Accessibility and dimensionality: enhanced real time creative independence for digital musicians with quadriplegic cerebral palsy

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ABSTRACT
Inclusive music activities for people with physical disabilities commonly emphasise facilitated processes [1], based both on constrained gestural capabilities, and on the simplicity of the available interfaces. Inclusive music processes employ consumer controllers, computer access tools and/or specialized digital musical instruments (DMIs). The first category reveals a design ethos identified by the authors as *artefact multiplication* – many sliders, buttons, dials and menu layers; the latter types offer ergonomic accessibility through *artefact magnification*.

We present a prototype DMI that eschews artefact multiplication in pursuit of enhanced real time creative independence. We reconceptualise the universal *click-drag* interaction model via a *single* sensor type, which affords both binary and continuous performance control. Accessibility is optimized via a familiar interaction model and through customized ergonomics, but it is *the mapping strategy* that emphasizes transparency and sophistication in the hierarchical correspondences between the available gesture dimensions and expressive musical cues. Through a participatory and progressive methodology we identify *an ostensibly simple targeting gesture rich in dynamic and reliable features*: (1) contact location; (2) contact duration; (3) momentary force; (4) continuous force, and; (5) *dyad* orientation. These features are mapped onto dynamic musical cues, most notably via new mappings for vibrato and arpeggio execution.

Keywords
Accessibility; bespoke design; cerebral palsy; customized mappings; dimensionality; expressivity; feature extraction.

ACM Classification
H.5.2 [User Interfaces] User-centred design, H.5.5 [Sound and Music Computing] Methodologies and Techniques, K.4.2 [Social Issues] Assistive technologies for persons with disabilities.

1. INTRODUCTION
Consumer DMI controllers, with numerous differentiated control artefacts in close proximity, are not optimally accessible to people with impaired motor skills. Assistive computer interfaces for people with a physical disability simplify this interaction model through large tactile switches, grips or overlays, for enhanced touch accessibility; specialised *inclusive* DMIs employ similarly assistive features, but too often require menu navigation. With scant few exceptions,[1] the tools available to performers with a physical disability are non-optimal for independent real-time creativity [3] [9]. Inclusive music processes employing such interfaces commonly require setup and maintenance by a non-disabled facilitator [4] [15] [21], and creative control of musical cues is achieved through sequential and offline processes.

In pursuit of enhanced *real-time* and accessible performance independence, we employed a participatory methodology that quantified the gestural capabilities of a small group of digital musicians with quadriplegic cerebral palsy. We then formulated a multi-dimensional and transparent mapping strategy based on interaction models familiar to them. The participants were drawn from Drake Music Project N. Ireland's *Wired* ensemble,[2] and all three are wheelchair users with quadriplegic cerebral palsy, an impairment characterized by upper-limb gesture execution noise. They are eminently familiar with the common X-Y grid of control artefacts – the performers target and strike a single pad or button, or target and move a fader. During composition or performance processes, this impoverished mode of creative interaction affords discretised control over single sound events or single-destination continuous parameters. Our research suggests that, while the available performance control gesture *is* constrained, it reveals a number of dynamic and repeatable features. The following studies highlight gestural control on the Z axis, or targeting contact *force* and *duration*; as the methodology matured an additional gesture feature – *dyad* orientation – was demonstrated by the group.

[1] The *Skoog* (http://www.skoogmusic.com/) employs large foam rubber buttons on five sides of a cube; force data is mapped onto physical instrument models. The *Soundbeam* (http://www.soundbeam.co.uk/) employs remote gesture-sensing and MIDI sound sources. Both rely on menu-driven flexibility.

[2] http://www.drakemusicni.com/

2. METHODOLOGY

Adherence to a participatory methodology can enhance the transparency of a multi-dimensional performance-control map [12], while familiar models can enhance the learnability of novel interactions [17]. The iterative capability analyses adhered to the Inclusive Design ethos (after [5] [13]): (1) emphasise the participants' comfort, safety and dignity; (2) assess optimal capability, not maximal ability; (3) use a variety of person-centred, non-stigmatising formats and methods. The three case studies below represent (1) artistic, (2) game-based, and (3) indicative methods, allowing formal assessment of the range of gesture dimensions available for mapping. Each study employed a customised sensor pad consisting of a silicone rubber disc (10mm x 50mm) embedded with a DIY force sensor and light-emitting diode (LED), housed beneath a flexible *Perspex* overlay. This design reflects the form factor of an accessible switch (figure 1), while also extending a switch's strictly binary functionality. Contact force is mapped onto LED brightness, thereby optimising visual, tactile and passive haptic feedback. The control layer of the system employed the *Arduino*[3] prototyping platform, and *Max*[4] for re-mapping and sound synthesis.

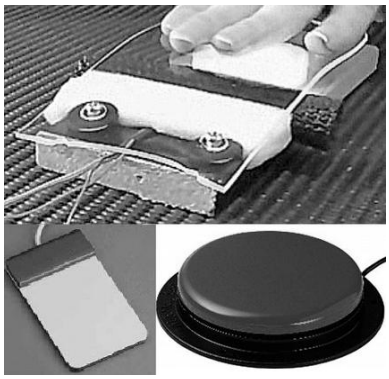

Figure 1. Customised sensor pad (top), with examples of accessible switches (bottom).

2.1 Case study data

The first study offered linear control of the pitch and amplitude of a simple FM synthesis engine, mapped between 100 ~ 1200 Hz and -60 ~ 0 dBFS respectively. The performance control boundaries were described within the group as "loud, soft, high or low", and the participants demonstrated intentional control of repeatedly strong or soft targeting gestures. Across all three studies the participants were free to demonstrate their own stated intention, or to respond to grouped exercises, for example "those were all high pitched and loud, would you now like to try low pitched and soft?". This first study subjectively demonstrated the degree of coarse control amongst the participants in the domain of discrete *momentary force*.

The second study employed a game-based activity, to determine the degree of control over *continued force*. The performers used contact force and duration to control a virtual paddle-and-ball game; the ball was assigned virtual physical properties (mass, velocity and restitution) using the native *Max* object *jit.phys.body*. Hard strikes cause the paddle to rise rapidly and the ball to bounce repeatedly; soft presses cause the paddle to rise slowly, with reduced movement in the ball. Holding the paddle steady causes the ball to come to rest on it.[5] During delivery of this study the *explicit* control boundaries (hard or soft strikes) were soon abandoned by the participants in favour of the more engaging *implicit* boundaries (balancing the ball).

Participant A realised six out of eight soft bounces, before demonstrating precise control over *sustained force* in the 'balancing' control gesture.[6] Participant B's interaction with the environment proved to be equally intentional. He executed numerous strikes using maximum pressure, intending the paddle to rise rapidly, and he was equally responsive to the balancing task.[7] Participant C immediately demonstrated his control of the balancing task.[8] The competitive element of this task was introduced by the participants themselves, who then challenged each other to hold the ball steady on the paddle.

The third study employed a dynamic table in *Max* to record the participants' responses to coarse forces and durations, across grouped iterations. The averages for the participants' individual responses illustrate their ability to differentiate between the descriptors "short or long, soft or strong".

Table 1. Grouped averaged responses from study no. 3.

		averages				dynamic range	
participant	cycles	soft	strong	short	long	soft	strong
A	12/12/10	36.67 31.3	109.67	460ms	2.15s 3.41s	27% 22%	54%
B	11/10/10/11	10.09	59.27	240ms	1.88s	13.2%	23.5% 28.1%
C	10/10	66.9	74.7	290ms 230ms	N/A	46%	51.9%
author	21	56.71	N/A	190ms	N/A	33.6%	N/A

As an example of the source of these averages, Participant A's first cycle consisted of 12 long and soft strikes: he discretely varied force between values of 4 and 58, or c. 25% of the total 0-255 range. Long durations were greater than 1 second 75% of the time, with the remainders around 500ms. In the second cycle of 12 strikes, strong force was consistently between 60 and 206 (54% dynamism), with short durations regularly less than 800ms; in the third cycle, soft force is between 3 and 72 (22% dynamism), and long durations were greater than 1 second 50% of the time. The remaining participants generated comparable responses, with Participant C demonstrating less dynamic control during soft strikes. Soft strikes, amongst the group, were less than 25% of the available range, and hard strikes were between 30% and 50% of the total range. Short durations were consistently less than half a second, with longer presses over 1.5 seconds. The data from the author's execution of 21 cycles (soft, short), presented here not as an exemplary benchmark but indicative of the responsiveness of the system itself, reveals comparable figures.

[3] http://www.arduino.cc/
[4] http://www.cycling74.com/

[5] Paddle-ball demo.
[6] Bounce-balance demo 1.
[7] Bounce-balance demo 2.
[8] Bounce-balance demo 3.

3. MAPPING GESTURES FEATURES ONTO DYNAMIC MUSICAL CUES

After Rovan *et al* [14] and Hunt *et al* [7, 8], we employed a tripartite mapping strategy, common within DMI design (for example [11] [16] [18]). In the guitar model underpinning our prototype (figure 2) the coarse and local pitch of a *Karplus-Strong* string engine reside in the X-Y domain (discrete contact *location*); instantaneous amplitude, onset shape and timbre are governed via the Z axis (momentary contact *force*).[9]

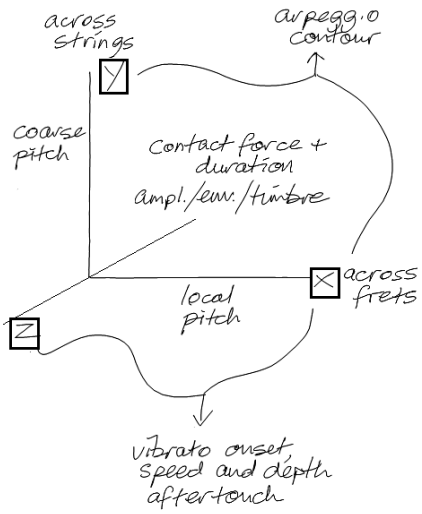

Figure 2. The prototype performance-control model.

3.1 The affordances of the interface

In their design of a prototype accessible DMI the authors eschewed *control artefact multiplication* in favour of *artefact magnification* and *duplication*. The instrument's interface (figure 4) presents a 3x4 grid of dynamic pads (plus latching switches on the right, for static musical functions). Its design is influenced in equal measure by the participants' capabilities, familiar DMI models, and ergonomic accessibility.

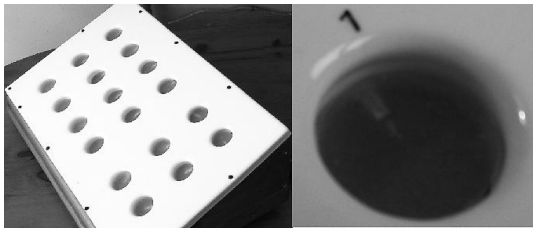

Figure 3. The prototype interface, and aperture detail.

The pads sit beneath an overlay of recessed apertures of 10mm depth for enhanced targeting accuracy, and the face of the controller is inclined to optimise comfort. The force data from each sensor is mapped as follows: 0 ~ 1023 at the hardware input pin → 400 ~ 800 actual range → 0 ~ 255 for serial transmission to *Max*. The lower limit in actual range (400) is imposed by the weight of the silicone pad on the force sensor; the upper limit of 800 represents the averaged maximum force applied by the participants as a group.

[9] Amplitude is commonly cross-coupled with other sound parameters [6] [20] [22].

3.2 Details of the final mapping

Beyond the dimensions of contact location and momentary force, a third layer of the prototype's mapping strategy exposes more nuanced musical cues: a *contact duration* threshold exposes dynamic vibrato, and; *dyad orientations* generate diatonic arpeggios.[10]

Dynamic control of the pitch/timbre, amplitude/shape, and duration/speed of musical sound – *prosodic* cues vital to expressive communication [10] [19] – requires nuanced fine motor control. In the absence of such capability we exploit an available gesture feature: contact duration. If contact duration exceeds 800ms the vibrato algorithm initialises: increased force produces a deep vibrato, and decreasing force reduces the effect. This ultra-low level dimension is neither assessed nor demonstrated herein, but intentional control of vibrato *onset* is clearly demonstrated.[11] The mapping is retained in anticipation of future opportunities for longitudinal learning and exploration. A second expressive cue commonly inaccessible to physically disabled performers is the articulation of dynamic melodic contours [2]. One of the performers, presented with a grid of targets during early prototyping, addressed two sensors using the index finger of each hand. The group ultimately agreed that this was a valuable and accessible modality.

The pitches generated by the sensor array are identified in *Max* by their index: the targets are numbered in order from the bottom left corner (1), to the top right corner (12). Numerous *dyad* orientations between rows are then possible, and the authors limit this functionality to *neighbouring* rows only (figure 5), as two of the participants prefer to execute this gesture unimanually.

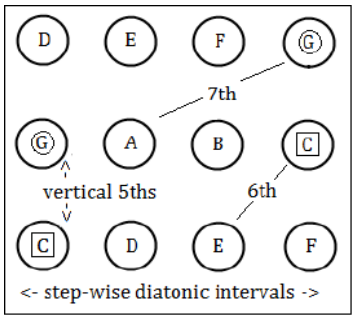

Figure 4. The prototype's default pitch collection, and examples of *dyad* orientations between neighbouring rows.

The nature of this modality strongly suggests an arpeggio performance-control source. If contact events overlap the arpeggio algorithm determines the odd or even quality of the pitch indices, and then populates the interval with a chain of diatonic thirds. The authors identified a final control dimension herein: because variable momentary force is demonstrated, then the force of the *second* of a pair of triggers might also be accessible. Arpeggios of an immutable tempo are artistically one-dimensional, and the aforementioned gesture feature is therefore mapped onto articulation *speed*. The participants clearly demonstrate control over the execution of arpeggios,[12] but arpeggio *speed* control is currently not assessed. Again, the authors retain this mapping in anticipation of future opportunities for collaborative design and development.

[10] Author's demo of the entire mapping.
[11] Participants' control of vibrato onset.
[12] Participants' execution of arpeggios.

4. CONCLUSIONS

The goal of this project has been to offer digital musicians with a physical disability an instrumental interface for enhanced *real-time creative independence*. Independent control over gross/local pitch, amplitude, vibrato onset, and melodic contour is clearly evidenced herein. The project participants were excited by the opportunity to control a dynamic instrumental model based on an ostensibly simple targeting gesture; they felt a degree of ownership for this prototype, designed as it was for their particular capabilities. In respect of the methodology, the authors intend to develop the game-based case study by adhering to a more formalised method of data gathering and analysis – for example, a larger user-group; preordained task cycle-numbers; reference to clinical data.

The aperture overlay needs revising: it should be removable, with more and smaller sensor targets, based on low-level idiosyncrasies of the gesture: one participant has a double-jointed fingertip, which causes the *interphalangeal* joint to connect with the rim of the aperture. The other two participants prefer unimanual execution of *dyads*, necessitating reduced spacing of targets, but they find the recessed apertures helpful. We deem the *mapping strategy*, however, to be accessible and sophisticated, particularly in the area of vibrato and arpeggio control. Intentional control of contact location, momentary force, duration, sustained force and *dyad* orientation, amongst a small group of digital musicians with quadriplegic cerebral palsy, is demonstrated through this research, as is the suitability of a *bespoke* DMI mapping strategy for enhanced real-time creative independence, for those commonly excluded from such activities.

5. REFERENCES

[1] T. Anderson, C. Smith. Composability: widening participation in music making for people with disabilities via music software and controller solutions. In: *Proceedings of the 2nd International conference on assistive technologies*, April 11-12, 1996, New York: ACM, pp. 110-116.

[2] A. Aziz, B. Hayden, C. Warren, S. Follmer. The flote: an instrument for people with limited mobility. In: *Proceedings of the 10th ACM conference on computers and accessibility*, Halifax, Nova Scotia 2008, p. 295.

[3] B. Cappelen, A-P. Andersson. Musicking tangibles for empowerment. In: *Proceedings of the 13th International conference on computers helping people with special needs*, ICCHP 2012. LNCS, p. 255.

[4] G. Doherty, T. Anderson, M. Wilson, G. Faconti. A control centred approach to designing interaction with novel devices. In: *Proceedings of HCI International Conference on Universal Access in human computer interaction*, New Orleans 2001. Lawrence Erlbaum Associates, p. 287.

[5] J. Goodman, P. Langdon, J. Clarkson. Formats for user data in inclusive design. In: C. Stephanidis (ed.) *Universal access in HCI part 1*, LNCS 4554. Springer-Verlag 2007, pp. 117-126.

[6] D. Hall. *Musical acoustics*, (2nd ed.) California: Brooks-Cole 1991.

[7] A. Hunt, M. Wanderley, R. Kirk. Towards a model for instrumental mapping in expert musical interaction. *In: Proceedings of the International computer music conference*, ICMA 2000, pp. 209-212.

[8] A. Hunt, R. Kirk, M. Neighbour. Multiple media interfaces for music therapy. *IEEE Multimedia*, 11(3) July-September 2004, pp. 50-58.

[9] F. Hwang, S. Keates, P. Langdon, J. Clarkson. Mouse movements of motion-impaired users: a sub-movement analysis. In: *Proceedings of the 6th international conference on computers and accessibility*. New York: ACM 2004, p. 102.

[10] P. Juslin. Communicating emotion in music performance: a review and theoretical framework. In: *Music and emotion: theory and research*, New York: OUP 2001, p. 317.

[11] L. Kessous, D. Arfib. Bimanuality in alternate musical instruments. In: *Proceedings of the International conference on new interfaces for musical expression*, NIME 2003, p. 141.

[12] D. Meckin, N. Bryan-Kinns. MoosikMasheens: music, motion and narrative with young people who have complex needs. NIME 2014 workshop on accessibility.

[13] K. Price, A. Sears. Performance-based functional assessment: an algorithm for measuring physical capabilities. In: *Proceedings of the 10th ACM Conference on Computers and Accessibility*, New York: ACM 2008, pp. 217-224.

[14] J. Rovan, M. Wanderley, S. Dubnov, P. Depalle. Instrumental gesture mapping strategies as expressivity determinants in computer music performance. In: *Proceedings of the International Kansei technology of emotion workshop* [online], Paris: IRCAM 1997.

[15] T. Swingler. The invisible keyboard in the air: an overview of the educational, therapeutic and creative applications of the EMS Soundbeam. In: *Proceedings of the 2nd European conference on disability, virtual reality and associated technology,* Sweden 1998, University of Reading: ECDVRAT, p. 255.

[16] T. Ungvary, R. Vertegaal. Cognition and physicality in musical cyberinstruments. In: M. Wanderley and M. Battier (eds.) *Trends in Gestural Control of Music*, Paris: IRCAM 2000, pp. 371-386.

[17] D. van Nort, M. Wanderley, P. Depalle. Mapping control structures for sound synthesis: functional and topological perspectives. In: *Computer Music Journal* 38(3), pp. 6-22, MIT Press 2014.

[18] M. Wanderley, J. Viollet, F. Isart, X. Rodet. On the choice of transducer technologies for specific musical functions. In: *Proceedings of the International computer music conference*, Berlin 2000.

[19] A. Wennerstrom. *The music of everyday speech: prosody and discourse analysis*, New York: OUP 2001, p.vii.

[20] D. Wessel, M. Wright. Problems and prospects for intimate musical control of computers. In: *Computer music journal* 26(3) Fall 2002 Cambridge, MA: MIT Press, pp. 11-22.

[21] C. Williams. Unintentional intrusive participation in multimedia interactive environments. In: *Proceedings of the 7th International conference on disability, virtual reality and associated technology,* Portugal 2008. University of Reading: ICDVRAT, p.205.

[22] L. Wyse, D. Nguyen. Instrumentalising synthesis models. In: *Proceedings of the International conference on new interfaces for musical expression*, NIME 2010, pp. 140-143.