Playing with Constraints: Stylistic Variation with a Simple Electronic Instrument

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The current ubiquity of embedded sensing and computing technologies, in concert with the facility of real-time digital signal processing, has fostered a more rapid pace of invention of new musical instruments than we have seen since electricity was tamed for widespread use. The state of interactive music performance has progressed significantly since John Cage, in 1937, lamented, "most inventors of electrical musical instruments have attempted to imitate eighteenth- and nineteenth- century instruments, just as early automobile designers copied the carriage" (Cage 1961, p. 3). This progress is, in large part, thanks to Cage's own work and legacy. Yet, although the "desire to imitate the past rather than construct the future" (Cage 1961, p. 4) has diminished in some quarters, contemporary authors have called attention to the changing nature of creation and perception of performance with computer-based instruments in the absence of a strong correspondence to the acoustic instruments with which we are familiar. There remains a widespread desire to see virtuosic performance, in which there is not only evident mastery of the instrument, but also an individualized contribution from the performer (Schloss and Jaffe 1993; Schloss 2003; Dobrian and Koppelman 2006). In many cases, however, it is not obvious how such virtuosity can be achieved in an interaction with an electronic device or computer system, which may have programmed, random, or otherwise non-deterministic behavior. In computer music, it is frequently difficult to distinguish between the performer's and computer's contributions, or to know how the performance might differ in the hands of another person.

In this article, we address the individuation of performance with electronic instruments—what we refer to as *style*. We first derive a working concept of style as distinct from *structure* in an activity, which we propose as a useful framework for considering virtuosity and individuality in interactions with technology, including musical ones. Drawing on recent work that has explored the role of *constraint*—a limitation in an interface's allowed, suggested, or perceived activities—in facilitating personally expressive actions and interactions (Norman 1999; Boden 2004; Hornecker 2005; Stokes 2006; Magnusson 2010), we posit an alliance between constraint and the development of style. The bulk of the article then describes a qualitative study that explores the emergence of personal performance styles in experienced performers with a novel, constrained electronic musical instrument.

The study aimed to embody aspects of a realistic situation within the new interfaces for musical expression (NIME) community: A performer must determine how to perform with a new instrument for which there is no established performance practice and no instruction manual. In particular, we sought to examine such a circumstance where the instrument in question offers a limited number of obvious physical controls. Apart from a small number of commercial controllers, it is a rarity in the NIME community for a substantial number of performers to take up a new instrument at the

Computer Music Journal, 36:1, pp. 23–41, Spring 2012

same time. Thus, in order to investigate individual variations, multiple copies of a new instrument were simultaneously distributed to performers who were asked to develop a performance in isolation from one another. The study was not a positivistic experiment that treated constraint as a control and style as a dependent variable; rather, drawing on phenomenological and "third paradigm" research in human–computer interaction (Dourish 2001; Bødker 2006; Harrison, Tatar, and Sengers 2007), it was a qualitative investigation of approaches to performance with this particular constrained and novel device.

Through observations of the performances at the end of the study period, we characterize performers' approaches and outcomes—for example, whether they played the device in the most obvious way possible, or discovered and invented different ways of playing it. We describe attributes of the performances by which the participants individuated themselves, and show that in some cases these arose as an explicit response or reaction to perceived constraint. This analysis is complemented with detailed interviews and questionnaires in order to discover how situational, experiential, and other factors interacted with the design to give rise to the performances we observed, with particular attention paid to notions of constraint. Three distinct orientations in the performers' approaches to practice with the instrument emerged: exploration, problem solving, and operation within constraints. Each of these was associated with identifiable outcomes in the performances and attitudes toward the instrument.

Style and Structure; Skill and Virtuosity

Following an idea by Bill Verplank (2001), we propose the term *style* to account for the individual variations in the realization of a task: the variety of outcomes that would be observed if different people were asked to draw a line from point A to point B. Brand and Hertzmann (2000) similarly distinguish between style and structure. The *structure* of an interaction consists of a series of qualitative states and transitions between them. Structure describes an activity in the abstract: for example, pitching a baseball consists of progression through the states of grip, windup, leg kick, push-off, and release. Like Verplank, Brand and Hertzmann use the term *style* to account for the quantitative variations in specific instantiations of a structure. These variations will be influenced by the particular selection among activities that are encompassed within the structure—a curveball will look different from a fastball—and by the actor's physical, cognitive, and emotional attributes. We further define *personal style* as a pattern of observable similarities across different realizations of a structure that are attributable to an individual: a baseball pitcher's style will appear to be somehow consistent from one pitch to the next, regardless of the particular type of pitch; John Coltrane's personal style of saxophone playing is recognizable whether he is playing a tenor or soprano saxophone, whether a ballad or a blues.

Implicit in this notion of style is the suggestion that the richness of an interaction lies not merely in a progression of states, but in the chosen path between them. Ingold (2007) frames this distinction in terms of the difference between *transport* and *wayfaring*, between traveling *across* a map versus *along* a path. To him, the richness in finding one's way between two states is lost in knowledge representations or interactions that are confined to linear connections between points. Elsewhere, Ingold (2001) argues that the expressive or communicative potential of skilled practice exists in the variation in individual embodied action, as opposed to the rote mechanical reproduction of artifacts. He paraphrases Rubin (1988), asserting that "to understand skilled practice . . . we need to think of making in terms not of the simple, mechanical execution of complex *structures*, but of the form-generating potentials of complex *processes*" (Ingold 2001, p. 22). That is, the richness of skilled practice arises through variation in the process of realizing a structure (what we refer to as style), not in the structure itself.

However, as Djajadiningrat, Matthews, and Stienstra (2007) lament, there is a trend in product design away from reliance on humans' perceptual-motor skill, resulting simultaneously in an increased burden on our cognitive abilities and a loss of the expressive potential that comes from physical movement: "Performing bodily movements and

building bodily skill can be both challenging and highly rewarding, whilst we are also perceptually sensitive to the beauty and expressiveness of movement in our physical environment" (p. 658). According to Jensen, Buur, and Djajadiningrat (2005, p. 9), these cognitively oriented products "ignore the possibility that human actions can also be a source of beauty and a rich carrier of emotions." They see this trend manifested in the proliferation of what Norman (1998) calls *weak general* products—those, such as the mobile phone, in which the user's actions are generic and can give rise to any number of functions. Leach (1976) argues that there is significant overlap in what we might typically distinguish as *technical* and *expressive* actions, that even seemingly mundane and skilled actions have significant expressive potential: "The way I prepare the coffee and the instruments which I use in the process give information about my cultural background" (p. 9).

Style and Virtuosity in Music and Beyond

Style and skill are thus intimately connected. Skilled practice depends on the same variability in realizing a structure that allows style to emerge. This relationship becomes more pronounced when we consider the problem of performing music with interactive digital systems. Several authors (e.g., Arfib et al. 2002; Wessel and Wright 2002; Jordà 2004; Dobrian and Koppelman 2006) have tried to address the erosion of virtuosity (Schloss and Jaffe 1993) that is occurring alongside the proliferation of digital technologies in music performance. The rise of laptop music, in which performers are "content to sit on stage gazing at their computer screen and moving their mouse" (Schloss 2003), has been maligned due to its lack of performativity, which results precisely from a shift toward reliance on cognitive engagement and away from bodily skill. Owing to the use of weak general interfaces, "the computer music process . . . is driven by intellectual ideas, and it involves office gestures" (Zicarelli 2001). This has likely been magnified by a trend of "instant music now, subtlety later" (Cook 2001) and a concomitant tendency to create music devices that are "easy to use" or offer expressive capabilities to novices (e.g., Blaine and Fels 2003; Chew et al. 2005; Freiberg 2005). Wessel and Wright (2002) argue that instruments intended to be "easy to play" exhibit a toy-like novelty in which interest quickly fades away; they do not engage the user in the long-term practice that is necessary for skill development.

It is widely accepted that virtuosity requires not only skilled practice, but also a personal contribution that is unique to the performer. Thus, we can consider virtuosity in terms of style; a virtuosic performer is not only skillful enough to realize difficult or complex structures, but can do so with a style deemed desirable. As in the previous examples of making coffee (Leach 1976) or dialing a telephone (Djajadiningrat, Matthews, and Stienstra 2007), the perceived expressiveness of a particular instantiation of a skilled music performance arises through stylistic variation. Along these lines, Jordà (2004, p. 708) uses the term *micro-diversity* to describe, in musical terms, how two performances of the same piece can differ: "variation . . . that could occur within a given piece while keeping it recognizable."

In a broad range of performative interactions, it is frequently important that a spectator should be able to distinguish between structure and style—between what the performer is doing and how they are doing it. For example, anyone who has visited Ireland knows that there is an art to pouring a pint of Guinness. The act is defined by a recognizable sequence of states and transitions between them: select a glass, turn on the tap, put the glass under the tap, wait, turn off the tap, set the glass down, wait, turn on the tap again, etc. A bartender has any number of options in their particular realization of each stage, however. Do they flip the glass in the air as they select it? At what angle do they tilt the glass? Exactly when do they stop the flow? How long do they wait before topping it off? These characteristics define the particular style with which the bartender pours the beer, and an observant customer will take note. The judgment of "a good pint" frequently has as much to do with the customer's (spectator's) assessment of the bartender's style as it does with the taste of the beer.

Consider a hypothetical digital version of the same technology, in which a user places a glass beneath a spout, presses a button, and beer is poured. Regardless of the resulting taste, this experience is deficient without the opportunity to appreciate the bartender's style. We know that pleasure can cause us to overestimate a product's value or inflate our assessment of its functionality (Norman 2004). Therefore, we are faced with the significant challenge of designing new interactions that simultaneously reap benefits of novelty, efficiency, repeatability, and scalability that digital technologies afford, while also allowing for the emotional reward that arises from the ability to cultivate and appreciate style. This is especially true when we consider the search for virtuosity in interactive music performance.

Constraint

Through a series of design workshops, we identified *constraint* as a significant factor in facilitating style and enabling a spectator to discern structure (Gurevich, Stapleton, and Bennett 2009). We posited that interactions with highly constraining structures help make those structures apparent to the spectator, but may limit the degree of stylistic variation. Conversely, a loosely constrained interaction might lead to a great diversity of styles but also to a difficulty for an observer to recognize the structure underpinning a particular performance. The literature on creativity similarly suggests that constraints can be valuable in generating novelty. Based on analyses of creative innovators in various artistic disciplines, Stokes (2006) offers a technique of setting up multiple, opposing constraints to create a unique, confined solution space for creative problems. Boden (2004) argues for a strong connection between creativity and constraint, using the metaphor of maps. Physical maps provide an infinite number of ways to get from point A to point B, but also provide boundaries within which one can explore. "Maps of the mind"—theories or conceptual frameworks—similarly provide constraints that "guide thought and action" (p. 59).

In general, we take constraint to mean a limitation of the variety of activities suggested by a design, whether by physical means, by implication, or by imposed conditions. This follows Hornecker's (2005) definition: "constraints restrict what people can do and thereby make some behaviors more probable than others" (p. 27). In discussing interactive music systems, Magnusson (2010) contrasts constraints with affordances (Gibson 1979; Norman 1988; Gaver 1991; Norman 1999), arguing that the latter suggest specific and immediate possible actions or uses, whereas the former circumscribe the entire range of expressive potential that may be explored over a long period of time, thus making "designing constraints" a more appropriate perspective for creators of music systems.

In a design context, we can consider both the physical constraints of an interaction or a device, as well as the perceived constraints in the mind of the user to which the device gives rise. In other words, we can conceive of a design's constraints in the world, as well as the constraints in the user's mental representation of the interaction. We call these *physical constraints* and *perceived constraints*, respectively. The former circumscribe the interactions that are actually possible, depending on the physical limitations of human performance as well as cognitive and innate ability (Stokes 2006), and the latter define the limits of what a user thinks can or should be done. Indeed, in design, constraint can alternatively be seen as a technical limitation that impedes usability, or as a resource to generate desirable social interactions or creative solutions (Candy and Edmonds 1997; Boden 2004; Hornecker and Buur 2006; Stokes 2006). Ullmer, Ishii, and Jacob (2005) were primarily concerned with physical constraints to limit the placement or motion of tangible tokens, but acknowledged that constraints can also be manifested as visual cues "that are not mechanically confining" (p. 84). Even physical tokens lead to perceptual constraints in that they can "passively express allowable combinations and alternative usage scenarios" (p. 84). Pearce and Wiggins (2002) use the term *internal constraints* and Coughlan and Johnson (2008) use the term *conceptual constraints* roughly in place of our *perceived constraints*, to specify local,

context-dependent, self-imposed limitations during the compositional activity. In an interactional context, we prefer to highlight the perceptual facet of such constraints; like Pearce and Wiggins's (2002) internal constraints, they are dynamic, but are also provoked by the user's perception of the appearance and behavior of the interactive system during active exploration. Perceived constraints describe the limitations in what the user thinks they "should do" at any given moment, which, as in composition, may present a number of varied, rapidly changing options.

Physical and perceived constraints map roughly onto the first two of Norman's (1999) three kinds of constraints: physical, logical, and cultural. Logical constraints are deduced by the user in response to some required action. We argue, however, that in a creative context, actions are not necessarily "required" to complete a task, as they are in Norman's example of clicking five buttons when only four are visible (p. 40). Rather, where tasks are ill-defined, user actions or behaviors are devised or conceived by the user in response to the confluence of their goals and what they see as the limitations in what the device makes possible; hence, our term *perceived* constraints.

In addition to physical and perceived constraints, we account for a third class: *external constraints* that may be imposed on an interaction. A performer's interaction with a musical instrument is constrained by the physical limitations presented by the instrument and their perception of what can and should be done with the instrument, but also by "the piece" that they are playing. The piece here may include not only a score or fixed composition, but also a set of norms according to the genre of music, performance practice, and social convention. Norman (1999) uses the term *convention* to describe a *cultural constraint* that has become codified through cultural practice. Stokes (2006) locates these under the rubric of *domain constraints.* Whereas Pearce and Wiggins (2002) use the term *stylistic constraints* in the context of composition to describe those imposed by genre or convention, we see these as a subset derived from the "superordinate principles of harmony and structure" that they locate in the domain of external constraints (p. 18).

Of course, external constraints, such as those of "the piece," are ultimately discretionally interpreted by the performer. But, as they are situated and not material to the fundamental interaction of, for example, playing a violin, we refer to them as external. We prefer the term *external constraint* because it implies a broader set of situated external conditions that may impose upon an interaction. Along with Pearce and Wiggins (2002), we propose that external constraints facilitate the distinction between style and structure by spectators.

In the study documented here, we investigate the relationship between constraint and style—between the diversity of suggested and actual behaviors. In particular, we look at a condition with high degrees of physical constraint and expected perceived constraint, and fairly minimal external constraints. The motivation is to examine the diversity of behaviors that actually emerge when creative users, given minimal instructions, interact with a device that has limited functionality and will be perceived as such. In an experimental context, it would be easy to externally impose constraint on an interaction by simply instructing users to operate a device in a particular way (e.g., Baraldi, De Poli, and Rodà 2006). Given a 101-key computer keyboard, which suggests a wide variety of behaviors, one could easily constrain the interaction of a user by telling them to press the "F" key. This is the kind of constraint that can "preclude the surprising and promote the expected," what Stokes (2006, p. 7) calls "constraints for conformity." Rather, we are concerned with the behaviors that result spontaneously in the absence of significant external constraints.

Our aim was not to evaluate the musical usefulness of a particular device, nor to compare styles of use between different interfaces. Instead, the goal was a multi-faceted, "thick description" of musicians' approaches to practice, engagement, and performance with an electronic musical instrument that is physically and perceptually constrained.

Methodology

The basic premise of the study was to give a number of performers each an identical copy of a novel

electronic instrument with limited capabilities that was anticipated to be perceived as constrained, and to identify and characterize similarities or differences in style, approach, and perception of the instrument that arose. In preparation for short solo performances, participants practiced with the instrument in isolation. A structured interview was conducted with each participant immediately following the performance. The performances and interviews were videotaped and analyzed using a qualitative data analysis approach informed by grounded theory (Corbin and Strauss 2008). In contrast to quantitative methods of experimental inquiry, grounded theory research does not begin with a hypothesis that is to proved or disproved. Rather, it seeks to generate a theory, rooted in data such as interviews, observation notes, or log books, that explain some facet of human experience. Like all qualitative research, it "allows researchers to get at the inner experience of participants, to discover how meanings are formed through and in culture, and to discover rather than test variables" (Corbin and Strauss 2008, p. 12). In strict grounded theory, data are subjected to a prescribed regimen of coding, concept generation, and categorization, from which a theory is generated. Nearly all contemporary qualitative research draws in some way on the theory and techniques of grounded theory, though, as in our study, it is rarely used in an orthodox way. Our methodology is additionally informed by the phenomenological approach to qualitative research (Moustakas 1994; Creswell 1998) which, even in its orthodox form, bears resemblance to grounded theory.

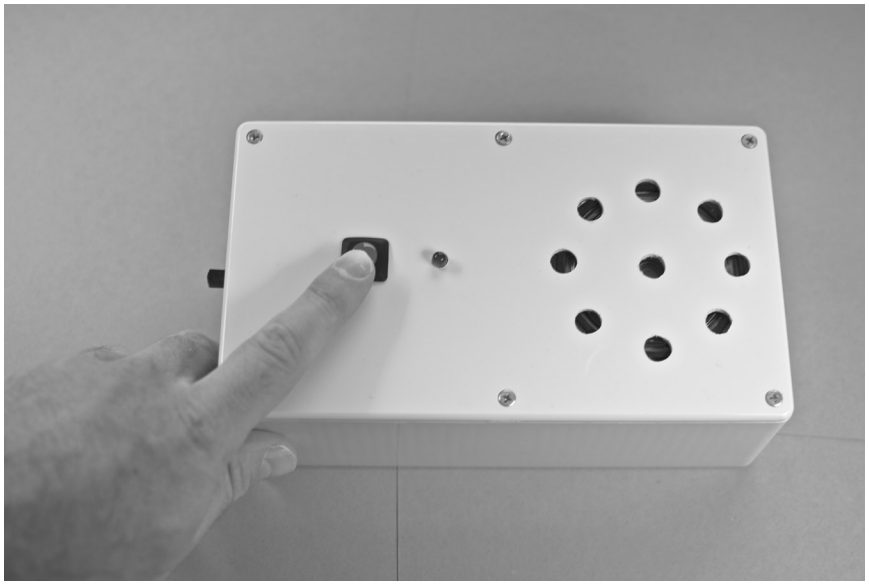
There are some inherent difficulties in qualitative approaches to electronic music studies. Etiquette, convention, and the very nature of performance make it nearly impossible to study performers and audiences in naturalistic settings, as qualitative researchers are advised to do. Furthermore, when investigating phenomena such as the emergence of style and constraint, it is necessary to provide some catalyst for style to emerge. In other words, the specificity and nature of the phenomena being studied required intervention on our part. This kind of "experimental intervention" in qualitative studies is certainly not unprecedented, however. In computer music, Stowell et al. (2009) explicitly adapted Foucauldian discourse analysis in order to investigate the experiences of users of a new interactive music system. We also draw on Gaver's notion of cultural probes (Gaver and Dunne 1999; Gaver, Dunne, and Pacenti 1999; Gaver et al. 2004) and its numerous adaptations (Boehner et al. 2007). In the present study, we introduced a novel instrument as a "probe" into the performers' environment, and provided them with open-ended instructions to engage with it. Consistent with the observation of Boehner et al. (2007), the adaptations we made to the probe concept were necessary in order to suit the particular context and objectives of our study.

Instrument Design

A simple and new electronic musical instrument, depicted in Figure 1, was designed specifically for this study in order to ensure that there was no established performance practice or other normative convention that could impose external constraints among participants. Furthermore, the instrument was not given a name in order to avoid explicit suggestions of meaning or purpose to the participants. (We will call it "the instrument.") An obvious way to physically constrain a design is to limit the number of controls, the number of degrees of freedom of each control, and the outcomes that are mapped to those controls. We therefore tried to create a device with a minimal number of mechanically constrained physical controls and sonic parameters, and a one-to-one mapping between them. The instrument consists of an unadorned project box with a single momentary pushbutton on its top surface whose only control is the duration of a single tone.

A tone of fixed pitch and amplitude plays from a speaker embedded in the box for as long as the button is pressed. The tone is roughly a square wave, generated by an oscillator circuit built with a simple 555 integrated circuit timer, that is filtered acoustically by the housing. The sound is projected through holes drilled into the top surface of the box. Owing to slightly different construction conditions among the handmade units, the pitches of the

Figure 1. The instrument used in the study.



ten instruments varied somewhat, although all were within an octave between about 500 Hz and 1 kHz. As the button was inserted directly into the oscillator circuit, the instrument had a rather sharp attack and decay. A light-emitting diode on the box illuminated while the button was pressed. Battery drain was an issue in a prototype version of the instrument. Compensating for this would have required increasing the complexity of the circuit, and so, as a compromise, a power switch was added to the side of the box.

Protocol

Participants consisted of nine volunteer undergraduate and postgraduate music students. All competently played a musical instrument and had experience with improvisation and electronic music. Overall conditions were controlled to minimize explicit externally imposed constraints. Where external constraints were necessary in order to structure the activity assigned to the participants, they were applied uniformly. Each participant received one copy of the instrument and was instructed to practice with it daily over the period of one week. Participants were told that at the end of this time, they would be asked to give a solo performance with the instrument lasting no more than two minutes. Each was informed that they would be interviewed subsequent to the performance. No further instructions or information regarding the instrument's design or purpose were given. The performance sessions were conducted in vacant private offices in the authors' department. Apart from the performer, only the interviewer was present in the room, although the performers were aware that the sessions were being recorded. Performers were given no directions as to their physical comportment, and all were presented with the opportunity to sit, stand, and use a table surface according to their preference. The performances began once the participant felt ready to do so, and they were not instructed to stop by the interviewer; the decision to end a performance was left to the performer. The structured interview followed the conclusion of the performance.

Analysis

Videos of the performances and interviews were analyzed in order to extract data based on both direct observation of the performances and participants' interview accounts. Expecting that at least some

stylistic variations would be observed, the purpose of the interview was to shed light on what might have led participants to generate their particular performance realizations and to trace the motivations, impressions, and approaches across participants. Although specific lines of questioning were developed in order to elicit data in these categories, most of the participants volunteered a significant amount of the desired information in response to the initial question, which asked them to describe their approach to what they had just played.

The interview contained lines of questioning to address the following areas: (1) musical content (the personal approach taken during the performance, and the range of material played); (2) impressions of the instrument (initial reactions, mental model of the instrument, expectations, perceived limitations or constraints, and previous experience with other similar instruments); (3) physical interaction (range of playing styles and physical postures); (4) learning process (approach to practice and engagement with the instrument); (5) skill development (perceived improvement through practice and skill self-assessment); and (6) suggestions for further development of the instrument.

The video from each performance was manually analyzed in an effort to identify common and divergent features present across performances. The study did not have explicit hypotheses regarding the relationships between style, constraint, and the participants' approaches to the instrument, therefore the approach was to gather data and allow these relationships to emerge through qualitative analysis. Recordings of the performances were initially freely coded with descriptors of salient performance attributes. These were subsequently grouped into conceptually unified performance characteristics. These concepts were merged into a set of non-overlapping categories, and data were then recoded to ensure that each category was accounted for. Within each category, a set of codes classified behaviors or activities; each performance was assigned one or more codes in each category based on the presence or absence, and in some cases the frequency, of the associated activity. Codes were not predetermined, and each category was sparsely populated; that is, new codes were generated only by newly observed activities. Six categories of performance attributes are relevant to our analysis. These are: note durations, silence durations, posture, ways of holding the instrument, ways of playing the instrument, and sonic variations. These categories are explained subsequently as the pertinent observations are introduced. Table 1 lists the categories and activities observed in each.

Interview transcripts were also initially freely tagged with open codes. These were subsequently analyzed for semantic and thematic similarities and grouped into categories. Owing to the semi-structured nature of the interview, the seven categories that emerged reflected, to some extent, the lines of questioning, with some emergent themes appearing as well. These categories were: initial impressions, approaches, perceived limitations, expectations, strategies for overcoming limitations, skill, and associations with other devices. Coded transcript sections were then correlated against each other, and against performance observations, in order to identify patterns and relationships across participants' behaviors and comments.

Observations

We present observations from performance and interview data alongside one another in order to examine how participants' use of the instrument in practice relate to accounts of their experiences and impressions.

Perceptions of Constraint

All nine of the participants' initial impressions of the instrument indicated that it was perceived to be excessively constrained in some way. Seven of these described a generic simplicity or limitation; four added that the instrument's potential was immediately obvious or easily explored. The remaining two participants, along with two of the previous seven, described the initially perceived constraint in sonic terms: the lack of control over variation in pitch, timbre, and/or dynamics. In order to further assess impressions of constraint, at the very end of the

Table 1. Categories and Codes of Performance Observations

Note Durations	*Silence Durations*	*Posture*	*Ways of Holding*	*Ways of Playing*	*Sonic Variations*
Short (<1 sec)	Short (<1 sec)	Sitting	Resting on table	Button press with finger	Rhythmic beeping
Med (1–3 sec)	Med (1–3 sec)	Straight back	Resting on lap	Button press with thumb	Arrhythmic beeping
Long (>3 sec)	Long (>3 sec)	Leaning forward	Held in the air	Finger taps on box	Rhythmic tapping on box
		Arms at side	One handed	Thumb taps on box	Arrhythmic tapping on box
		Arms out	Two handed	Hand taps on box	Tremolo/filtering
		Elbows free	Lengthwise	Manual filtering	Button noise
		Elbows resting	Widthwise	Spatialization	Simultaneous events
		Feet on floor	Rotated on any axis	Power switch	
		Legs crossed		Combined techniques	

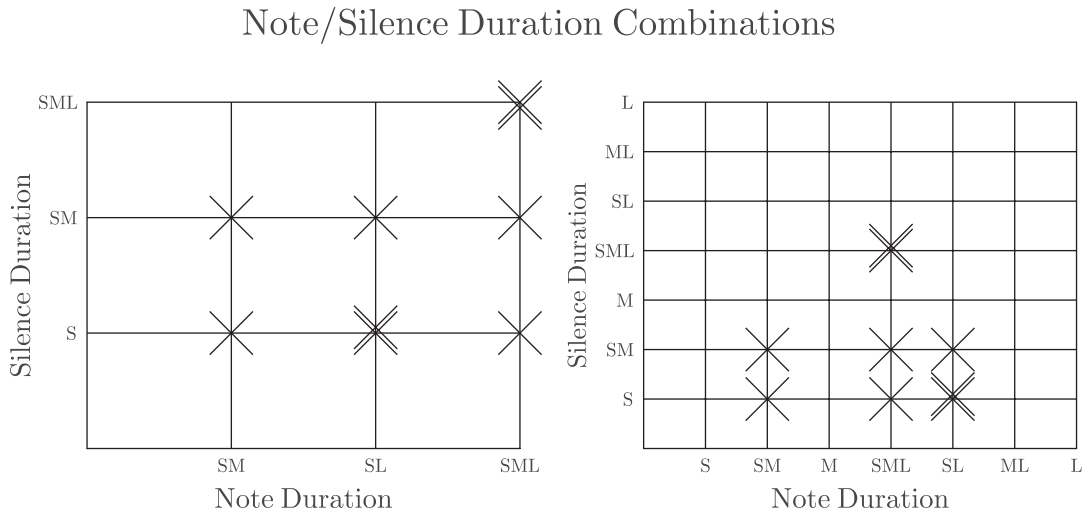
interview participants were asked to describe how they would change the instrument. These responses were alternately framed in terms of sound (control of frequency, timbre, and volume) or interface (add more buttons, introduce sliders). Several performers expressed an appreciation of the simplicity of the interface, however. Because of this, they did not want to drastically change the instrument and commented that a minor change or addition, such as volume or frequency control, would suffice to substantially increase the musical possibilities of the instrument. Participant EJ offered one such opinion: "I like the simplicity of it. I think it would be neat if it had some sort of velocity [sensitivity] or something like that . . . I like the idea of the one-button thing . . . I would make it something in the touch . . . If touch controlled timbre; something touch-sensitive like that, but just with that one button."

Note and Silence Durations

Viewed strictly within its immediately apparent constraints, the instrument offers only control over the timing of note onsets and offsets. This provides access to higher-level musical attributes like rhythm and meter, but at the most basic level, we can assess the diversity of behaviors among participants in terms of note durations and silence durations. A performance that exclusively consists of short notes separated by long silences has a different style from one of long notes interspersed with very short silences. By clustering the durations of all notes and silences observed in all performances, we classified note and silence durations into three categories: **S**hort (<1 sec), **M**edium (1–3 sec), and **L**ong (>3 sec). Each performance was then assessed for the presence or absence of notes and silences of each duration class. There are a total of seven possible combinations each for note durations and silence durations. Of these, three combinations of note durations and three combinations of silence durations were observed in the nine performances. For note durations, these were: **SM**, **SL**, **SML**; for silence durations: **S**, **SM**, **SML.**

Each performance can be classified in terms of the pair $\{N, Q\}$, where N and Q represent the set of note and silence durations observed in that performance, respectively. Out of 49 possible pairs that can characterize each performance, seven unique pairs were observed, drawing from the three sets of note durations and the three sets of silence durations listed above. These are illustrated in Figure 2. By this measure, we see a high degree of stylistic diversity between the performers. The right-hand plot of Figure 2 indicates that these performances were concentrated into a narrow region of the overall set of possibilities, however. Participants exhibited

Figure 2. Note and silence durations in the nine performances.



a distinct tendency toward short note and silence durations and a clear avoidance of exclusively long and medium/long notes and silences.

The interview data offer an explanation for the lack of long notes: four participants described the sound of the instrument as monotonous or static and one indicated that it was loud. According to another (TK), "let's say that if you play it for too long, well, it's not very pleasant." There were few long silences, appearing in only two participants' performances. One of these (EJ) described the deliberate use of silence as a stylistic choice: "You've been playing a lot and then all of a sudden you drop out, or you've been playing something rhythmic and then you drop out. Then you're setting up this situation where's there a lot of room to play around." The external constraints, however minimal, imposed by the context of the performances within the study may have also influenced the trend toward short silences: The relatively short suggested duration may have discouraged participants from spending long stretches of their two minutes in silence.

Overall, we see the confinement of the distribution of $\{N,Q\}$ pairs to a limited region throughout the total possible space as an indication that the combination of physical, perceived, and external constraints steered users toward a normative style of use. However, within the region that participants did operate, very little overlap in styles was observed, suggesting that individual performers' contributions based on their particular experience, motivations, and choices led to individualized realizations.

Other Performance Attributes

Although the analysis of note and silence durations gives some insight into the stylistic diversity of the performances, it is clear that this could not truly characterize the variability in approaches and outcomes.

Physical Engagement

One way to examine this diversity is in the variations that emerged in physical engagement with the instrument. As the device had no established performance practice prior to study, we wanted to see to what extent the performers developed similar playing habits in response to the design. Three relevant categories arose from the data: posture, ways of holding the instrument, and ways of playing the instrument. The codes observed under each category are listed in Table 1. Salient features

of posture were coded in terms of spine angle, foot position, arm position, elbow position, and whether the participant was sitting or standing. Two variations were observed in each of the first four of these classes. No participants elected to stand, resulting in a total of nine codes. Performances were coded for the presence of each postural trait at any point in the performance, such that multiple codes for each attribute would be assigned if the participant changed posture.

Ways of holding the instrument refers to the position of the instrument in the hands and around the body, changes of which were similarly accounted for during the performance. Seven distinct ways of holding the instrument were observed, as shown in Table 1. Ways of playing the instrument describe physical actions that directly led to sound production or modification. In this category, *combined techniques* refers to the use of more than one simultaneous way of playing, such as pressing the button with the thumb while tapping on the box with the other hand. This code is only assigned when one or more technique is used at the same time, in order to differentiate this practice from the sequential employment of different ways of playing.

Sonic Diversity

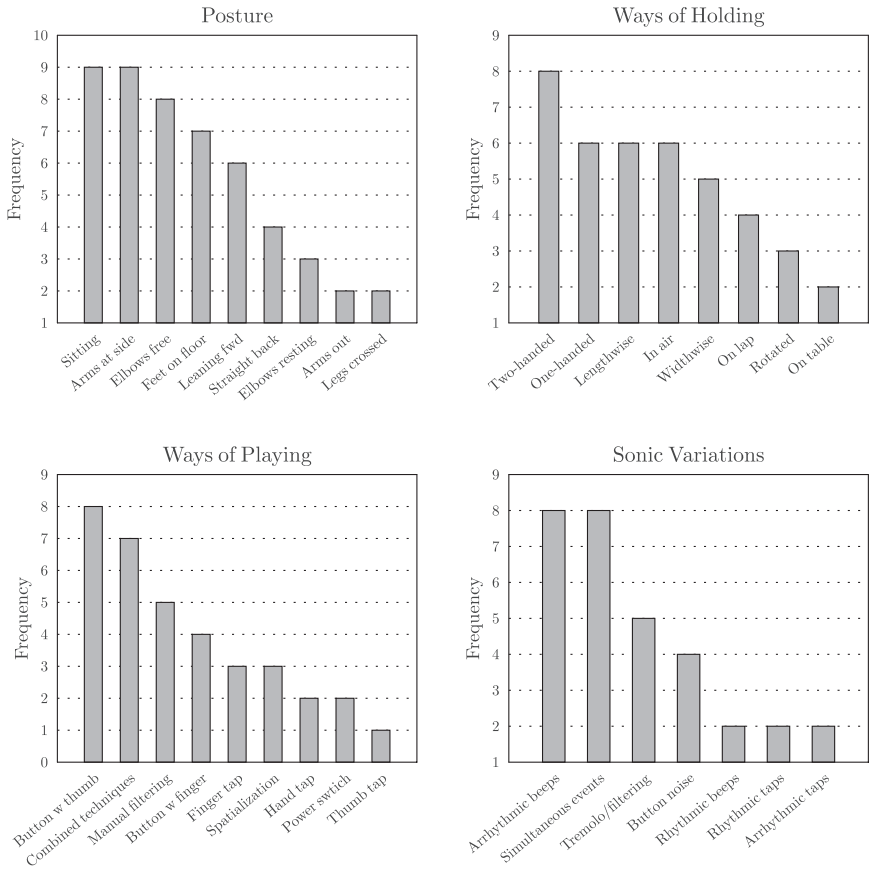
A fourth category of performance attributes, sonic variations, describes the diversity of sonic characteristics achieved by the participants, independent of the playing techniques used in their realization. Among these are codes that consider whether performances contained rhythmic elements, requiring higher-level temporal structuring. We do not differentiate between particular rhythms or meters, only whether the playing is rhythmic or not. Rhythmic playing was ascribed when sound events were organized with an audible pulse; arrhythmic playing was ascribed when no pulse could be detected. Other sonic variations include filtering the sound emanating from the speaker (which some used to achieve a tremolo effect), moving the instrument around in space, and exploitation of mechanical noise of the button to achieve variation in timbre. Simultaneous events refers to multiple sonic variations occurring at the same time: for example, tapping the box while playing beeps with the button.

Histograms indicating the frequency of occurrence of codes in the four aforementioned categories—posture, ways of holding, ways of playing, and sonic variation—are shown in Figure 3, with the *x*-axis ordered by decreasing frequency. These plots all indicate a tendency toward a normative overall playing approach characterized by the two or three most common codes, with divergent styles appearing much less frequently. We expect that as the number of participants increases, the "tails" would grow longer as more performers introduced unique personal variations, but that we would also see further consolidation in the region of "normal" activity.

Manual Filtering and Spatialization

Correlations between the occurrence of these other performance attributes and trends in the analysis of note/silence durations help explain some of the observed behaviors. The activity of manual filtering occurred in five performances, all of which were among the seven that included long note durations. That is, in all but two performances with long notes, the performers manually attenuated or filtered the sound of the instrument. Among these participants, four variously described the sound of the instrument as "monotonous," "static," "loud," and having "limited . . . musical dynamics." The fifth participant (FB) who used this technique specifically mentioned manual filtering as a method of introducing variation to the static sound of longer notes: "At first I only sustained the tone; [I] left it pressed and, after a while, tried to vary it in some way. And the way I did that was to dampen the speaker." Three of the five participants who used manual filtering also used spatialization—moving the instrument around in space in order to achieve some variation in pitch or timbre. One (MC) described "moving it across my face so that it could [achieve] a very small Doppler effect. Extremely small Doppler effect." Of the two participants who played long notes but did not manually dampen the sound during performance, one (RH) described discovering the technique during rehearsal but

Figure 3. Histograms of four categories of performance attributes.



rejecting it before his performance: "And then with—doing like muffling it—just to see, you know? It just sort of went 'wah wah wah.' "

The observed correlation between notes of long duration and manual filtering suggests that some users found "hidden affordances" (Gaver 1991) in order to overcome an initial perceived constraint of the interface. For participant FB (quoted earlier), manual filtering (described as "dampening") was used in order to realize his desire to introduce variation to the static sound. Another participant (GA) described using manual filtering as an attempt to uncover some otherwise hidden potential: "Its simplicity made me think that there was something I was missing . . . it made me, you know, wonder what I was missing." GA reiterated this idea later in the interview, this time suggesting the monotony was a source of limitation: "I kind of knew that it had only one sound, but I thought that there was something else to it that I was kind of missing."

Mechanical Noise

Several participants further overcame initial perceived constraints after noticing that the button on the instrument generated mechanical noise at the edge of the contact region, causing a chaotic, noisy sound from the circuit. The power switch was similarly incorporated by some performers, introducing further variations in timbre and possibilities for control beyond the button. In the interviews, it became apparent that eight of the participants were aware of one or both of these techniques, yet only half of these used them in performance. Those who did not use these techniques either found the resulting sounds too unappealing or else expressed

an impression that the instrument was not supposed to be played that way.

Extended Techniques

Nevertheless, it is significant that almost all of the participants discovered what amount to "extended techniques" in a short amount of time. These led to a surprising diversity of performance styles even given the widely perceived constraint. The subjective impressions given by the performances confirm these measures of diversity. One participant (RH) played almost exclusively bimanual hand drumming techniques on the instrument, using the button to play syncopated accents. Another (EJ) focused entirely on arrhythmic, timbral exploration of the sound produced by the mechanical noise of the button. A third (GA) played with the button depressed for nearly the entire performance, using the power switch and dampening the speaker to generate variation.

Approaches to Practice

We examined in detail the participants' approaches to the instrument, revealing what may have motivated or precipitated the observed stylistic diversity. When prompted to describe their approach to their performance, participants tended to do so in terms of their evolving relationship with the instrument through practice. As discussed previously, initial impressions were dominated by a sense of limited possibilities, indicating that the perceived and physical constraints steered users toward a restricted set of behaviors. Interviews revealed three distinct approaches to dealing with the constraints that participants adopted over the course of their practice with the instrument. We describe these as: (1) operating within the constraints, (2) a problem-solving approach, and (3) an exploratory approach.

Operating Within Constraints

Two participants effectively stopped exploring the instrument after assessing its immediately apparent constraints. Even after having a week to practice with the instrument, one of these participants (NS) said, "it just has that one sound it makes and the one way to trigger it." This participant expressed the most outwardly critical view of the instrument; the initial limitations discouraged him from further exploration. The other participant (RH) who operated entirely within the immediately apparent constraints similarly saw little further potential: "The box itself beeps and flashes a light and that's really it then. It's like one frequency, which is boring anyway. So the only other thing I could do anyway, besides taking it apart, was bang on it." Although this suggests awareness of at least one way to overcome these constraints—modifying the internal circuitry of the instrument—it was not pursued, nor were other possibilities investigated. Unlike the other participant who adopted this approach, the constraints seemed to suit RH's practice as a percussionist: "To me [it] was more interesting musically, because I'm from a musical background . . . so I need to make music and rhythms with things that I would find interesting. So that was the only thing I could do."

Problem-Solving Approach

The majority of participants approached the perceived constraints in terms of specific aims or problems to be solved. For these five (FB, PD, MC, TK, GA), the aforementioned techniques of manual filtering and spatialization were discovered in deliberate attempts to overcome the static or, in the case of participant PD, loud nature of the instrument: "I discovered the envelope thing [manual filtering] because I tried to make the volume softer. At first the volume seemed too loud to me and then I covered it to make it less loud. I mean, I realized that it could be another musical parameter." Also typical of this group, participant FB described discovering manual filtering and spatialization in terms of overcoming a limitation: "And then practicing another—like another type [of variation]—that, with that limitation, can achieve another sound. Either not having the sound directed towards me, but trying to vary it, covering it, moving it [moves box around] basically."

One participant (TK) described seeking and discovering possibilities for the instrument beyond the initially perceived constraints, but viewed the

results as unsatisfying: "I tried changing—trying to close it to change the volume or something like that, trying to dampen it like this (puts hand over speaker) to see if it could do anything else, but it seemed that . . . it didn't do much. It's like a very pure tone, so it wasn't possible to do much."

Exploratory Approach

Despite the fact that all participants ascribed a sense of simplicity or constraint to the instrument, two were undeterred, expressing that they were able to find valuable musical potential. Unlike those who adopted the problem-solving approach, however, these participants' explorations were not bounded or motivated by specific goals or problems. The constraint was itself a motivation, but one that prompted discovery rather than impeding particular desired outcomes. According to one participant (EJ) who adopted this approach, "I find limitations being a good thing. And you know the idea is you could sort of make something musical out of anything, it's an attractive aesthetic I guess . . . It's definitely a rich environment . . . I was sort of skeptical initially, but . . . right away, I was actually 'you could do this, you could do that.' "

The two participants who adopted an exploratory approach did so in distinct ways. We describe them as vertical and horizontal explorations. In the vertical exploratory approach, the participant (EJ) described identifying a novel technique or way of engaging with the instrument and attempting to exhaust all of its musical potential until something new emerged. This participant described discovering the mechanical noise of the button through such a process: "I like to explore during the performance, and so starting to just do something rhythmic, and then I noticed there's this kind of flaw or something like that . . . so I thought 'that's something to exploit.' So the instrument sort of led me to the next [possibility]." When unexpected outcomes arose, they were capitalized upon and further incorporated into practice, but this participant described no intentional search for specific results or solutions to particular problems: "It just sort of revealed itself. The first thing, well, when you look, 'oh, that's a button,' so [it] just means I have to do something pulsed. Then I noticed—and I don't know if it was intentional or not—but those little flaws . . . that noisiness—that helped a lot. So I can actually change timbre a little bit. I thought I could change timbre a little bit." For this participant, the constraints were present in the background, but they did not explicitly guide his practice as they did for others.

The participant (WL) who exhibited a horizontal exploratory approach described attempting to enumerate all the possibilities of the instrument. Her practice consisted of exploring as many different interactions as possible, physically and musically: "Not anymore, it no longer goes 'beep.' Let's hit it, bite it, or let's throw it around. I was like 'what to do, what to do? . . . Well, today I will not play beep but I will only hit it.' " Once a novel technique emerged, she would pursue another one. This participant seemed to conceptually separate activities that were "by design" from unintended ones. As with the participant who adopted the vertical approach, appropriation of these "unintentional" sounds or techniques was viewed as *exploitation*: "I discovered that there were small things that were not part of that sound and that maybe were not the same. They're not of the same principle of the box. I'm talking about its purpose [plays and sings the pitch]. Well, before doing that there where some other sounds that are not perceived . . . a 'crick, crack, crick' and that, I think, can be exploited."

The vertical and horizontal exploratory approaches are also apparent in the performance data, specifically in the numbers of ways of playing the instrument. The participant (WL) who adopted the horizontal approach demonstrated seven ways of playing, higher by two than any other. The sole participant (EJ) who adopted the linear approach had the lowest number; a single, unchanging way of engaging with the instrument in his performance. This participant similarly showed no changes in posture or in the ways of holding the instrument during the performance. He described 'mastery' as a priority, which possibly motivates his prolonged engagement with each particular approach, having not discovered the technique of manual filtering (described as "vibrato"), which was common among other participants, until the interview: "Or if I wanted to master this sort of spatialization

technique . . . that you could do with a violin or a clarinet and you experiment with it. You know, let's see, oh I never—ooh! [dampens speaker]—I never really tried the vibrato."

Skill

Although the two participants who adopted exploratory approaches produced radically different performances, the commonality in their approaches is reflected in their self-assessments of skill. During the interview, all participants were asked to rate their level of skill on the instrument on a 5-point Likert scale, with 1 being completely unskilled and 5 being an expert. The two participants who adopted exploratory approaches assigned themselves the lowest ratings of the group, scores of 1 and 2. (Only one other participant rated themselves a 2; the median rating was 3.) Participant WL's explanation for this assessment reflected a need for further exploration and discovery in order to improve: "Two . . . Because to be an expert I would need more time, perhaps . . . because you can always do something else, something different." The other participant (EJ) adopting an exploratory approach similarly commented on time investment but suggested also that technical mastery is not the only component to skill. He gave himself a rating of "1 for sure. A complete beginner. I think there's a level of competency I think you can develop [but] the rest is more a matter of musicality." In contrast, the sole participant who assigned himself a rating of 5 (NS) was among those who operated entirely within the immediately apparent constraints. His assessment is revealing: "if a master is a person who can turn this on and press it, then, let's say [I'm a] 5."

Discussion and Conclusions

The approaches to practice with the instrument that we identified were distinct and pronounced, and were the strongest reflection of the nature of the participants' engagement with the instrument. Although we did not attempt to evaluate the performances aesthetically, it was clear that the two participants who adopted the exploratory approach created the most stylistically distinct performances. The interviews with these participants, especially in their self-assessments of skill, also revealed that they saw the most potential for continued engagement with the instrument and improvement in their performances.

Whether successful or not, participants who adopted the problem-solving approach appeared to be motivated specifically by the constraints or limitations they perceived in the instrument. The static nature of the sound led some to seek variations in pitch, dynamics, or timbre, and the single active control prompted detailed examination of its mechanics. The constraint caused these participants to develop individual styles—personalized approaches based on their needs—and we observed significant "micro-diversity" (Jordà 2004) in terms of particular combinations of notes, silences, and techniques. A number of these innovations occurred across multiple participants, however. This "normative style" we observed suggests that the repertoire of techniques with which participants could develop style was limited; the physical and perceptual constraints appeared to be excessive for some.

Yet some participants, including those who adopted an exploratory approach, seemed to espouse Stokes's (2006) idea that paired, opposing constraints can lead to creative solutions. These participants deliberately applied their own constraints onto their activities in addition to those already inherent in the instrument. Participant WL, after realizing that the instrument can only make beeping sounds, described a process of deliberately trying to engage the instrument musically without making beeps, a self-imposed constraint. Participant EJ chose to drastically limit his sonic palette and set of playing techniques, focusing on the musical potential in a single way of playing and a single kind of sound.

In summary, we observed style emerge both as a direct result of constraint (in the performers who sought innovations in order to overcome perceived limitations) as well as in spite of constraint (in the performers who exhaustively sought the inherent musical potential no matter what the instrument was). Although we do not have explicit records or accounting of the participants' rehearsal process,

and none produced any kind of score or notes for their performances, the interview accounts of most of the participants give credence to Coughlan and Johnson's (2008) and Pearce and Wiggins's (2002) emphasis of the role of constraints in the process of composition. In the problem-solving and exploratory approaches, the participants seemed to incorporate the externally-imposed constraints as well as the physical limitations of the instrument into their creative cycle.

We can view participants' diverse performances in terms of a concept allied to style—*interpretation*. Interpretation can be seen as the process of assigning meaning to the structures and functions of a system, relying on its contextualization by a particular user (Sengers and Gaver 2006). As with style, multiple interpretations can co-exist in a given system, and Sengers and Gaver (2006) tout the value of designs that support multiple interpretations in a variety of interactive contexts, including digital art. Of course, in music, interpretation is a well-worn term, referring to a performer's challenge to make a personal contribution in the face of a known, "fixed" piece and established performance practice. In this we can see an essential relationship between style and constraint. Musical interpretations rely on the constrained structures of performance practice and compositions in order to make the performer's contribution—their style—apparent.

Sengers and Gaver (2006, p. 102) advocate "clearly specifying usability without constraining use," that is, "what the system does and how it can be controlled" should be obvious, "but the ultimate purpose, meaning, and usefulness of the device is left open for users to decide." In our terms, this is a call for a limitation of external constraints. Our study arguably featured more external constraints than this ideal—participants were told that the device was a musical instrument and were given a context of use, namely, a performance. In the responses of a number of participants, however, there was evidence that a better understanding of "purpose" would be beneficial. Participant WL, who adopted the horizontal exploratory approach, expressed a need to further understand the instrument's purpose in order to develop the necessary skill to improve upon her self-assigned score of 2: "[I would need to] study the box, see what's inside it. Know what its purpose is . . . because I like to have concepts like 'this is for this, that is for that' and then break it . . . Or follow it. But if I don't have the slightest clue [gestures in frustration], I don't know." This participant was among those who avoided playing with the mechanical noise of the button out of a fear that it may be harmful to the instrument or otherwise "wrong." Although this suggests that at least the bounds of purpose were implicitly perceived, the fact that the constraints represented by these bounds were fabricated by the participants themselves further emphasizes the importance of actual external constraints as a means for some participants to structure their activities.

Although this participant was still able to devise a diverse array of performance techniques, in others we observed a difficulty in confidently crafting a personal contribution, absent more explicit direction or constraint from outside of the design. Indeed, the very term interpretation—in music, art, language, and otherwise—relies on some understanding or attempt thereof of an original intent or meaning imparted on a system by its creator. We can view this understanding of purpose as a kind of external constraint that was absent in our study. As in WL's case, self-imposed constraints can be seen as a surrogate for external constraints imposed by convention, the designer's intent, or a composition. It appears that these kinds of constraints may rival physical constraints in facilitating style.

This points to perhaps a more salient concept than interpretation, namely, that of *appropriation*. Dourish (2001, p. 172) states that, in general, "users play a much more active role in determining precisely how a technology will meet their needs—needs that are continually changing, and that will be satisfied using a variety of features of the setting, of which the technological artifact is only one." Salovaara (2008) situates appropriation as akin to *adaptation*, midway on Eglash's (2004) continuum from *reinterpretation* to *reinvention*, implicitly suggesting that users develop and react to an understanding of an intended purpose on the part of the system designer.

We see strong evidence of appropriation by our study participants regardless of their approach to

practice. Participant RH exemplified appropriation by incorporating the instrument into his existing hand-drumming practice, using the beep to create accents. In this case, the constraint appeared to be effective in promoting individual style; the system had clear usability and it was effectively purposed to meet the participant's unique needs. Of the limited repertoire of sounds, RH said: "It's not the end of the world, especially for a drummer. You don't need those melodies too much." Participant EJ similarly identified and adhered to the chaotic sound generated by mechanical noise in the button, which suited an aesthetic tendency of incorporating noise into his musical practice. Thus, we can also view the problem of interpretation—participants lacking an understanding of purpose or suggestion of musical usefulness—in terms of a mismatch with their needs: the constrained nature of the instrument suggested meaning or usefulness in a musical context to some participants but not to others.

The implication that the performer's contribution to the interaction is an important factor in style should not be surprising, but it provides an opportunity to reflect back on the concept of virtuosity. There has been a tendency to describe the potential for virtuosity in terms of properties of the device (Wessel and Wright 2002), but our study shows that some performers saw enormous potential in "simple-to-use" devices. Neither of the participants who adopted exploratory approaches thought that they had exhausted the instrument's potential, and both expressed a need for a significant additional investment of time in order to improve their skill. Another participant (FB) stated, "there are always people that can achieve a greater level of virtuosity with a given instrument, simple or complex as it might be."

We have been asked numerous times how the outcomes might have differed with another instrument. Recalling Corbin and Strauss's (2008) assertion that one purpose of qualitative research is to identify rather than test variables, our response is that, as with any qualitative study, the outcomes with a different instrument would depend on the local circumstances. Our study has provided a better understanding of the factors at play in the early stages of adoption of a particular new electronic instrument. We have shown that performers' approaches to practice, perceptions of constraint (including physical, conventional and those imparted by the designer), as well as the relationship between the instrument and their particular personalities and experiences, all played an important role in their development of individual practice. These factors can be expected to be important in other scenarios and, as such, can serve as a basis for future studies. In our view, musical instruments and the musicians who play them are sufficiently complex that it would be futile to reductively characterize them by a set of variables that could be controlled across experiments, and we have, instead, attempted to offer rich description of a particular scenario that illuminates the emergence of individuality, both in spite of, and because of, limitation.

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