On the Inclusivity of Constraint: Creative Appropriation in Instruments for Neurodiverse Children and Young People

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ABSTRACT

Taking inspiration from research into deliberately constrained musical technologies and the emergence of neurodiverse, child-led musical groups such as the Artism Ensemble, the interplay between design-constraints, inclusivity and appropriation is explored. A small scale review covers systems from two prominent UK-based companies, and two iterations of a new prototype system that were developed in collaboration with a small group of young people on the autistic spectrum. Amongst these technologies, the aspects of musical experience that are made accessible differ with respect to the extent and nature of each system's constraints. It is argued that the design-constraints of the new prototype system facilitated the diverse playing styles and techniques observed during its development. Based on these observations, we propose that deliberately constrained musical instruments may be one way of providing more opportunities for the emergence of personal practices and preferences in neurodiverse groups of children and young people, and that this is a fitting subject for further research.

Author Keywords

neurodiversity, appropriation, constraint, design principles and concepts

CCS Concepts

•Human-centered computing → HCI theory, concepts and models; User centered design; •Applied computing → Sound and music computing;

1. INTRODUCTION

Proponents of the social model of disability and the neurodiversity movement have argued that disability is socially constructed, that there is a pressing need for greater representation, quality of life, agency, and for the acceptance of neurological difference as another aspect of human variation [11, 15, 16]. Pullin makes the related argument that the inclusion of more artistic, critical and radical practices in design for disability would benefit designers and disabled users alike through an increase in choice and creative opportunity [14]. There has been a recent increase in projects that have aimed to put these values into practice, creating opportunities for neurodiverse groups of young people to meaningfully shape the musical direction of the groups they perform in. The *Artism Ensemble* is one such example, led by a group of young autistic musicians, in which participating neurotypical adults were often pushed out of aesthetic comfort zone, being "asked to play things and play in ways that defy their 'common sense' musical sensibilities" [1, 2]. What an ensemble like this shows is that there is an emerging need for a) musical instruments that are open enough to support these contexts, and b) resources that support adults in reaching a better understanding of the preferences and practices of individuals within neurodiverse groups. We believe that amongst existing musical resources, questions of artistic choice and the meaningful appropriation of instruments could be explored further with respect to neurodiverse children and young people. The "least dangerous assumption" [5] that can be made is that in an inclusive environment with the right tools, every person would be capable of exploring and appropriating an instrument, provided they wanted to do so.

As we will discuss, commercially available accessible instruments tend to offer a high degree of choice and configurability, if set up by a facilitator. These instruments could be considered products of ability-based design approaches [25], as their adaptability places a focus on users' abilities rather than disabilities. The complexity of such resources, however, can be daunting for facilitators, and in the worst cases may preclude the use of these instruments in schools [24, 23]. Furthermore, the need for configuration by a facilitator may place aesthetic constraints on some users, inhibiting deeper engagement with a DMI [9], and leading to "involuntarily relinquished" [23] choices being made on their behalf.

The above are the themes that have underpinned Wright's research, exploring the usefulness of moderately incongruent interaction-design [26], and more recently, the provision of accessible choices for sounds and interaction styles in the design of prototype digital musical instruments (DMIs). Although not a direct topic in his research, constraints have become an increasingly dominant theme in the evaluation and testing of these prototypes.

The significant role of constraints in this area is not surprising. As Norman [12] discusses, physical, cultural, semantic and logical constraints can be used to inform a user how to correctly interact with a design. Constraints in this sense assume some degree of commonality of experience in the world and that there is a correct mode of use for a device, but this may not always be the case in inclusive musical contexts. The affordances of an instrument (the actions available to an agent based on an interaction between an object's physical qualities and the abilities of the agent [7]) will be affected by differences in the ways that neurodiverse

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people interact with the world. As the example of the *Artism Ensemble* revealed, young neurodiverse musicians may also have different ideas of what is musically 'correct'.

At their extremes, however, constraints in the design of musical instruments may circumvent such problems: requiring little in the way of technical demand or configuration, giving rise to "playful aesthetics" [3], and offering relief from the complexities of more sophisticated musical tools [10]. Even the simplest one-button instruments have been shown to give rise to very individual performance strategies in which users explored *hidden affordances*, often turning incidental physical attributes into expressive musical features [8]. Similarly, Zappi & McPherson's [28] study on dimensionality and appropriation found that the diversity in users' responses decreased when groups were given an extra degree of freedom (DoF) in the control over a DMIs output. This introduced the idea of *dominant constraints*, in which the nature of a particular constraint becomes the focus of user's attentions, reducing the likelihood of creative appropriation and the discovery of hidden affordances. Constrained DMIs of this kind are of great relevance to inclusive musical contexts, emphasizing the "individual approaches and attitudes" [8] of individuals, and minimizing the need for training and support.

2. APPROACH TO THE REVIEW

Our small-scale review of inclusive DMIs has the following aims: to identify the nature and extent of any constraints among these instruments, and to explore how these constraints might render aspects of musical performance more or less accessible. We focus our discussion on technologies from two companies — Skoog Music[17, 18] and Soundbeam [6, 20], chosen for their prominence in SEND schools across the UK [24] — and contrast them with Wright's own prototype instruments for sonic-play. The DMIs are considered from the point at which they are configured for use, but as some of these systems are highly configurable, however, multiple use-cases will be discussed. By considering these instruments from the point of configuration, we place our focus on those aspects of each musical system that all individuals within neurodiverse groups will have creative control over in their musical practice. Our review of each instrument or system is conducted with the following three points of focus: one, user input; two, intended usage; and three, constraints in primary use cases. Point one considers the engagement with the input-stage of a system and the ways that a system relates physical gestures with usable data. Point two establishes the intended or imagined use-cases of the instrument. For the commercially available instruments, this is established through a survey of promotional/instructional material on each company's YouTube channel, which demonstrate the ways in which the designers of these devices feel they can or should be used. Point three explores the degree of constraint or complexity for each use-case, and the extent to which there is potential for a user to appropriate the instrument as part of a creative practice. We do so using the concepts of *hidden affordances*, *degrees of freedom*, *physical constraints* and *dominant constraints* as described above. We will also introduce our own term: *stylistic constraint.*

3. SOUNDBEAM 6

The Soundbeam 6 system comprises a central touchscreen computer, which is controlled through some combination of ultrasonic beams and wireless switches [6, 20]. The computer comes pre-loaded with 'sound-sets' "that range from tracks which allow the exploration and performance of different genres" [20]. General setup of the beam sensors and switches, as well as selecting and creating new sound-sets is potentially difficult for users with complex needs, and so this is typically done by a music facilitator. In such cases, users are removed from the configuration process, stymieing full appropriation of the system.

The accessible parts of the system are the beams and switches, essentially an array of one-dimensional controls and triggers that can be configured in a number of ways. The wired beams are typically fixed to stands, and translate the distance between it and an occluding object to a quantized pitch parameter in a pre-configured synth. The beams can also be configured as trigger-and-hold controllers; the user breaks the beam and a musical tone from a pre-defined sequence is generated. The system's switches work in a similar fashion, requiring the user to press a switch pad to trigger one shot samples, loops, note-sequences or chord-progressions. At this stage we can already identify designed constraints in the Soundbeam system, which is perhaps its greatest strength. As each of its input devices have one DoF, the system is very open to great variety of physical gestures.

At the time of writing, our survey of Soundbeam's YouTube account [21] covered 91 videos. Of these, 48 showed a recent iteration of the Soundbeam system in use. The following configurations were common: the user is using the beams only (58%); both beams and switches are available to user (56%). Only two videos featured the use of switches without the beam sensor, and as such, they will not be considered on their own.

The Soundbeam system demonstrates a number of *dominant constraints* in the way a user controls sounds with the beams and switches. Every video on the company's YouTube channel demonstrates the beams being quantized and mapped to an equal-tempered scale. This leaves no way for the user to explore the 'notes in between', or other ways of relating with pitch. This tonal restriction of the beams alone is likely to become a salient feature, where the pitch-constraints become the primary concern for the user, reducing available "cognitive bandwidth" [28] for other forms of exploration with the system. Once the switches are added, the restricted control over set harmonic, structural and melodic material is likely to become a yet more dominant constraint.

The system offers almost no secondary sensory stimuli: the user has no physical contact with the beam sensor, and the switches have minimal physical travel and visual feedback. With few physical features to explore, combined with the probability of dominant musical constraints, it is doubtful that a user would have much opportunity to explore *hidden affordances* with either beams or switches. Furthermore, the lack of contact with the beams when configured as a scalar instrument places a very high demand on a persons accuracy of movement. This is clearly seen in the "Soundbeam 6 Demonstration" video [21], where the demonstrator's linear arm movements result in erratic, non-linear glissandi. These jagged melodies are characteristic of the Soundbeam system.

In spite of Soundbeam's openness to a very wide range of physical gestures from users, it is far less open in other respects. The system's sound-sets provide the user with a range of musical genres that can be configured for them, though musically these may be considered as pastiche rather than allowing the user to fully explore their own musical creativity and interpretation of those genres. What *is* offered is perhaps based on an assumption of what the user wants or should be trying to achieve musically, denying the possibility of failiure. When this is combined with the dominant pitch constraints, lack of scope for hidden affordances, and an erratic melodic fingerprint, the overall effect is to constrain the gestures of users into a highly pre-determined set of musical outcomes. We identify this lack of expressive and creative opportunity as a *stylistic constraint*, where differences in a user's approach will do little to influence the nature of a system's output.

4. SKOOG & SKWITCH

The Skoog is a cuboid musical interface which communicates wirelessly with sound-making apps on mobile devices and computers [18]. Inside the Skoog is a 6-DoF sensor that detects linear and torsional movement in all directions [22]. Visually, however, it appears as a cubic array of five rounded buttons arranged around the outward and upper faces of the interface. The Skoog's layout and pliable materials will likely afford some kind of physical interaction for most users. In spite of the higher complexity of the interface, omnidirectional sensor also allows the Skoog to recognize a very broad range of gestures. This is again made possible by the configuration of its sensitivity and sounds in a companion app.

At the time of writing, the Skoogmusic YouTube channel had a total of 233 videos, 181 featuring the Skoog in use [19]. On the basis of these videos, we have identified the following key use-cases for the instrument: *keyboard configuration*, where each face of the Skoog is given a different note (83%) or sample (9%); *sound configuration*, where the instrument is perceived to have one composite-sound (18%); and *single-button configuration* (2%), where only one of the Skoog's faces was active. We include this last configuration here, in spite of its low representation, as it bears great relevance to the ideas of constraint that we wish to discuss.

Keyboard Configuration. In this configuration, the Skoog has five active faces, each assigned to a different note or sample, a loose analogue of a keyboard-style interface. When used with the system's native instrument sound-sets, physical models provide a complex relationship between users' gestures and sounds. Press gestures on a face will increase the volume of a note, while additional gestures (twisting/squeezing) will modify the Skoog's timbre. The control of samples in this configuration is simpler: each face triggers a sample, and the volume at which they are played again increases with pressure.

The function of the instrument in this case becomes melodic, particularly when tuned to five notes and set against an ensemble or backing track. This makes the Skoog is an excellent interface for accessible melody making, yet as with Soundbeam, this focus may also place high cognitive demands on the user, serving as a *dominant constraint* that distracts from the extended possibilities for stylistic and technical variation. The effects of this dominant constraint might be lessened when recorded samples are used in such a way that pitch-relationships are de-emphasized, but the distribution of five samples across the cube would still demand much from the user in terms of accurately triggering desired sounds. If the tuning of the Skoog's five notes in a particular context such that a user cannot play a 'wrong note', the Skoog would also place *stylistic constraints* on the user, albeit in a milder form than identified with the Soundbeam system.

The multiple means through which each button can be activated does allow it to be activated through a wide range playing techniques, as any force applied by a person or an object will trigger some kind of sound from the instrument. The Skoog is easiest to use and understand when placed/braced on its bottom base, and when the instrument is oriented consistently with respect to the user on repeated sessions. In situations where the instrument is in motion, or is not rested or braced consistently, it would be harder for the user to remember, recognize or differentiate between the sounds assigned five faces. As five out of six faces on the interface are active, there is a high likelihood that when trying to press a particular face, a user might inadvertently trigger another when trying to grip the instrument. The Skoog, then, works best when rested or braced, and oriented consistently; it becomes awkward when held or moved. We see this as a *physical constraint*, that encourages a predetermined style of interaction with the instrument through a particular form factor.

Sound Configuration. In these use-case, users interacted with the Skoog as a single sound-making device, rather than as an array of 5 faces. In these contexts, each face can still serve as an individual input, but their sensitivity is increased to the point that all samples/notes are activated by small perturbations of the interface. This type of usage is best seen in Skoogmusic's video, "A new musical instrument for children with special needs" [19, 1:03], where the Skoog is manipulated as a whole by tilting, rocking and striking.

The harp-like output of the interface in this example is constrained, in that each gesture leads to broadly a similar output. The Skoog's responses in this configuration might be seen as complex sound-events [13, 26], that change subtly with differences in the style of physical engagement with it. With only one malleable class of sound, a wider range of actions can be supported without the above issues of holding the Skoog or needing to orient it a particular way. The constraints in this case are similar to those present in a 1-DoF instrument. As a result, this configuration of the Skoog places a much lower cognitive demand on the user, and as the example shows, might result in more diverse playing styles and exploratory musical approaches. However, the Skoog cannot produce its own sounds, and thus less open to the discovery of *hidden affordances* than the 1-DoF instruments used in constrained DMI research mentioned above. The creative appropriation of the Skoog in this configuration would, therefore, be most likely to emerge in the playing and gesture strategies of users.

Single-Button Configuration. This third configuration utilizes only one face of the Skoog, controlling a single note or sample. It is included due to the similarity of the interface in this context to the DMI used in Gurevich et al.'s research [8], and because this configuration can benefit users who would respond better to a 1-DoF interface as seen in the video: "Music lesson for special needs students using Skoog" [19].

In this case, the issues highlighted above with regard to the keyboard-configuration of the Skoog do not apply. The instrument can be rested or braced on its inactive sides, leaving it open to a far greater range of possible stances, grips and orientations. This might give users more freedom to explore how they interact with the device. However, one possible issue remains; that the inactive faces will still afford pushing, but yield no sounds, which may confuse or frustrate the user.

Skwitch Skoog Music have recently introduced a second accessible interface, the Skwitch [18]: a one-button version of the Skoog. The Skwitch is designed to clip onto a mobile device, and like the Skoog, uses a companion app to translate users' gestures into sound. The system allows a user to trigger tones from pre-defined melodic phrases which are either loaded as presets or composed in the app. The software also allows a user to configure how gestures manipulate the pitches within a phrase: triggering notes in sequence in a forwards or backwards direction, arpeggiating notes, or selecting random pitches from within the phrase. The button can also be divided into segments, increasing the interface's dimensionality. At the time of our review, all 21 videos featuring Skoog Music's Skwitch demonstrated its use as an interface for melodic manipulation, with a heavier reliance on touch-screen controls. The limitation of fixed pitches within a configured melody would introduce the same kinds of *dominant* and *stylistic constraints* from the point of configuration as were identified with the Soundbeam system, as the output to a variety of physical getstures will be bounded to the same melodic content. The dominance of melody might override opportunities for exploration of different gestures or performance strategies, and pre-configured melodies will limit the scope of users' musical play. As the Skwitch is designed to work only when clipped on to a phone or tablet, it has less scope than Skoog to accommodate diverse physical gestures and orientations. This again is a *physical constraint.*

5. SONIC-PLAY INSTRUMENTS

The effects of design constraints in prototype instruments were apparent, although the explicit focus in Wright's own research, which explored the design of sonic-play instruments with a small group of non-verbal young people on the autistic spectrum. Two prototype DMIs were developed over the process of this research. Both had a Skoog-inspired cuboid form factor, embedded loudspeaker, and embedded audio synthesis and LEDs using the BELA platform and SuperCollider [27]. The prototypes differed from one another in other respects, designed to target separate issues identified for the design of sonic-play instruments.

Figure 1: 1st Prototype Instrument

The first prototype (shown in figure 1) was designed to explore the ways congruent and semi-incongruent gesture-to-sound mappings might affect the use of the instrument in open play sessions [26]. The sensor made for this initial prototype had six segments, which could be used to provide some expressive control over sounds. LED lights were placed at the center of these segments. The overall appearance of the instrument, however, was intended to convey the impression of a single-button interface, taking inspiration from Zappi & McPherson's constrained instruments [28]. It was hoped that the visual impression of the instrument would be simple enough to allow a diverse range of performance-strategies, but also leave the possibility for finer grained exploration with the sensor's segments. The instrument had been designed with the expectation that users would primarily interact by pressing the sensors soft surface, as the demonstration video shows [27]. It was also designed to function with or without visual feedback from the LEDs, as it wasn't known in advance how this would affect users' play.

As this first prototype was similar to the single-button configuration of the Skoog, it proved suitable for exploratory play. Each of the participants in the study found at least

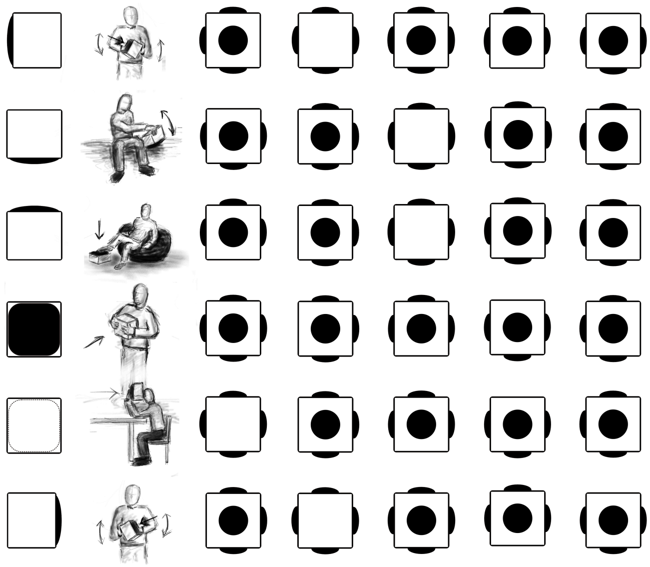

Figure 2: Orientations of Wright's sound-play prototype and the Skoog in six observed playing techniques

one unique way of playing the instrument. The differences in design between this prototype and the Skoog, however, reveal interesting tensions between the nature of each DMI's constraints. Of the many playing styles observed in the sessions, six are shown in figure 2, illustrating how the prototype was used in primary directions with respect to the player. These techniques were often repeated by participants from week to week, occasionally leading to situations where a player would fail to produce any sound, having attempted to orient the instrument properly for the repeated technique. It is true that with the constraint of one sensitive face, the prototype makes the production of *any* sound less accessible. The addition of additional active faces solves this problem, but also causes other issues. To illustrate this, 2 all the orientations in which each technique would successfully trigger a sound with the Skoog in place of the prototype. This higher success rate has a paradoxical consequence: the user is less likely to 'fail' to produce a sound; and more likely to press different surfaces, or multiple surfaces on repetitions of a technique. This reduces the opportunity for unique playing techniques to have meaning, or to have discreet replicable results. The constraints in the prototype's form, when compared to the Skoog, might offer a user a greater chance to meaningfully appropriate an instrument, and comprehend differences in performance strategies (albeit at the expense of more consistent success). This was at its most evident with one participant's unique play with both prototypes. He exploited the curvature of the instruments curved sensor by placing it face down on the floor and, after tipping it up, allowing it to rock back and forth under its own weight. This activity resulted in far more chaotic and dense sounds than any other playing techniques and was a hallmark of his play during Wright's research [26]. In other words, this participant exploited a *hidden affordance* and appropriated the prototype into a unique personal practice. This was only clear, and possible, because the instrument's blank faces allowed it to be manipulated by hand, without inadvertently triggering extra-gestural sounds. With the Skoog in its place, this hidden affordance may not have been discovered alongside sounds from four other faces. At the very least, it is doubtful this activity would have been carried out with such purpose and clarity.

Initially, the prototype was tested without the LED lights, as it was not certain how beneficial the visual feedback would be in supporting exploratory sonic play. When the lights were turned on in later sessions, they had the effect of limiting users' interactions to those orientations and techniques where the lights were in direct view. It encouraged a normative mode of interaction but restricted the range of personal playing styles that had developed without this visual feedback. This served as an inadvertent *persuasive constraint*, dictating how participants held and used the instrument.

The second-iteration prototype expanded on this original design, taking on board the responses of the user group. The size was reduced, and the build quality improved with 3D printed parts and a pliable silicone outer shell, and the instrument was given an open speaker grille on its bottom face for better sound projection. More significant changes were also made. The new instrument provided indirect visual feedback; LED lights were diffused through the translucent materials. Most significantly, a small collection of switches were added which would allow users to curate the sounds and responses of the instruments themselves, rather than having these choices made for them. Each switch would activate one sound-set, and multiple active sound-sets would also affect each other, creating subtle variations with each combination [27]. It was hoped that these switches could be simple enough to be comprehensible (perhaps given some time), but again have the potential for more complex play when used in combination.

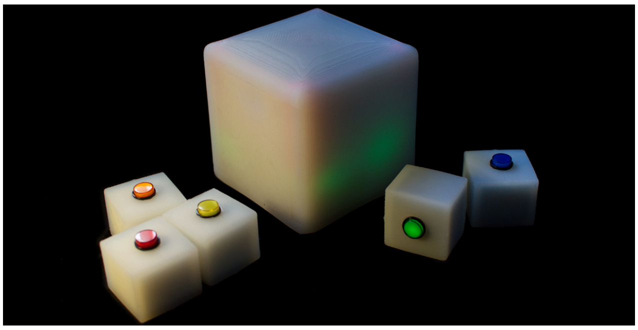

Figure 3: 2nd Prototype system: refined instrument with wireless switches

The open speaker grille on the updated instrument had provoked many exploratory responses. The default sound-set of the instrument (filtered white noise) was particularly effective in highlighting the movement of any reflective surfaces in motion relative to the speaker grille (although this wasn't an intentional design feature). Sure enough, the play of most participants focused on this *hidden affordance* at some point: the instrument was moved over flat surfaces; hands, feet, arms and ears were moved over the instrument. As with the previous prototype, the pseudo 1-DoF design of the instrument may have provided a clarity against which these effects became more noticeable. Many of the actions associated with the White Noise would have been occluded by accidental triggers from extra active faces.

The use of 1-DoF wireless switches gave users choices about the stylistic sound and behavior of the instrument, rather than structural aspects of a pre-composed musical environment. The provision of this choice once again provided the opportunity for users to fail, playing sounds that they did not like. In some cases, participants liked some but not all of the sound-modules that the switches could provide. On the one hand, this might mean that the user does not always get to hear sounds he or she likes, but this is also one way in which aesthetic choices can be made, and preferences acquired. In the four case studies conducted in the latter stages of Wright's research, each participant made some progress in comprehending these kinds of choices for themselves, even if the range of choice was very limited. For two of these four participants, the switches also provided access to some sounds that were pleasing, and some that were displeasing. It is probable that, given a longer period of use, each of these four young people would have been capable of curating at least some aspects of their play with the second prototype. This was only possible because the *stylistic constraints* of the pre-configured commercial instruments were lifted, in favour of a more demanding, but artistically accessible design. These choices, however, gave rise to a more turbulent journey through the user testing sessions for these two young people, raising challenging ethical dilemmas. While there were gratifying peaks in these participants experiences with pleasing sounds, there were also phases of visible frustration with undesirable ones, the latter not being an intended or desirable outcome.

Finally, it could be argued that the limitation of the instrument's output to six sound-sets (one default, five assigned to switches), is a form of *stylistic constraint*. But there are two key differences in the pre-coding of this prototype. Firstly, these sound-sets are made more accessible to young neurodiverse users; four out of the five participants who spent time with the instrument showed an emerging understanding of the switches' function after five weeks of testing. Secondly, the sound-sets interfere with one-another when combined. When the user's gestures are also taken to account, the sonic design of this system leaves room for sounds that weren't anticipated in its design, i.e sounds can be more meaningfully related to playing choices and style.

6. DISCUSSION

Unsurprisingly, instruments with few *Degrees of Freedom* afford a wide range of physical gestures, as the linear beam interface in the Soundbeam system demonstrates. While not strictly a 1-DoF interface, the apparently single-input of Wright's prototypes yielded a similar breadth in stylistic response. Some of these responses also replicated the idea low-DoF can lead users to explore *Hidden Constraints* [28, 8], only with a small non-verbal group of autistic participants. Conversely, the *physical and persuasive constraints* identified in the Skoog and the LED lights of Wright's first prototype had the effect of restricting the diversity, but improving the aesthetic consistency of play.

Finally, our small scale review reveals two separate approaches to the implementation of these concepts along with *dominant and stylistic* constraints. One strategy strives for maximum participation within defined bounds, the other grants greater individual choice with increased risk of frustration. The latter must be handled carefully, but it is also possible this choice can bring new opportunities that allow expert and non-expert musicians to "examine [their] preconceptions of failure and detritus more carefully" [4], and make the development of aesthetic preferences more accessible.

We propose that this is an area that could provide fruitful grounds for further study. Previous research with constrained DMIs [8, 28] could be replicated with neurodiverse user-groups. Equally, designer/performer individuals or teams might also tackle the question in another way, by designing sets of instruments with varying degrees or types of constraint, and putting them to the test in child-led ensembles modelled after the Artism Ensemble [2, 1]. With further study, we hope that more detailed insight may be revealed on the nature and inclusivity of constraints.

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