.
- an *autonomous stage*, where the movement patterns do not require as much conscious attention on the part of the performer.

Relating this to how a performer learns to play a particular a musical instrument, we define the first cognitive stage as *learnability* and the second fixation stage as *playability*. Essentially, learning the motor-pitch associations of a new instrument requires the performer to perceive and remember pitch patterns. Once these pitch patterns are learned, the performer becomes more focused on eliminating various sources of motor error. [4] To test how well the participants have learned the new layouts and perfected their motor pattern, we are interested in the transfer of learning from one task to another. For instance, a piano player will practice scales, not only so they will achieve a good performance of scales, but so they can play scale-like passages in other musical pieces well. In our study, we designed a training and testing paradigm for the different pitch layouts such that the test involved a previously un-practised, but familiar (in pitch) melody.

1.3 Study Design

For this experiment, we are interested in examining how features of a pitch layout affect the ease with which musicians can adapt to it. Musically experienced participants played three different layouts successively. In each such layout, they received an equivalent training program and then performed a test melody four times. The independent variables were *Adjacency* $\in \{0, 1\}$, *Shear* $\in \{0, 1\}$, *LayoutNo* $\in \{0, 1, 2\}$ (respectively the first, second, or third layout played), and *PerfNo* $\in \{0, 1, 2, 3\}$ (respectively the first, second, third, or fourth performance of the melody in each layout). Participants were presented the layouts in different orders to permit analysis of ordering effects. In using musically-experienced participants, we assume that they share a high level of musical information processing skill, thereby reducing its impact on the results. Participants' preferences were elicited in a semi-structured interview, and the accuracy of their performances was numerically assessed from their recorded MIDI data.

2. METHODS

2.1 Participants

24 participants were recruited (age mean = 26, range: 18-44) with at least 5 years of musical experience on any one instrument (excluding the voice).

2.2 Materials

2.2.1 Hardware and Software

The software sequencer Hex [14] was modified to function as a multitouch MIDI controller, and presented on an Asus touch screen notebook, as shown in Figure 5. Note names are not shown on the interface, but middle D is indicated with a subtly brighter button to serve as a global reference. The position of middle C was indicated to participants, this being the starting pitch of every scale, arpeggio, or melody they played.

In order to present training sequences effectively, both aurally and visually, Hex's virtual buttons were highlighted in time with a MIDI sequence. All training sequences were at 90 bpm and introduced by a two-bar metronome count.

[3] A *shear* is a spatial transformation in which points are shifted parallel to an axis by a distance proportional to their distance from that axis. For example, shearing a rectangle parallel to an axis running straight down its middle produces a parallelogram; the sides that are parallel to the shear axis remain parallel to it, while the other two sides rotate.

[4] Because achieving motor autonomy is a lengthy process – one that can seldom be captured by experiments – our current study focuses on only the first two elements of motor learning.

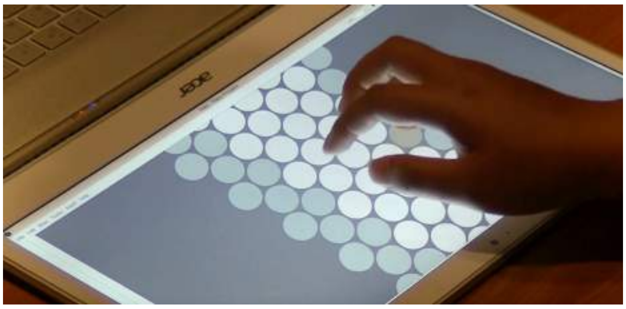

Figure 5. The multitouch interface used in the experiment.

2.2.2 Musical Tasks

Melodies for musical tasks were chosen to be single-line sequences to be performed solely with the right hand. The training melodies consisted of a set of C major scales and a set of arpeggios (again only using the notes of the C major scale) spanning two octaves, and all starting and ending on middle C. The well-known nursery rhyme *Frère Jacques* was used as a test melody; it too was played in C major and began and ended on middle C.

2.3 Procedure

Participants played three out of the four layouts under consideration: all 24 participants played both AS' and AS, with 12 participants each playing either $A'S$ or $A'S'$.

The layouts were presented in four different sequences, with each sequence played by 6 participants: AS' then $A'S'$ then AS; or AS' then $A'S$ then AS; or AS then $A'S'$ then AS'; or AS then $A'S$ then AS'. This means that the non-adjacent seconds layouts ($A'S'$ and $A'S$) were always presented second, and that participants who started with the unsheared adjacent layout (AS') finished with the sheared adjacent layout (AS), and vice versa.

2.3.1 Training Paradigm

For each of their three layouts, participants were directed through a 15-minute training paradigm involving i) scales and ii) arpeggios. For each stage, this involved:

1. watching the sequence once as demonstrated by audiovisual highlighting

2. playing along with the audiovisual highlighted sequence three times

3. reproducing the sequence in the absence of audiovisual highlighting, for four consecutive performances.

All demonstration sequences and participant performances were played in time with a 90bpm metronome, and recorded as MIDI files.

2.3.2 Testing

A final production task asked participants to a well-known nursery rhyme – *Frère Jacques*. Participants first heard an audio recording of the nursery rhyme to confirm their knowledge of the melody. They were then given 20 seconds initially to explore the layout and find the correct notes before giving four consecutive performances. Again, these performances were instructed to be played in time with a 90 bpm metronome. Although this represents a fairly simple task, the nursery rhyme was chosen as it facilitated measurement of participants' skill with each particular layout. We assume that as the participants' memory for the melody was intact, their performance would only be affected by their memory of the layout itself.

2.3.3 Post-Experiment Interview

In a semi-structured interview taking place after the training paradigm and test performances concluded, participants were asked to choose their preferred layout from the three presented. Participants were asked to detail what they liked or disliked specifically about their preferred layout (and any of the others). When required, the experimenter would prompt participants to consider how it felt playing the scales, arpeggios, or melodies from the training section.

2.4 Data Analysis

2.4.1 Qualitative User-Evaluation Statements

Preferences for any specific layout were noted only for participants who clearly indicated a distinct preference (23 out of 24). 102 statements were made by the 24 participants regarding their likes and dislikes of the layouts they were exposed to. Eight statements were categorized as preferences for a specific layout feature without any clarification. Two statements were deleted as they neither identified a preference nor discussed any particular layout feature. The remaining 92 statements were coded independently by the two authors, categorized as issues of *Learnability* or *Playability*. Mention of visual aspects of a layout, or any reference to a collection of buttons in rows or patterns that may represent cognitive processing on the part of the performer was classified as *Learnability* (see Section 1.2). Mention of any physical aspect of playing that may represent the perfection of motor skills was classified as *Playability*. Each category was further classified into whether statements made were positive or negative.

2.4.2 Quantitative MIDI Performance Data

Each MIDI performance was analyzed for accuracy of pitches by comparing against an ideal performance of the melody at 90bpm. To account for participants who may not have been able to play the full melody, a score was given for the number of 'correct' notes played. This score was adjusted by giving negative points for any wrong or extra notes. The maximum score for a performance in this case was 32.

	Learnability		Playability		Learnability/Playability	
	Positive	Negative	Positive	Negative	Positive	Negative
A	25	3	13	2	8	1
A'	3	24	2	10	0	0
Both	1	0	0	0	0	0
AS	6	3	7	0	5	1
AS'	9	0	6	2	2	0
Both	10	0	0	0	1	0
$A'S$	1	15	1	6	0	0
$A'S'$	2	9	1	4	0	0

Table 1. User evaluation statements categorized by Learnability, Playability, or Learnability/Playability. These statements are separated in terms of the positive or negative meaning, and the particular layout they were referring to in terms of *Adjacency* (A, A') and then *Shear* (S, S').

3. RESULTS

3.1 User Evaluations

3.1.1 User Preferences

There was a strong consensus amongst the participants in terms of *Adjacency* (22 participants selecting either layout AS or AS', 1 participant selecting layout AS). However, no conclusive preference was registered in terms of *Shear*, with 12 participants selecting layout AS, and 10 participants selecting layout AS'.

3.1.2 User Statements

Participants made from 0 to 7 qualitative statements each (mode = 4). Only two participants made no useable statements. Table 1 shows the statements as they referred to at first the *Adjacency* of the layout, and then as they refer to the *Shear*.

3.1.3 Learnability

The large majority of statements made (61%) concerned the learnability of a certain layout. 29 statements were positive, 25 of which related to the adjacent M2 layouts (AS and AS'). Performers noted that the pattern in the adjacent M2 layout was easy to grasp, easier to remember and see where the notes were, implying that they quickly perceived the appropriate pitch patterns for the scale and arpeggio exercises. The consecutive adjacent notes were mentioned explicitly as being helpful to remembering where pitches were, as well as the “3-4 pattern” formed by the diatonic scale. The three positive statements made in relation to non-adjacent M2 layouts all concerned the adjacent octave notes. One statement again referred to the aligned octaves in reference to both adjacency types. 24 negative statements were made regarding the layout adjacency, particularly in nonadjacent (A') layouts. These referred to the difficulty in “seeing the lines”, “finding the notes” and it being harder to determine which note was which. Shear in these non-adjacent layouts did not appear to particularly help or worsen the confusion. Negative statements that referred specifically to the shear of the adjacent layouts referred to layout AS. Three statements from two participants clarified that the shear contributed to confusion in being able to separate out the different rows of buttons.

3.1.4 Playability

29% of statements referred to the playability of the layouts. Again, the majority of positive statements referred to the adjacent layouts (AS and AS') and the majority of negative statements referred to the non-adjacent layouts ($A'S$ and $A'S'$). Five participants made six positive statements in total regarding the unsheared layout AS', mentioning that the straight line in particular helped them to play, and that the circles made the notes spaced out a bit more than the ovals (an effect of the shear). They also liked fewer notes to a row (in comparison the the non-adjacent layouts). The statements on playability for the sheared layout often contained specific details to do with the shear itself. Participants liked the ergonomics of the slant, commenting on its versatility, the better angle for the hand, and the ease of moving between rows. Two positive statements referring to the non-adjacent layouts (one each for $A'S$ and $A'S'$), commented that the larger width between adjacent notes made it easier to play, and that the layout gave them more freedom. The negative statements (largely referring to non-adjacent layouts), commented on having to physically spread the fingers out more to play consecutive notes. The close proximity of non-adjacent notes (due to the interleaved layout of buttons), also contributed to some discomfort as performers mentioned that they often hit the wrong note on the wrong “row”. Two statements referred to the unsheared adjacent M2 layout (AS'), commenting that the vertical alignment of rows made the performers more likely to miss a note as their hand was in the way.

3.1.5 Other

The remaining 10% of statements did not fit into one category as they mentioned both cognitive and physical aspects of playing. These all referred to the adjacent layouts. Two participants stated that AS' was the easiest layout to “get used to”, particularly as it was very similar to other instruments like the piano. The statements referring to the

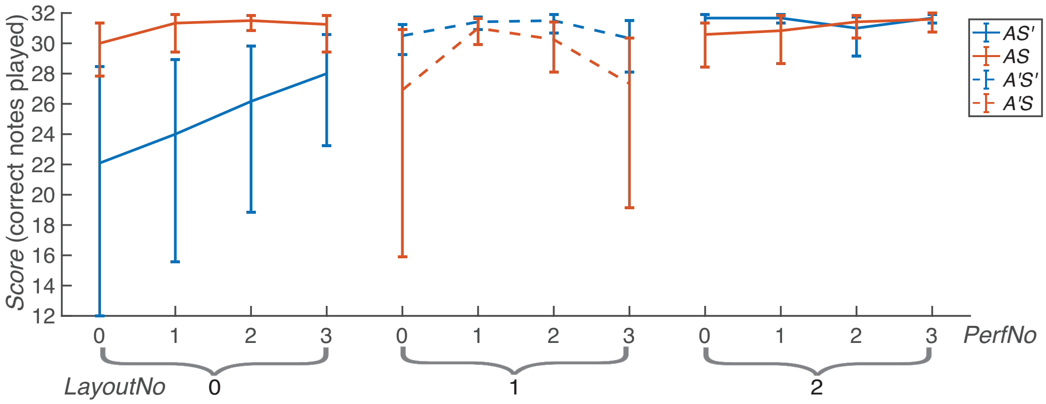

Figure 6. Performance scores, averaged across participants, as a function of layout number (where 0 codes the first layout presented to the participant, 1 codes their second layout, 2 codes their final layout), and performance number (where 0 codes their first performance in each layout, 1 codes their second performance, etc.). The error bars show 95% confidence intervals obtained by bootstrapping.

Fixed Effects	Estimate	SE	t-Stat	DF	p-Value	95% CI
(*Intercept*)	26.25	1.49	17.65	274	.000	$[23.32, 29.17]$
Adjacency	-3.38	1.28	-2.65	274	.008	$[-5.90, -0.87]$
LayoutNo	3.95	0.81	4.86	274	.000	$[2.35, 5.55]$
Adjacency×*Shear*	4.70	1.85	2.54	274	.012	$[1.06, 8.33]$
Shear×*LayoutNo*	-3.05	1.25	-2.44	274	.015	$[-5.51, -0.59]$
PerfNo×*LayoutNo*	-1.04	0.39	-2.69	274	.008	$[-1.80, -0.28]$

Table 2. A linear mixed effects model of *Score* with random effects on the intercept grouped by participant. For simplicity, non-significant predictors are not shown, although they were included in the model.

sheared, pitch-adjacent layout AS commented on the angle of the rows making it easier to visualize where the fingers would go next and an intuitive sense of moving upwards. As these statements hadn't specifically stated whether this related to learning/visualizing the patterns of pitches or the actual ergonomics of playing, we did not further categorize them.

There were also eight extra statements (separate to those in Table 1) that noted a preference for a specific feature of one or more of the layouts. Participants here noted a preference for the circle rather than oval buttons (an effect of the shear), and a preference for the "compact" layout that minimized gaps between notes (adjacency). Two statements noted the flat (unsheared) layouts were easier, and one noted that the sheared, adjacent layout (AS) would work well as a split screen when considering two-handed playing.

3.1.6 Summary

Participants clearly show a preference in terms of adjacent M2 layouts. Their main concerns are reflected in the learnability of a layout, and being able to figure out the pitch patterns. Playability is concerned particularly in statements regarding the shear of a layout.

3.2 MIDI Data

The scores (correct notes played) for performances of *Frère Jacques*, averaged across participants, are summarized in Figure 6 as a function of layout type (AS, AS', $A'S$, or $A'S'$); layout number (where 0 is the first layout presented to the participant, 1 is the second layout presented, 2 is the final layout); performance number (where 0 is the first performance in any given layout, 1 is the second performance, etc.). The 95% confidence intervals were obtained with 10,000 bootstrap samples.

The correlation between participants' preferences and their correct note score was $r = -.05$ and not significant ($p = .441$).

3.2.1 Model 1

To analyse which factors, and which of their interactions, impact on participants' scores, a linear mixed effects model was run with *Score* as the dependent variable, and the following fixed effects predictors: *Intercept*, *Adjacency*, *Shear*, *PerfNo*, *LayoutNo*, *Adjacency*×*Shear*, *Adjacency*×*PerfNo*, *Shear*×*PerfNo*, *Shear*×*LayoutNo*, *PerfNo*×*LayoutNo*, *Adjacency*×*Shear*×*PerfNo*, *Shear*×*PerfNo*×*LayoutNo*. Because all non-adjacent layouts were second, interactions between *Adjacency* and *LayoutNo* are not linearly independent of the main effects and so cannot also be included in the model. The intercept was treated as a random effect grouped by participant, which allows the model to take account of participants' differing aptitudes regarding the task as a whole.

The strongest significant effect is the interaction *Adjacency*×*Shear*, which indicates the generally superior per-

Fixed Effects	Estimate	SE	t-Stat	DF	p-Value	95% CI
(*Intercept*)	21.72	2.03	10.70	91	.000	$[17.69, 25.75]$
Shear	8.71	2.86	3.05	91	.003	$[3.21, 13.50]$
PerfNo	2.14	0.54	3.99	91	.000	$[1.08, 3.21]$
Shear×*PerfNo*	-1.75	0.75	-2.33	91	.022	$[-3.25, -0.26]$

Table 3. A linear mixed effects model of the scores obtained during the first presented layout, which was either AS' or AS.

formance of the sheared and adjacent layout *AS*. The significant negative conditional effect of *Adjacency* indicates that *Adjacency* reduces the score with unsheared layouts. This results from the fact that non-adjacent layouts were only presented second, by which time learning had already resulted in *Score* approaching the ceiling. This can be seen in Figure 6 by observing the course of the blue lines (the unsheared layouts) – the initial score is relatively low, but rapidly improves due to learning and has hit the ceiling by the time the second (non-adjacent) layout is presented.

The conditional effect of *LayoutNo* indicates that it has a strong positive impact across the first performance of unsheared layouts; the negatively-weighted interaction between *PerfNo* and *LayoutNo* shows that the impact of *LayoutNo* reduces as *PerfNo* increases, and vice versa.

The negatively-weighted interaction between *LayoutNo* and *Shear* shows that the positive impact of *Shear* is essentially swamped by the time the final layout was presented – another consequence of the ceiling effect.

3.2.2 Model 2

The ceiling effect, established above, suggests that the results that are most indicative of the initial learning of a new layout are those that arise during the first presented layout (i.e., when *LayoutNo* $= 0$). Table 3 summarizes a regression of the scores obtained during only the first presentation on *PerfNo* and *Shear* and their interaction, with a random effect on the intercept grouped by participant.

This model shows that – for the first presented layout, which always had adjacent seconds – both *Shear* and *PerfNo* have strong positive effects on *Score*. However, the interaction shows that the positive impact of *PerfNo* is much smaller when the layout is sheared, and that the positive impact of *Shear* is somewhat reduced as *PerfNo* increases. As before, these inferences can be readily identified in Figure 6.

3.3 Limitations

The current analysis considers the correct note score for performances of a well-known melody, where the maximum score is 32. We see a strong ceiling effect, particularly for layout AS where performances are close to the maximum number of correct notes possible. The musical task used for testing is simple to ensure that performance is affected only by the layout manipulations and not by participants' ability to memorise a new melody. What may be more revealing is an analysis of the timing with which participants are able to play these melodies.

The design of the experiment may also have contributed to the preferences and disparity of statements concerning *Adjacency*. Each participant was exposed to three different layouts: two with adjacent major seconds (sheared and unsheared); one with non-adjacent major seconds (sheared or unsheared). The adjacent M2 layout always came second; a more complete set of orderings would be desirable. The experiment tests for right-handed performance of single-note melodies after a short training paradigm.

Results presented on a transfer task immediately after training show an effect of shear on learning of this single-note melody, however, as different tasks are theorised to benefit from different layouts, effects may differ for performance of chords or left-handed bass lines, not to mention more complicated tasks such as modulation or improvisation. Further testing would also be necessary to determine the long-term effects from training.

4. CONCLUSIONS

Non-standard pitch layouts have been proposed since the late nineteenth century and, over just the last ten years, a number of products utilizing novel pitch layouts have been demonstrated at conferences such as SMC and NIME [6,7,9,21–23], or released commercially (as previously referenced). Purported advantages of such layouts are often theoretically plausible but they are rarely subjected to formal experimental tests. There is a multiplicity of different factors that may play a role in the learnability and playability of pitch layouts; furthermore, these factors are often non-independent. We have used two independent spatial manipulations (*Adjacency* and *Shear*) – realized with a multitouch interface – to tease apart some of the underlying factors that affect learnability and playability. These spatial manipulations allow us to gain insight into the impact of: spatially privileging major seconds by adjacency or angle; spatially privileging the pitch axis by angle.

The quantitative MIDI analysis indicates that shear provides a significant improvement in participants' ability to learn quickly and to play accurately – indeed, even on first performance, their correct note score was typically very good. Having the non-adjacent M2 layouts presented only second makes the impact of this factor on learnability harder to assess. Fortunately the user evaluations provide insight here.

The user evaluations suggest that M2 adjacency has a strong effect on the learnability of a layout, with adjacent M2 layouts easier to grasp and process, perhaps due to familiarity with previous motor-pitch associations, and perhaps due to their importance as an interval in Western music. In the user evaluations, shear is only considered as a secondary concern, when a motor-pitch pattern has already been acquired and needs to be perfected.

The quantitative analysis does not allow us to determine whether the key factor behind shear's impact is how it changes the direction of the pitch axis or how it changes the direction of the M2 axis. The user evaluations, however, suggest that both underlying factors play a role. Future research may aim to differentiate between these two explanations, and to collect more data to eliminate the ordering effect on adjacency.

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