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Intermittent motor control in volitional musical imagery

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Abstract: We have previously defined musical imagery as "our mental capacity for imagining musical sound in the absence of a directly audible sound source, meaning that we can recall and re-experience or even invent new musical sound through our 'inner ear'." (Godøy and Jørgensen 2001, ix), a definition that still holds, however my focus in this chapter is on how we, at will, may be able to conjure up such mental images of musical sound. The basic assumption here is that mental imagery often resembles real-world sensations, and that triggering of such images may resemble triggering of real-world events. Also, recent motor control theory has suggested that body motion is optimally controlled in an intermittent, so-called *serial ballistic* manner, that is, in a point-by-point, or discontinuous way, and I try to argue in this chapter that intermittent motor control fits well with the triggering of mental imagery for musical sound.

Keywords: Musical imagery, motor control, intermittency, body motion, shape cognition, anticipative cognition, postures

1. Introduction

How can composers, arrangers, or conductors predict sound features of music just by reading scores? Or how can musicians rehearse music in their minds without recourse to an instrument? These questions concern what we call *triggers of volitional musical imagery*, and although we in the last couple of decades have seen a large number of publications on musical imagery topics (including on so-called *involuntary musical imagery,* see e.g. Williams 2015), we seem not to have so many publications on what are efficient and robust triggers of volitional musical imagery.

Yet during these same decades, research on music-related body motion (see e.g. Godøy and Leman 2010) has documented that mental images of sound are closely related to mental images of sound-producing body motion, suggesting that mental images of body motion could actually trigger mental images of sound. The basis for such trigger relationships are the massive amounts of previous experiences most people have of causality in sound production and which I have tried to summarize in the concept of *motormimetic cognition* (Godøy 2001; 2003): I can imagine hitting a drum, and thus conjure up the 'boom' sound of the drum, or: I can imagine my fist softly depressing bass region keys on the piano, and with that, the sound of a soft and dark piano cluster chord.

Accepting that mental images of musical sound may be triggered by mental images of sound-producing motion, the next question becomes how to trigger mental images of sound-producing body motion. Of current theories on motion initiation in human movement science, the most suitable for our purposes seems to be the theory of so-called *intermittent motor control* (see e.g. Karniel 2013, Loram et al. 2014, Sakaguchi et al. 2015), a theory claiming that human motor control proceeds in a discontinuous, point-by-point, and anticipatory manner, because continuous feedback control would be too slow for skilled fast body motion as is typically required in music performance. Musicians need to be ahead of events, i.e. to in an instant visualize and prepare for the upcoming sound-producing body motion trajectories. In other words: musicians need to adopt *piecewise anticipatory motor control* and *point-by-point motion initiation*, so in this chapter, I will argue that volitional musical imagery can be triggered by similar intermittent schemes in motor imagery.

The aim of this chapter is then to present what I like to call the "intermittency hypothesis" for musical imagery, and some of the research findings and conceptual arguments that converge in suggesting that this is indeed a plausible hypothesis. That said, the prospect of developing concrete techniques for reliable volitional musical imagery could potentially also be of practical benefit for performers, composers, and improvisers, as well as for anyone interested in exploring their own mental images of music.

2. Object-based musical imagery

Musical imagery may encompass several different features, and we have seen studies that focus on imagery for pitch, melodies, timbre, dynamics, timing, and expression (see Cotter 2019 for an updated overview). But the content of musical imagery could also be explored in view of holistic chunks of musical sound, hence, as more in line with our current topic of intermittency. Such a chunk-focused approach was in fact advocated by Pierre Schaeffer and co-workers as the foundation of a more universal music theory based on *sound objects,* i.e. on chunks typically in the 0.5 to 5 seconds duration range (Schaeffer 1966; 1998). Interestingly, we may in so-called ecological psychology (Gaver 1993), as well as in more recent work on imagery for multimodal events (Nanay 2018), see focusing on sonic events that resemble the holistic sound objects of Schaeffer. However, Schaeffer's sound objects are based on their overall dynamical shapes, rather than their source identity and/or everyday significance.

Schaeffer's ideas of sound objects grew out of the use of sound fragments in the *musique concrète*, and evolved from being basically a collage composition tool into becoming the basis for a new music theory. This theory comprised a scheme for the top-down ordering of salient subjective perceptual features in music, extending from the images of overall dynamic, pitch-related, and timbre-related envelopes in what was called the *typology of sound objects* (Schaeffer 1966, 429-459), down to images of internal timbral-textural detail features called the *morphology of sound objects* (Schaeffer 1966, 509-597). One of the remarkable features of this scheme is that of capturing so many of the most salient features as *shapes*, and as will be argued below, shapes that are inherently holistic and lend themselves very well to intermittent motor control.

The typology has three main categories of dynamic shapes: *impulsive*, *sustained*, and *iterative*, and three main categories of pitch-related features: *stable*, *variable*, and *unpitched* (inharmonic or noise dominated sounds). The morphology is extensive with numerous categories and sub-categories for the internal features of sound objects, and just to mention two prominent ones, *grain* (the rapid fluctuation of dynamic, pitch, or timbre in a sound object, e.g. as in a tremolo) and *gait* (the slower undulating motion in a sound object, typically at a walking or dancing pace). Equally important is that these sound object shapes resemble body motion shapes, shapes that we experience in synchrony with sounds, e.g. a protracted violin sound as similar to a protracted hand motion shape, an impulsive drum sound as similar to an abrupt hand motion shape, and a piano tremolo sound as similar to a rapid back-and-forth shaking hand motion shape. This means that we may have motormimetic components in parallel with the sound object features, hence what can be called *sound-motion objects* (Godøy 2019).

3. Motor-related musical imagery

Following Schaeffer's approach of "interroger la conscience qui écoute" (Schaeffer 1966, 147, in English: "questioning the listening consciousness") and the top-down strategy of digging further into the subjectively perceived features of sound objects, we will see that the sound object and its features are not about 'pure sound', but are composite, in particular so that the border between sound patterns and body motion patterns may become blurred (Godøy 2006). Once we make this transition to the multimodal, we can see how sound objects are shaped by sound-producing motion, and how motion features become part of the sound objects, firstly in the observable features, i.e. visual images of motion trajectories and postures (using video, motion capture, or just seeing and annotating), and secondly, in more indirect observations of effort, e.g. based on motion velocity and electromyographic (EMG) data of muscle activation, see e.g. Gonzalez Sanchez et al. 2019. The motion elements all contribute to sound object formation, evident in the following *audible features*:

- All kinds of contours, cf. the *typology* mentioned above, manifest in rhythmical-textural figures, as well as in motives, melodic fragments, ornaments, etc. are *de facto* also body motion shapes.
- All kinds of timbral and harmonic shapes, cf. the *morphology* mentioned above, are also reflected in body motion shapes.

And upon a closer study of sound-producing body motion, we can list some crucial *motor control features* that contribute to sound object formation:

- *Phase-transition*, denoting a shift in grouping based on rate and proximity of motion elements, e.g. the transition from a slowly pulsating sound to a tremolo sound because of increase in the rate of sound onsets (Godøy 2014).
- *Coarticulation*, the fusion of motion elements because of the transitions between postures, resulting in a contextual smearing of singular events (Godøy 2014). In fact, performance and interpretation are coarticulatory fusions of singular tone events into coherent phrases, i.e. into coherent sound-motion objects.
- *Hierarchies of motor control* so that certain tasks are carried out automatically and without detail control (Grafton and Hamilton 2007; Klapp and Jagacinski 2011).
- The *psychological refractory period* (PRP) denoting a temporal bottleneck in motor control at around approximately 500 milliseconds (Klapp and Jagacinski 2011; Loram et al. 2014).
- *Action gestalts*, i.e. preprogramed motor control units with no need for continuous control, only needing intermittent control (Klapp and Jagacinski 2011).
- *Postures* at salient moments in time as frames of reference for body motion (Rosenbaum et al. 2007; Rosenbaum 2017).
- In addition, we have *motion optimization* elements such as shifts between effort and relaxation, conservation of momentum, exploitations of rebounds, etc., that point in the direction of intermittent effort.

But needless to say, we still have substantial challenges in exploring various features of sound-producing body motion. In particular, issues of motion initiation (including intermittent motor control) seem to be not well researched, and we are currently working along three main avenues here:

- Indications of intermittency in the motion data (Sakaguchi et al. 2015).
- Indications of intermittency in the EMG signals (Aoki et al. 1989).
- With co-workers, reverse engineering of intermittent control in relation to continuous motion.

However, the main point for now is to see how motormimetic simulation of sound-producing motion makes for salient presence of sound-motion objects in musical imagery.

4. Shape cognition

What emerges from reflections on musical sound and music-related body motion, is that most features of both sound and body motion may be envisaged as instances of shapes:

- Postures and motion trajectory shapes of the sound-producing effectors (fingers, hands, arms, vocal apparatus, etc.).
- Shapes of the derivatives of sound-producing motion, i.e. of velocity, acceleration, and jerk of the effectors and of other motion data, e.g. EMG, as shapes.

And we have the following shapes in perceived sound, often similar to the shapes of sound-producing motion:

- Contour shapes of dynamics, pitch, and timbre of single sounds.
- Shapes of motives, textures, rhythmical patterns, tempi, and expressivity in more composite sounds and sound passages.

When it comes to shapes in musical imagery, it seems to be not so well researched, but besides the mentioned numerous shape elements in Schaeffer's seminal work, we have indirect behavioral evidence of shape cognition in our own work:

- *Air-instruments* (Godøy et al. 2006), studying listeners' imitations of sound-producing body motion.
- *Sound-tracing* (Nymoen et al. 2013), studying listeners' manual shape tracings of various sound objects.

Given these instances of shapes, it seems reasonable to regard shape cognition as a mediating element in multimodality, enabling mapping from e.g. sound-producing motion shapes to auditory imagery. The very basic role of shapes in human cognition and behavior is a fundamental element of *morphodynamical theory*, based on the idea that shapes are inherently holistic and efficient means for grasping and understanding complex phenomena (Thom 1983; Petitot 1990).

Importantly, shapes are instantaneous, i.e. 'all-at-once', as opposed to that which is sequential, i.e. which requires a step-by-step perceptual process. We thus hypothesize that shape cognition could be a high-level code for the musculoskeletal system at the chunk timescale, in line with the theory of action gestalts (Klapp and Jagacinski 2011), and in turn, that these action gestalts can be triggered by intermittent motor control.

5. Timescales

Musical imagery may involve different timescales ranging from the here-and-now of short-term memory, to the long-term imagery of large-scale works, cf. the timescales discussed in Snyder 2000. We may assume that there are variable degrees of acuity in such mental images, e.g. that they may be vague recollections of overall 'sound' or 'mood' of large-scale works, or they may be salient images of particular details. It could be useful then to distinguish the following timescales and their corresponding salient sound and motion features in view of imagery:

- *Micro* timescale with continuous features such as of steady state pitch, dynamics and timbre, i.e. as more piecewise stationary features of sound-motion objects.
- *Meso* timescale at the chunk or object timescale, i.e. at the very approximate 0.5 to 5 seconds timescale, with salient features of dynamic, pitch-related, and timbre-related envelopes, as well as salient stylistic and aesthetic-affective, features. This is also the timescale that has (variably so) been associated with sensations of the present moment (see e.g. Pöppel 1997 and Varela 2000).
- *Macro* timescale with concatenations of meso timescale chunks into large-scale musical works.

Of these three timescale categories, major constraints of music making and music perception converge in making the meso timescale privileged in volitional musical imagery:

- Instrumental envelope constraints, i.e. shapes of the excitation, sustain, and decay of sound objects, are typically found in the 0.5 to 5 seconds range (Godøy 2013).
- Coarticulation constraints, i.e. that there always is a contextual smearing of both motion and sound are likewise found in this duration range (Godøy 2014).
- Motor control constraints necessitating hierarchical control schemes privilege the meso timescale (Grafton and Hamilton 2007; Klapp and Jagacinski 2011).
- Perceptual duration thresholds, defined as the minimum duration required for any feature to be manifest, e.g. one measure of a waltz in order to perceive a waltz, are also typically found at the meso timescale.

We may assume that these constraints represent a *quantal element in music* (Godøy 2013), facilitating a holistic, 'all-at-once' presence of sound-motion objects in musical imagery.

6. Intermittency

The relationships between the continuous streams of sensory experience and the more discontinuous entities in our experience was one of the main topics of phenomenology and early gestalt theory. Husserl's famous tripartite model of *retention*, *primary impressions*, and *protention*, first published in 1893, suggested that perception and cognition proceed by a series of "now-points", by intermittently stepping out of the sensory stream in order to make sense of it as more holistic chunks (Husserl 1991). This remarkable insight could now be supplemented with ideas from recent cognitive science research. In particular, the idea of intermittency in motor control, firstly seen as a solution to various constraints e.g. the PRP, latency of body response, noise (i.e. disturbances of the neuronal information flow from the brain to the effectors), and need for anticipatory motion as in coarticulation, could now also be seen as relevant for the emergence of sound-motion objects in imagery.

In addition to theories of intermittent control (Karniel 2013; Loram et al. 2014; Sakaguchi et al. 2015), we have corroborating elements in support of intermittency:

- Detecting discontinuities in motion data (Sakaguchi et al. 2015).
- Detecting muscle contractions and relaxations in EMG data (Aoki et al. 1989).
- Theories of hierarchical motor control (Hamilton and Grafton 2007).
- Action gestalt theory (Klapp and Jagacinski 2011).

- Postures at salient moments in time (Rosenbaum et al. 2007; Rosenbaum 2017).

In more detail, intermittent control "… is executed as a sequence of open-loop trajectories, that is, without modification by sensory feedback apart from the instances of intermittent feedback." (Loram et al. 2014, 119) And furthermore: "Using new theoretical development, methodology, and new evidence of refractoriness during sustained control, we propose that intermittent control, which incorporates a serial ballistic process within a slow feedback loop, provides the main regulation of motor effort, supplemented by fast, lower-level, continuous feedback. Refractoriness distinguishes the slow intentional from the fast reflexive loop. IC in which optimization and selection occur within the feedback loop provides powerful advantages for performance and survival. A potential neurophysiological basis for IC lies in centralized selection and optimization pathways including, respectively, the basal ganglia and cerebellum". (Loram et al. 2014, 124). In short, intermitent control is a point-by-point, and top-down, motor control scheme that could be optimal both in musical performance and musical imagery because it entails:

- Hierarchical and anticipatory control, bypassing the PRP and other bottlenecks.
- Feedforward or so-called *open loop*, with no need for online correction.
- Effector optimization by coarticulation, i.e. that effectors are in place prior to use.
- Minimization of physical effort by conservation of momentum and rebounds.

Interestingly, it has also been hypothesized that the very fast triggering by the so-called *startle effect*, i.e. reaction to the sudden playback of a loud sound, may rely on a subcortical store of readymade motor programs (Valls-Solé et al. 1999). And on a more informal note, the very fast and non-hesitant triggering of sound-producing motion in musical improvisation could likewise be possible because of such readymade motor programs that only need an intermittent trigger to get going.

7. Control and effort

For sound-producing body motion, it makes sense to see motor control and physical effort as inseparable, however, in much motor control literature, there seem to be little or no mention of physical effort. There seem to be assumptions of some kind of servomechanism, so that once a control signal has been given, the musculoskeletal system just does the rest, i.e. provides the needed power for the ensuing body motion.

But in terms of imagery, it seems reasonable to claim that we not only have visual images of motion, but also salient sensations of effort, i.e. of muscle activations (Jeannerod 2001). With sensations of muscle activations as an integral element of imagery, we have come closer to establishing efficient and robust triggers for musical imagery. Brain imaging studies have detected close relationships between various body motion tasks and the motor control areas of the brain, however the relationships between motor control and effort, both mental and physical, seems not so well studied. Our own ongoing pupillometry studies of mental effort seem to suggest correspondences between levels of difficulty and mental effort, but we are also looking into effort issues as follows:

- Motion signals, in particular velocity, acceleration, and jerk, assuming that such higher derivatives are costly in terms of effort.
- EMG signals, detecting effort peaks and relaxation phases, including the *pre-motion silent period*, a relaxation phase before an effort peak (Aoki et al. 1989).

The bottom line in the motormimetic view of music perception and imagery is that all sound events, hence, all sound features, are included in some kind of body motion trajectory, and that there often will be some sense of effort associated with sounds. In view of the various constraints presented earlier in this chapter, we may hypothesize that effort is unequally distributed, i.e. is concentrated in peaks, with shifts between effort and relaxation phases, shifts optimal because:

- Concentration of effort in intermittent peaks allow for relaxation and restitution between these peaks, i.e. necessary to avoid strain injury.
- Biomechanically, effort-relaxation shifts can conserve momentum (e.g. in bowing) and exploit rebounds (e.g. in drumming).
- Anticipatory cognition, i.e. 'all-at-once' shape images of what to do next, is clearly necessary for efficient hierarchical motor control and for coarticulation.

In sum, it seems that intermittency of both control and effort concerns optimization of motion, both in the real-world and in mental imagery.

8. Triggering imagery

For lack of more knowledge, a possible hypothesis here could be that the triggering of effort and control peaks also entail physiological sensations, similar to the mentioned startle that sets effectors in motion (Valls-Solé et al. 1999). In musical imagery, such triggers could be generated internally, but we need much more knowledge of how such triggering works. Intuitively, we may guess that there has to be some kind of threshold between non-action and action, i.e. that there could be a preparatory buildup to some threshold and then a sudden triggering, i.e. as a kind of capacitor model of a charge release.

Intermittent motor control in both imagery and real-world conditions could then be understood as a combination of anticipatory motor cognition, represented as sound-motion shape images, with the activation of these shape images by some intermittent trigger, in other words that we have:

- Open loop, feedforward, serial ballistic triggering of sound-motion chunks with no correction once the object has been initiated, but with monitoring of the outcomes and with possibilities of correcting the features of the chunk the next time it is triggered. Thus, there are two timescales at work here, one for the intermittent triggering of motion chunks (typically in the ≈ 500ms range), and another, much faster and more fine-grained, for monitoring the output, e.g. fluctuations of pitch, dynamics, timbre, timing, etc. in the course of the chunks' unfolding (Loram et al. 2014)
- The sound-motion chunks as a coherent chunks in the sense of being singular action gestalts (Klapp and Jagacinski 2011), i.e. coherent due to the PRP at this timescale (i.e. ≈ 500ms), evident in the performance of ornaments and other similar fast figures (Godøy et al. 2017).

Actually, we focus on various such rapid sound-motion objects, i.e. mostly ornaments on various instruments, in our present work in the hope of finding out more about the triggering of anticipatory motor programs.

9. Volitional imagery for musical creativity

The hypothesis here is that efficient and robust volitional musical imagery may be enabled by intermittent serial ballistic triggering of sound-motion objects. This is all based on the convergence of behavioral features, first of all the phenomenon of anticipatory cognition in motor control and manifestations of this in observable body motion features (in PRP and response times, postures, trajectories, coarticulation, motion derivatives, and EMG data), and secondly on resultant musical sound features (in objects, shapes, and various patterns). This means that we may have imagery for sound-motion objects, imagery that we may test out in musical creation, first of all in improvisation and composition, but also in interpretation of scores (the transition from discrete tones to coarticulated chunks in Western music) and in mental practice for performance. An object-focused strategy as used in Schaeffer-inspired music theory teaching could be useful here, with the following categories (see Godøy 2010, 60, Figures 1 and 2, for examples of these object types):

- *Composed objects*, meaning the generation of incrementally different sound-motion objects by the superposition of sounds, e.g. proceeding from 'slim' to more 'thick' objects.
- *Composite objects*, i.e. making different extended objects with sounds fused by coarticulation, starting with singular sound-motion objects that then are moved so close together that they fuse and have continuous transitions between them.

More large-scale contexts are possible with concatenations of several intermittent and serial ballistic triggered objects, resulting in an emergent continuity, which in turn could be the content of instantaneous overviews of large forms "in-a-flash" as attested to by several composers, e.g. Hindemith (2000) and Xenakis (1992).

In summary, musical imagery may work in improvisation, composition, sound design, etc. by a series of chunks, each generated by imagery of singular ballistic motion, each being monitored but not corrected during the unfolding, but each being corrected in the subsequent ballistic motion, as suggested by the abovementioned principles of intermittent motor control.

10. Conclusion

The line of reasoning here can be summarized as follows: Volitional musical imagery may be triggered by volitional motor cognition. The proximity of mental imagery and motor cognition has been quite well documented in brain imaging studies (e.g. Lotze 2013), but what seems less focused on, is the actual triggering of body motion, both in real-world motion and in motion imagery. However, the idea of intermittent control does give us some novel perspectives on the temporal features of body motion and resultant musical sound, perspectives that can help us designing models to be tested on concrete music-related sound and motion data.

Intermittent motor control actually concerns the fundamental relationship between the continuous and the discontinuous in musical experience, hence, touches on some important epistemological issues. We are now in a position to proceed from the remarkable introspective insights of Husserl on "now-points" in perception and cognition to more behavioral evidence for fundamental intermittency in perception and cognition, and in particular, to advance our knowledge and practical skills in using intermittent motor control in musical imagery.

Also, ideas presented in this chapter are closely related to artistic practice, so that the use of intermittent motor control in practical situations will be part of the further development in parallel with more conventional research. Improvisation, both in actual online live performance, and in more offline compositional processes, could be a prime testing and development ground for the intermittency hypothesis.

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