Can Micro-Gestural Inflections Be Used to Improve the Soniculatory Effectiveness of Parameter Mapping Sonifications?

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Parameter mapping sonification is the most widely used technique for representing multi-dimensional data in sound. However, it is known to be unreliable when used for detecting information in some types of data. This is generally thought to be the result of the co-dependency of the psychoacoustic dimensions used in the mapping.

Positing its perceptual basis in a theory of embodied cognition, the most common approach to overcoming this limitation involves techniques that afford the interactive exploration of the data using gross body gestures. In some circumstances, such exploration is not possible and, even when it is, it may be neither necessary nor sufficient.

This article explores some other possible reasons for the unreliability of parameter mapping sonification and, drawing from the experience of expressive musical performance, suggests that the problem lies not in the parametric approach *per se*, nor in the lack of interactivity, but in the extent to which the parameters employed contribute to coherent gestalts. A method for how this might be achieved that relies on the use of micro-gestural information is proposed. While this is speculative, the use of such gestural inflections is well known in music performance, is supported by findings in neuroscience and lends itself to empirical testing.

1. PARAMETER MAPPING SONIFICATION

Parameter mapping sonification (PMSon) is the most widely used technique for representing multi-dimensional data as sound (Worrall 2009a). PMSons are sometimes referred to as sonic scatter plots (Flowers, Buhman and Turnage 1997), nth-order parameter mappings (Scaletti 1994) or multi-variate data-mappings, in which multiple variables are mapped to a single sound (Kramer 1994). In this case, data dimensions are mapped symbolically to sound parameters: either to physical (e.g. frequency, amplitude), psychophysical (e.g. pitch, loudness) or perceptually coherent complexes (e.g. timbre, rhythm).

In an early exposition of the technique of data sonification, Scaletti describes one way of implementing it as a 'mapping of each component of a multi-dimensional data point to a coefficient of a polynomial and then using that polynomial as the transfer function for a sinusoidal input' (Scaletti 1994: 223). Within an overall analogic mapping, symbolic representations such as auditory beacons (Kramer 1994) can be used to highlight features such as new maxima and minima, or absolute reference points, such as ticks to indicate the regular passing of time. Frysinger provided an overview of the early history of the technique (Frysinger 2005). *The Sonification Handbook* provides a contemporary perspective and outlines some of the critical issues involved (Grond and Berger 2011).

1.1. The mapping problem

Flowers highlighted some of the pitfalls of PMSon, including the observation that 'while the claim that submitting the entire contents of "dense and complex" datasets to sonification will lead to the "emergence" of critical relationships continues to be made, I have yet to see it "work"' (Flowers 2005). The main limitation of the technique is thought to be the non-orthogonality or co-dependence of psychophysical parameters: linear changes in one domain produce non-linear auditory effects in another. These perceptual parameter interactions can also produce auditory artefacts that obscure data relations and confuse the listener regarding the parametric origin of the effect. A similar scenario occurs in visualisation, such as when parallel lines can appear more or less curved on different backgrounds.

There is general agreement among sonification researchers that the mapping problem (TMP) (Flowers 2005) is the most significant impediment to an otherwise flexible and potentially powerful means of representing information. Kramer suggested that, although a truly balanced multi-variate auditory display may not be possible in practice, given powerful enough tools, it may be possible to heuristically test mappings to within acceptable limits for any given application (Kramer 1994). Despite the enunciation of general heuristics and the development of significant alternative approaches, the problem has essentially remained unsolved.

I have previously outlined the historical and paradigmatic nature of TMP (Worrall 2009b) and

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argued (Worrall 2010) that it is related to the problem faced by artificial intelligence (AI) researchers in the 1960s and 1970s when trying to build a computational model of behaviour based on representation and predicate calculus. The failure of this cognitivist approach for all but the simplest scenarios, so devastatingly critiqued by Dreyfus (1992), accelerated the search for alternate means based on robotics, principally based on the belief, now somewhat verified, that to show real intelligence a machine needs to have a body (McCorduck 2004).

In parallel with this work in AI, there has been a growing interest among sonification researchers in using sound to interactively mediate perception–action feedback loops (Hunt and Hermann 2011). There has also been a shift of focus in music perception and cognition scholarship, and in compositional tools for computer music composition and performance, away from the human listener as a passive receiver of auditory stimuli towards actively engaged embodiment (Diniz, Demey and Leman 2010; Godøy and Leman 2010). While this line of research almost exclusively employs gross body gestures in interactive sound exploration, such interactivity is not always possible or appropriate, for example when using sonification to monitor sets of yet-to-be-fully-manifested events, such as occur with real-time data streams.

Not all data sonifications require parametric independence, so TMP is only a problem if the ambiguities arising through parameter co-dependencies are undesirable – that is, they have a negative impact on the contextual listening experience. It is thus useful to distinguish data sonifications whose main purpose is that of facilitating communication or interpretation of relational information in the data, and those for which such considerations do not apply. It is not possible to always infer such strictures from artificially contrived scientific–artistic or pragmatic–aesthetic continua. So, in order to distinguish a type of data sonification in which the principal purpose is to articulate the information being sonified as clearly as possible (information intelligibility) rather than for (just) the sheer beauty of the sound or other artistic or ornamental purpose, I coined the term *soniculation*, a portmanteau of *sonic* and *articulation* (Worrall 2009b). The mapping problem, then, needs to be understood not as a genre-specific issue, but as a technical problem which impacts to a greater or lesser degree on the soniculatory effectiveness of a sonification, which itself, depending on the purposes for which it is created, may or may not be an important consideration.

2. SONIFICATION AND MUSIC COMPOSITION

There is no one way, or reason, to listen to music; different musics require different ways of listening in different contexts which may involve whole complexes of social dimensions that are simply not relevant to the perceptualisation of data relations (Tuuri, Mustonen and Pirhonen 2007; Tuuri and Eerola 2012). Although music may be composed of syntactic structures, there is no universal musical language and there is no absolute requirement that these structures be made explicit, nor even aurally coherent in a musical composition. So while the rules of functional harmony might prohibit parallel fifths and octaves in order to maintain the soniculatory independence of polyphonic lines in some genres of music, stylistic or even dramatic considerations may require the exact opposite, such as in the orchestration of spectral mixtures by melding instrumental timbres, for example. On the other hand, information sonification which is user-driven in real-time for exploration of datasets using dynamic scaling in multiple dimensions, perhaps with auditory beacons (Kramer 1994: 185–221), may not result in musically coherent sound streams. Even if listened to *as* music, data sonifications may provoke critical commentary about issues such as the appropriateness or formal incompleteness of the resulting sonic experience. There is, however, some evidence that knowledge of (artificial) musical structures is implicitly acquired from passive exposure to acoustical and statistical properties of musical sounds in the environment (Loui, Wessel and Hudson Kam 2010).

Perhaps, as Polanski suggested, the closest point of contact between 'scientific sonification' and 'artistic sonification' is in compositions in which a composer intents to 'manifest' mathematical or other formal processes (Polansky and Childs 2002). This motivation was first explicitly enunciated by Xenakis, who illustrated the process for several compositions in detail (Xenakis 1971). While many composers use mapping and other algorithmic techniques of one kind or another in their compositions, they are rarely interested in featuring the mapping explicitly. Nor do they use mapping in order to simplify the working process or to improve production efficiency, but in order to enunciate or support the emergence of musical forms.

In order to gain a deeper insight into the way composers map conceptual gestures into musical gestures, Doornbusch surveyed a select few composers who employ the practice in algorithmic composition (Doornbusch 2002).

> I am not interested in projecting the properties of some mathematical model on to some audible phenomena in such a way that the model be recognized as the generator of some musical shape. (Doornbusch 2002: 150).

So, those interested in producing music of a certain complexity may shy away from simple mappings, as they can be hard to integrate with other musical material of a substantial nature. On the other hand,

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reflecting Flowers' earlier remark, Larry Polansky explains, 'the cognitive weight of complex mappings degenerates rapidly and nonlinearly such that beyond a certain point, everything is just "complex" ' (quoted in Doornbusch 2002: 155).

Even a suitably complex, structurally coherent mapping may not be musically sufficient if the composition relies on a (human) performer, as composer Richard Barrett emphasises: 'In a score one is always dealing with the relatively small number of parameters which can be recorded in notation, and which interact with an interpreter to produce a complex, "living" result' (quoted in Doornbusch 2002: 151).

3. COMMON TOOLS, DIFFERENT EPISTEMOLOGIES

Whilst information soniculators and music composers may share a common need to render structures and relations into sound, they have different intents and epistemological imperatives, and consequently may require different outcomes. Many of the software tools used for parameter-mapped data sonification have been adopted or adapted from software sound-synthesis systems for music. Seminally, the *Music* N series (Mathews 1969), which established the conceptual building blocks that remain in place in most music software systems, was designed to compose computer music not to soniculate abstract datasets. Such systems, including all those based on the MIDI protocol, adopted the score-and-instrument model from Western instrumental music.

The adoption of a set of complex tools to perform tasks for which they are not designed is not value-free because without critical awareness, original assumptions are transferred to the new task domain (Worrall, Bylstra, Barrass and Dean 2007). I argue that while there are reasons that this has occurred in information sonification these assumptions may have protected TMP from critical exposure to its causal analysis and impeded progress towards empirically verifiable solutions. Such causes include the embedding in computer music software of the dominance of notation over performance as the primary mode of defining what is musically importance in Western art music, from an information-carrying perspective, together with the strong historical alliance between computer music research and a cognitivist/connectionist approach to artificial intelligence research (Todd and Loy 1991), which promoted a computational model of behaviour based on representation (i.e. notation). As indicated earlier, this cognitivist approach to AI research failed and was abandoned in favour of an embodied approach. At the same time, computer music researchers began to develop composition/performance tools to interactively engage in shaping sound using gross body gestures.

The next section examines the historical relationship between performance, notation and sounds, and asks, somewhat provocatively, 'is it possible that a significant amount of musical intelligence is transferred to listeners, not just in the compositional sequencing of the sounds themselves, but in the shaping of them by an embodied performer at the gestural inflection (fine motor) and agogic (micro-timing) levels?'

4. MUSIC NOTATION, PERFORMANCE AND SONIC OBJECTS

Western art music became increasingly conceived as a complex-patterned time-ordered series of disembodied acoustic events that vary in pitch, loudness and timbre, and that are absorbed and elicit emotions when listened to. This paradigm is embedded in scored compositions that are abstractly composed and realised by expert musicians in concert and/or, today, rendered to a recording medium for transmission to listeners.

Historically, the role of notation evolved, along with the notion of 'The Work', from a performer's *aide de mémoire* to a tool of thought for defining music of increasingly abstract complexity (Goehr 1994). So, notated scores came to be thought of as the encoded representation not of performance gestures, but of the sounds themselves: somewhat definitive objectifications of a composer's thoughts. That we (at least in English) now so frequently substitute the word 'note' for 'tone', and 'music' for 'score', exemplifies the strength of this conceptual elision. In a number of intricately notated works of the twentieth century, it seems the performer is sometimes considered an unfortunate necessity. Theodore Adorno noted a tendency to consider the bodily presence of the performer as a kind of contamination of musical experience as a manifestation of a commodity fetishism, where the 'immaculate performance … presents the work as already complete from the very first note. The performance sounds like its own phonograph record' (Adorno 1991: 44).

It was not uncommon for composers of early electroacoustic music to consider the lack of the need for performers as one of their motivations for working in the medium. In conversation, Tristram Cary, one of the pioneers of the genre, frequently spoke enviously of sculptors, who could create works that exist as objects in their own right, without the need for interpretation by performers. In the following quotation, notice also how Cary has the instrument doing the playing, rather than a performer:

> For composers of an exploratory turn of mind, the most frustrating limitation of normal instruments is *their inability to play* more than a few selected pitches with each octave. … The notion of realizing music as a recording rather than as a performance seems to have

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> grown almost simultaneously in the minds of a number of individuals, myself included, during the Second World War. (Cary 1992; xiv; emphasis added)

The inherent instability of analogue electronics at the time meant that exactly reproducing electronically produced sounds was well nigh impossible. When digital computers eventually became available, they were celebrated for their ability to generate sounds that were exactly the same: on time, every time. One of the early pioneers, F. Richard Moore, put it like this:

> What, then, is significantly different about computer music? … the essential quality is one of temporal precision. Computers allow precise, repeatable experimentation with sound. In effect, musicians can now design sounds according to the needs of their music, rather than relying on a relatively small number of traditional instruments. (Moore 1990: 4)

Composing music by assembling recordings of 'concrète' sound objects led Pierre Schaeffer to search for ways of producing structural morphologies from the sounds themselves, in a process he called reduced listening (*écoute reduite*): a technique he derived from the phenomenologist philosopher Edmond Husserl's methodological constraint he called *epoché* or 'bracketing'. Husserl was concerned with only what was experienced or intended by the perceiver, not whether the phenomena actually existed. So any object of attention that arises from the intentional acts of the perceiver must be 'bracketed' from any assumption of the correctness or existence of the object (Schaeffer 1966; Beyer 2011). Schaeffer applied this idea of 'bracketing' by encouraging composers to consider sounds as intentional objects – as they appear to constitute themselves in consciousness – reduced of any assumptions concerning their existence; reduced of any connection or association with anything, real or imaginary, from which they might have arisen (Kane 2007, Beyer 2012), including, of course, any actions performed in order to produce them.[1]

The desire to find a means of ordering 'found' sounds as musical material led Schaeffer to develop the notion of sonorous objects, holistically perceived fragments of sound typically in the range of a few seconds or less which afford the apprehension of the fragments as shapes – that is, as features independent of their identifiable sources (Godøy 2006, 2010) or of what Smalley calls their 'source bonding' (Smalley 2007). Schaeffer considered sonorous objects as intentional units (Beyer 2011: 263), which form somewhat stable images by a process Miller called chunking (Miller 1956). For Schaefer, such sonorous objects had the potential, given certain criteria were met, to become musical objects.

Smalley's spectromorphology was originally intended as a descriptive tool based on (a composer's) aural perception because 'composers need criteria for selecting sound materials and understanding structural relationships. So descriptive and conceptual tools which classify and relate sounds and structures can be valuable compositional aids' (Smalley 1997: 107). Spectromorphology 'is primarily concerned with music which is partly or wholly acousmatic', and is 'intended to account for types of electroacoustic music which are more concerned with spectral qualities than actual notes'. He considered the term 'spectro-morphology' to be the natural successor of the Schaefferian term 'typo-morphology' as well as being a better description (Smalley 1986: 220). Although this claim has been questioned (Palombini 1993), its acceptance probably has more to do with the lack of an English translation of the *Traité* than any enunciation of a convincing argument. Nevertheless, what was considered an important advance in 'the non-vernacular fork of the musical language' (Smalley 1986: 61) was a reduction to the spectral domain and this is in keeping with the firmly established trend towards a musical intelligence based on disembodied cognition.

5. GESTURE

5.1. Embodiment

Occidental art music today encompasses a wide range of motivations and listening practices, and reducing the intelligibility of such music to the conceptual level of scores and instruments has enabled an unprecedented level of complexity. However, there is a growing

[1]Schaeffer makes a fundamental formal error in adapting Husserl's methodology. Having initially considered the objects of empirical experience, Husserl shifts to the transcendental realm of ideas. So while he makes use of the concept of a 'natural attitude' to knowledge to undermine commonsensical thoughts about the world, Schaeffer remains in the empirical world, aiming for a new approach to the aural perception of the empirical experience of sonic varieties. This lack of distinction between understanding (thinking) and sensibility conflates of two distinct branches of knowledge, and is thus a false step. I hasten to add that this *faux pas* is not necessarily a fatal *musical* flaw, any more than any composer's understanding or interpretation of a philosophy validates or invalidates the expressive power of their music. However, when there is an acousmatic/spectromorphological 'movement' or 'genre' that has 'acousmatic composers' (Smalley 2007) which seems to be particularly evangelical in its calling on the support of Husserl's philosophy, the tenuousness of the logical connection needs to be explicated. There also seems no logical reason to assume that the ways composers organise their sonic material is, or needs to be, the same as the way listeners listen to it – especially when, in order *(F'note continued)* to do so, listeners may need to apply a 'bracketing' of the material from the common associations that it may invoke. While clearly there is more than one way to listen, Schaeffer's insistence that listeners should train their listening, just as a performer would train on their instrument (Thoresen and Hedman 2007), is clearly metaphorical; another leap of ideology at a time in the twentieth century when such directives to listeners were common.

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recognition among music researchers, supported by a significant body of research in neuroscience, the salient points of which I have summarised elsewhere (Worrall 2010), that the conveyance of this complexity is reliant, at least to some extent, on embodied interpretation for effective communication. It was not until it was technically possible to construct musical compositions without the assistance of embodied interpreters that it was possible to meaningfully speculate on the extent to which a listener's perception of the structural characteristics of a piece of music are dependent on the sound-encoded gestures of performers, and not just the notated score. This has the unfortunate consequence that if sonifiers follow the musical trends outlined above, which most have been apt to do, the intelligence that is recognised as embodied is not 'available' for use, at least not explicitly, through the adopted software tools.

> For many centuries, people learned to listen to sounds that had a strict relation to the bodies that produced them. Suddenly, all this listening experience accumulated during the long process of musical evolution was transformed by the appearance of electronic and recorded sounds. When one listens to artificially generated sounds he or she cannot be aware of the same type of concrete and mechanic relations provided by traditional acoustic instruments since these artificial sounds are generated by processes that are invisible to our perception. These new sounds are extremely rich, but at the same time they are ambiguous for they do not maintain any definite connection with bodies or gestures. (Iazzetta 2000: 259).

In a later reflection on the intelligibility of his spectromorphological approach, Smalley agrees but couches it in terms of the limitation of the listener:

> we can arrive at a situation where the sounding spectromorphologies do not correspond with perceived physical gesture: the listener is not adequately armed with a knowledge of the practicalities of new 'instrumental' capabilities and limitations, and articulatory subtlety is not recognized and may even be reduced compared with the traditional instrument. (Smalley 1992: 548)

5.2. Gestural-sonorous objects

Godøy's and other's research on musical gestures suggests that there are gestural components in the mental recoding of musical sounds (Godøy and Leman 2010, Godøy, Jensenius, Voldsund, Glette, Høvin, Nymoen, Skogstad and Tørresen 2012). Godøy extends Schaeffer's idea of the sonorous object to gesture. In developing his concept of the *gestural-sonorous object*, he found considerable evidence to support the hypothesis that when we listen or even just imagine music, we trace features of the sonorous objects heard by hands, fingers and arms and so on.

> This means that from continuous listening and continuous sound-tracing, we actually recode musical sound into multimodal gestural-sonorous images based on biomechanical constraints (what we imagine our bodies can do), hence into images that also have visual (kinematic) and motor (effort, proprioceptive, etc.) components. (Godøy 2006: 149)

These intentional objects 'chunk' at meso- and sometimes micro-timescales (seconds or minutes down to milliseconds), and there is simultaneous perception at the macro-level (the overall duration of the form in minutes or even hours) such that a succession of such chunks does not disrupt the experience of the continuity, even though the attentional focus may be discontinuous.

The association of body movement with music appears to be universal and independent of levels of musical training, and in 'sound tracing' studies there seemed to be a significant agreement in the spontaneous drawings of gestures that people with different levels of musical training made to musical excerpts (Godøy 2010). This work has been extended to include a solution for recording data and media in a synchronised manner, different types of analysis and visualisation strategies, and, given there seems to be no publicly available databases of music-related body motion data, a classificatory scheme for music-related actions that includes classification by both corporeal action and sonic features (Godøy and Leman 2010).

Much research to do with physical gestures in the performance of music has concentrated on understanding and generating the role of extra-notational aspects of music, particularly on emotional expression and affect (Godøy and Leman 2010). Godøy identifies several applications of the analysis of sound-related actions, including composition, improvisation, musical performance, music education and rehabilitation, musicology and music information retrieval, as well as music technology (Godøy 2010).

Musical instrument designers have taken up the call for more 'embodiment' in computer music as a call for better interactive tools for computer performance. The now ready availability of cheap gestural controllers, including generic 'smart-phones', has resulted in a wider acceptance of technology-mediated live music performance (Paine 2009), and gestural controllers have found applications in interactive sonification, such as by providing means to interact with data-derived resonator models in model-based sonifications (Hermann and Ritter 2005).

5.3. Haptics and gesture

Nearly all research on the use of human gestures in music and sonification production have concentrated on interactive control interfaces that employ gross corporeal-scale gestures such as arm waving. However, professional string players know that much of the art of playing is in bow control just as percussionists know that the different characteristics of a

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vibraphone, say, are revealed *not only* by whether it is struck, scraped or rubbed by wood, felt, rubber or metal of various sizes and densities, but by the subtlety of those actions. Thus, given the choice, percussionists will choose to use their personal collection of beaters and other interface devices on borrowed instruments, over the reverse.

This suggests that, while an analysis of the gestures employed in interacting with sonification models should provide valuable insights into improving their design, such research needs to be extended to include the development of a diverse means through which the energy in such gestures is conveyed to resonators; not only a wider range of modes of excitation (hammering, stoking, rubbing, squeezing, etc.) but considerable improvements in the sensitivity of haptic interfaces (Hermann, Kraus and Ritter 2002; Nichols 2002). Furthermore, as exemplified by the fact that musicians frequently employ physical gestures in order to better control their haptic interface with resonant objects (Großhauser, Großekathöfer and Herman 2010), for proprioceptive control of sound, it is erroneous to treat physical gesture and haptics as psychophysically independent. Micro-gestures, such as those small, often covert, physical movements that occur at haptic interfaces, are mechanisms of the perception–action cycle and are regarded as a basis for musical expressiveness and cognition (Kima, Demeyb, Moelantsb and Leman 2010). Some studies reveal that such gestural inflections are aurally 'available' to listeners, albeit sometimes subconsciously (Fyk 1997), and this appears to be the case not just for *agogics* (*notes inégales* and other micro-timings) but also for *elksis* (pitch interval flexibility when tones are intentionally micro-sharpened or micro-flattened, depending on their direction in a line).

6. SUMMARY

The investigation reported here originally began as a search for solutions to TMP for PMsons. Typically, PMSons consist of elementally composed sound-points (or spectral complexes) that are assembled in the hope that the psychophysical continuity of at least some of its parametric dimensions integrates the perception of those sounds into a single immanent object or perceptually coherent auditory scene. In the absence of an inherent 'system' synergy to integrate these spectral complexes, any holistic conflation has to currently be achieved by the listener, primarily using cerebral cognition alone. For example, although artificial reverberation is often employed to try to provide some spatial-binding, the simplistic uniformity of the result often just provides a mushy melding, which is rarely convincing and, at worst, actually anti-soniculate.

PMSon owes its conceptual origin to the 'notation-executing performer' model of music that it inherited through computer music composition software in which the performer is replaced with a software synthesiser and a parametrically mapped dataset replaces the score. With acoustic instruments, the necessity for a player to continuously input physical energy means that they are actively engaged in a tight feedback loop; controlling the modulation of all the parameters of the sound in a complex of cross-couplings within a resonating physically integrated object. It could be argued that the fact that parametric compositions work as well as they often do for notated music may be more due to the embodied intelligence of the performer and the cognitive ability of the listener than the robustness of the abstracted technique.

Performers are known to alter the manner in which they realise musical ideas based on a complex integration of the structural importance (e.g. *agogics* and *elksis*) and the physical limitations of both the musical instrument and their own physiology. These constraints and gestural inflections are encoded in the sound of music and 'neurologically' available to listeners through audition alone. There is a growing body of evidence to suggest that much of what is understood when listening to complex sonic structures such as music is based on the ability to unconsciously 'mirror' the corporal actions of performers, a 'worldly' knowledge of the effect of their actions and the physical nature of the resonators on which they act. Further, there is some evidence that the anticipatory sound-encoded actions of a performer, in preparing to arrive at a certain place in the music at a certain time, primes the listener for future events in the music. A detailed examination of micro-gestures of such pretensions is beyond the scope of this article; however, the circumstantial evidence suggests that these gestural inflections could be vitally useful as a basis for understanding what else to encode in software to produce information sonifications which are more holistic psychophysical continuities or perceptually coherent auditory scenes.

7. FUTURE RESEARCH DIRECTIONS

This article makes a case for why a simple note-and-instrument model of PMSon is unlikely to succeed in solving TMP and posits that a more promising approach, given all the available evidence from neuroscience and performance practice, is to extend the software used for information soniculation with a knowledge base of appropriate human micro-gesture transforms that can be used to control the multi-parametrical manipulation of the controls of a sound-synthesis engine.

The general nature of such extensions is known, but their soniculatory impact is not. So it is suggested that empirical investigations be undertaken to examine ways to codify and incorporate such micro-gestures into

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general principles and to empirically test their effectiveness in the process of translating information structures to sound. This implies the need for virtual instruments such as physical models that better integrate and cross-modulate parametric inputs over both space and time, the development of a wider variety of sound activator models for bowing, scratching and so on, and more refined techniques to couple these to sound generation apparatus so as to afford 'the generation of incrementally different variants of sounds, allowing systematic exploration of morphological features, e.g. minute control of various aspects of grain and mass' (Godøy 2006: 156).

Humans have been interacting with sound-generation devices through a variety of interface devices for thousands of years. These devices transmit performer-controlled energy through resonators to attentive listeners who are often able to infer the actions of the performer through the sound alone – even, remarkably, when the interface is not tightly coupled to the resonator itself. Research of the development of parametric sound controllers provides evidence that, with multi-parametric interfaces, people performed better on more complex tasks than with single parameter controllers, perhaps because they allowed people to think gesturally (Hunt and Wanderley 2002).

Such a programme of research is non-trivial but would be made more manageable through collaboration with those musicologists who are analysing and classifying the micro-gestural and haptic content of the action–perception cycles of musical performances, particularly that content which reveals aural protensions. Its outcomes have the potential to make a significant contribution to data soniculation both for informational listening and for new music.

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