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Godøy, Rolf Inge; song, minho; Dahl, Sofia

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EXPLORING SOUND-MOTION TEXTURES IN DRUM SET PERFORMANCE

Rolf Inge Godøy
University of Oslo
r.i.godoy@imv.uio.no

Minho Song
University of Oslo
minho.song@imv.uio.no

Sofia Dahl
Aalborg University Copenhagen
sof@create.aau.dk

ABSTRACT

A musical texture, be that of an ensemble or of a solo instrumentalist, may be perceived as combinations of both simultaneous and sequential sound events. However, we believe that also sensations of the corresponding sound-producing events (e.g. hitting, stroking, bowing, blowing) contribute to our perceptions of musical textures. Musical textures could thus be understood as multimodal, with features of both sound and motion, hence the idea here of *sound-motion textures* in music. The study of such multimodal sound-motion textures will necessitate collecting and analyzing data of both the produced sound and of the sound-producing body motion, thus entailing a number of methodological challenges. In our current work on sound-motion textures in music, we focus on short and idiomatic figures for different instruments (e.g. ornaments on various instruments), and in this paper, we present some ideas, challenges, and findings on typical sound-motion textures in drum set performance. Drum set performance is particularly interesting because the often very complex textures are produced by one single performer, entailing a number of issues of human motion and motor control.

1. INTRODUCTION

Our subjective experiences of any drum set performance may be characterized as that of *sound-motion textures*, meaning holistic perception of time-limited sequences of sound and body motion events, be that only of a single measure, or of a fragment of several measures, or of a whole work of music. Although the term *groove* is often used to denote various drum set patterns, we prefer to use the generic term *texture* to signify a more general notion of sound-motion patterns, so that *texture* may also denote all kinds of figures, e.g. such as ornaments.

The expression *sound-motion textures* also implies that we have a multimodal approach to rhythm perception and production, meaning that we understand the experience of rhythm as composite, as including both sound and motion features.

This in turn means that we need to consider body motion idiosyncrasies and constraints, as well as possibilities and constraints of the musical instruments involved. If we as a thought experiment imagine a drum set playing machine with solenoid activated mallets, we would have no biological constraints on the sound production. Such a machine could conceivably produce some sound-motion textures resembling that of a human drummer, but obviously without the motion constraints of the human body. So, if we could see this machine in action, it would probably also be at odds with our perceptual schemata of drum set music. In line with a so-called *motor theory perspective* on perception, we believe that the choreography of sound-producing body motion is an integral part of musical experience, see e.g. various contributions in [1].

The central idea here is that drum set sound-motion is produced by one performer, and that we at times may see an extraordinary virtuosity by drummers in handling several instruments. That such highly complex textures can be produced by one person, could lead us to take an *egocentric* perspective here, meaning a body-centered frame of reference for all that goes on [2].

Such an egocentric perspective may be extended to the perception of drum set textures, as demonstrated by some cases of *beatboxing*: reproducing a complex instrumental texture by the vocal apparatus could also suggest that we (variably so) may have a capacity for perceiving and imagining even quite complex sound-motion textures. But notably so, beatboxing is basically 'monophonic' because of the restriction of our vocal apparatus, yet this apparatus is capable of a sequential production of what may suggest a 'polyphonic' texture, similar to how polyrhythmic sequences may be conceived of, and controlled, as single sequential patterns [3], and all the time from a similar body-centered perspective.

The aim of the present paper is to give an overview of how we try to explore sound-motion textures in drum set performance, and in particular try to understand more of how a single performer can generate so complex, and also compelling, textures. With this aim in mind, we shall first consider some issues of sound-motion in view of multimodality, moving on to challenges of documenting sound-motion, followed by a presentation of various constraints of the sound producing body motion and the instruments used. We shall also present how we try to integrate our data into a coherent model of motion hierarchies and into what we call *sound-motion objects*, before listing what we see as some main challenges and directions for future work.

2. MULTIMODALITY

The basic tenet of our work is that sound-motion textures are multimodal, hence that we need to consider the perception of drum set performances as involving both sound and body motion. The sound-motion relationship may at times be so close that it is difficult to differentiate clearly between these two, i.e. difficult to distinguish between what is a sound event pattern and what is a motion event pattern in a textural excerpt. We may suspect that this interweaving of sound and motion also extends to aesthetic and affective features, such that e.g. subjective impressions of energy and gait in musical experiences combine sound and body motion sensations.

We here have the non-trivial task of trying to differentiate what goes on in complex drum set textures. First of all, this may be regarded as a more conceptual or ontological issue of trying to distinguish the ingredients in the multimodal mix. We should ask questions about what constitutes a sound event, and what constitutes a motion event. And furthermore, we should ask questions of what are the criteria for fusion of small-scale events into larger-scale events, e.g. between what is perceived as individual impacts, and what is perceived as a more fused stream of onsets e.g. as in a fill. Also, it will be useful to try to distinguish between what is strictly sound-producing body motion and what may be more sound-facilitating or even sound-accompanying motion of a drummer, e.g. recognizing what may be more communicative or theatrical body motion in a drum set performance [1].

Additionally, we need to take into consideration the acoustic features of the instruments as well as the logistics of the drum set instrument layout, as this is the spatial framework for the choreography of sound-producing body motion.

The next challenge will be to have a reasonably good understanding of what goes on in the production of these (at times quite complex) sound-motion textures. This will involve recording the body motion of the drummer, first of all the hands and arms, but also the whole torso and the head, as well as the feet. The use of both feet in drum sets necessitates balancing the body in the seated position so as to enable free motion of all four limbs (right and left hands/arms, right and left feet). Besides entailing various biomechanical constraints, this use of all four limbs will also needless to say be very demanding in terms of motor control. In addition to requiring extended practice, skilled drum set performance evidently also requires some efficient hierarchical and anticipatory control schemes.

Exploring the multimodal sound-motion relationships necessitates that we try to find out more about what goes on at the different timescales: clearly, we have the singular mallet-instrument impact-points and the corresponding sound onsets, but we also have the motion trajectories to and from such impact-points, trajectories that are both extended in time and usually involve more components of the effector apparatus, e.g. mallet-hand-wrist-lower arm-elbow-shoulder-torso.

In sum, this multimodal approach means that we need to consider chunks of sound-motion as holistic and coherent entities, as what we later shall call *sound-motion objects*, and try to understand how these sound-motion objects have new and emergent features not present at the timescales of individual impact-points.

3. DOCUMENTING SOUND-MOTION

In our explorations of drum set sound-motion textures, we need to collect data on both the sound and the sound-producing body motion, as well as to make extensive correlations between these two domains.

Starting with the instruments, we need to consider how the instruments work, i.e. know about their mode of excitation and resonant features, and importantly, the logistics of their positioning. Needless to say, one of the key elements of drum set performance is the instrument layout, enabling the performer with minimum effort, and at times also great speed, to alternate between the different instruments, cf. the layout of instruments depicted in Figure 1.

In earlier recordings, an acoustical drum set was used, but this required the use of so-called *active markers* for the infrared motion capture system, because the shiny metal parts of the instruments totally confused the tracking system so that passive markers could not be used. The use of active markers turned out to be both cumbersome (requiring wiring of the mallets) and not sufficiently reliable, making us use a MIDI drum set (Roland TD20) in subsequent recording sessions. Using MIDI drums made the use of ordinary passive markers possible, as well as gave us precise onset timing from the MIDI data. In our subjective opinion, the sound quality of the MIDI instruments was satisfactory, i.e. seemed to well reflect the different playing modes as well as the resonant instrument properties, and produced satisfactory contextual overlap for sound coarticulation (more on coarticulation below).

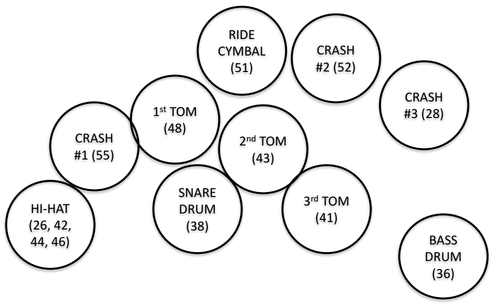

Figure 1. Layout of the MIDI drum set used in the recording sessions (the bass drum is actually placed below the 2nd and 3rd toms).

The data reported in this paper is based on recordings with a professional drum set player across one final session carried out after several pilot sessions over a period of one and a half years. During all these sessions, the drummer would perform a series of grooves and fills at different tempi, and often with multiple repetitions enabling future studies of motion invariants across repetitions.

For capturing the drummer's motion, we used an infrared motion capture system (a 13-camera Oqus Qualisys system, see http://www.qualisys.com) recording at 240Hz, with the drummer wearing a suit and cap equipped with reflective markers, and using drum sticks likewise equipped with reflective markers. Sound and MIDI data was recorded separately, and for reference, the recording sessions were also documented on video.

Further processing and graphing was done in *Matlab*, and there was not applied any smoothing here except for on the data reported in the middle plot of Figure 4, where a 5-points moving average for elbows, and a 17-points moving averages for wrists, was used.

Although infrared marker-based motion capture systems presently seem to be the most versatile method for collecting data on sound-producing body motion, it does also entail some serious challenges, first of all with the at times very rapid motion in expert drumming. Besides the mentioned issue of unwanted reflections, there is also the issue of dropouts, and most seriously, of not being able to completely capture what goes on even with very high frame rates (sample rates). As shown in [4], it may be necessary to have very high frame rates when studying detailed and fast motion.

Furthermore, capturing the precise moment of impact is not possible even with very high frame rates (in theory, approaching infinitely high sampling rates), so the use of a MIDI drum set is a practical solution in this regard also. As can be seen in Figure 2, there is a discontinuity in the motion trajectories around the point of impact, i.e. at the minima of the motion trajectories. That said, the point of impact may of course be estimated from the position data of the recorded motion frames by various means, such as by *functional data analysis* (see e.g. [5]).

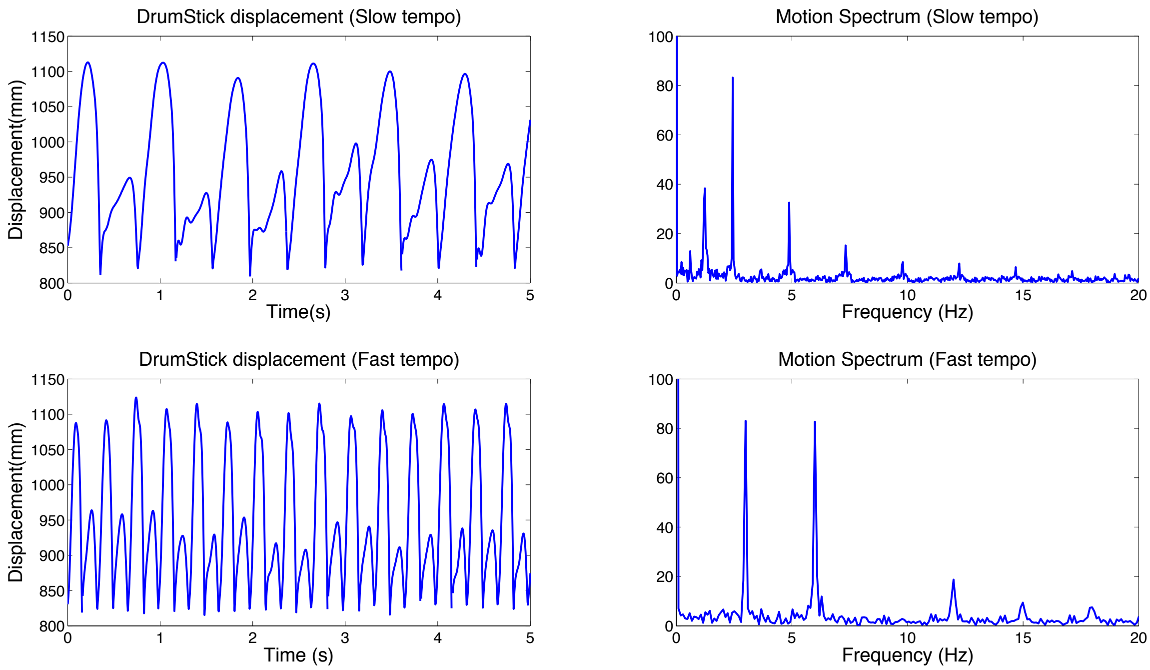

Figure 2. Two motion tracking examples using passive markers attached to a drumstick recorded at 240Hz. The two examples had different tempi (*slow, fast*) with mean velocities of 1448 mm/s and 3564 mm/s. Their peak velocities were 10096 mm/s and 11666 mm/s. Although the mean velocity of the fast motion was almost 2.5 times higher than that of the slow motion, we can see that peak velocities were almost the same. It means that the end velocities of single strokes do not vary significantly with respect to tempo. Also, every time when the marker reaches the lowest position (point of collision), we could observe discontinuities in the trajectories for both cases. It is interesting to note that the dominant frequency of the motion was less than 10 Hz, (see the right column), but the frame rate of 240Hz was not enough to capture the motion.

With our focus on sound-motion textures, we have the additional challenges of not only finding out what goes on in singular strokes, but also in an ensemble of markers to capture the overall motion involved in more composite textures.

The motion capture data will even with much care taken to avoid the problems presented above, usually have some need for preprocessing, typically removing spurious reflections, gap-filling dropouts, assigning markers to points on the body, and applying skeleton models. Usually, there will be a need for further processing that can result in representations as graphics and animations of the motion trajectories, as well as of derivatives, in particular of velocity, acceleration, and jerk, as well as more cumulative measures, such as quantity of motion. Processing is typically done in *Matlab* and associated toolboxes [6] or other software, e.g. *Mokka*, and the hope is to develop means for more synoptic overviews as suggested by Figure 4.

Further on, there are challenges of detecting and representing musically salient features from the continuous stream of motion data, challenges that border on to issues of motor control and perception, such as:

- Accurate onset detection, both of sound and motion
- Challenges of representing multiple trajectories (i.e. markers) in graphs, see e.g. Figures 4 and 5 below
- Discerning and understanding variability vs. constancy in trajectories, cf. the point made by Nikolai Bernstein as "An instance of repetition without repetition", meaning that we very often find approximate (i.e. non-exact) similarities between motion chunks in human behavior [7, p. 1726].

4. CONSTRAINTS

Needless to say, there are a number of constraints on non-electronic sound production in music. First of all, there are constraints of the instruments, such as their repertoire of possible output sounds and modes of performance. This includes various constraints such as the required force of excitation, of reverberation time, the need for damping, and also the need for positioning the effectors prior to impacts, in turn entailing important logistic elements in the layout of the instruments in the drum set that have consequences for the sound-producing body motion:

- All instruments must be reached from the sitting position.
- The drummer must be seated so that both the right and left foot can be used independently.

And there are of course many constraints on human sound-producing body motion: limitations on speed and amplitude of motion, on endurance, the need for rests and need for minimizing effort in order to be able to sustain such motion for extended periods of time and to avoid strain injury. In addition to such mostly biomechanical constraints, there are motor control constraints such as need for hierarchical and anticipatory control. In sum, we have the following main constraints on the production of sound-motion textures:

- There are basic motion categories that seem to be grounded in a combination of biomechanical and motor control constraints: *impulsive*, also sometimes referred to as *ballistic*, meaning a very rapid and brief muscle contraction followed by relaxation, such as in hitting; *iterative*, meaning a rapid back and forth motion such as in shaking the wrist or in rolling the hand; *sustained*, meaning continuous motion and mostly continuous effort, such as in stroking, but this category is not so common in drumming (found in scraping the cymbal, brushes on drums). Such a *motion typology* is clearly at work in shaping musical sound, hence, the labels may equally well apply to sound [8].
- All motion takes time, i.e. instantaneous displacement is not possible for the human body, and this in turn will lead to so-called *temporal coarticulation* in relation to sound onset events, i.e. that there is a contextual smearing of motion from event to event [9].
- Motion of end effectors, e.g. hands or feet, may also recruit motion of more proximal effectors, e.g. arms, shoulder, torso, and even whole body. This leads to so-called *spatial coarticulation*, meaning the recruitment of more effector elements than the end-point effectors, depending on the specific task [9].
- Coarticulation is an emergent phenomenon, cf. [10, p. 592]: "a control mechanism in which the different motor elements are not simply linked together in the correct sequence, but are also tuned individually and linked synergistically based on the final goal, with coarticulation observed as an emergent phenomenon."
- And furthermore, as argued in [10, p. 592], coarticulation is related to *chunking*, i.e. to the "…the integration of independent motor elements into a single unit. With chunking, there can be an increase of coarticulation and reduced cognitive demands because less elements are organized for a given motor goal"... "Chunking is also a critical element for automatization to emerge."
- *Left hand/right hand alternations* is a way around the constraints of speed, allowing for extremely rapid figures, similar to tremolo alternations in one hand figures on various other percussion instruments and on keyboards, and actually related to the back-and-forth shake motion of wrist tremolo in string instruments and triangle (or other confine-based instruments such as tubular bells).
- Phase relationships of left-right, cf. [2], suggesting different levels of stability depending on phase relationships.

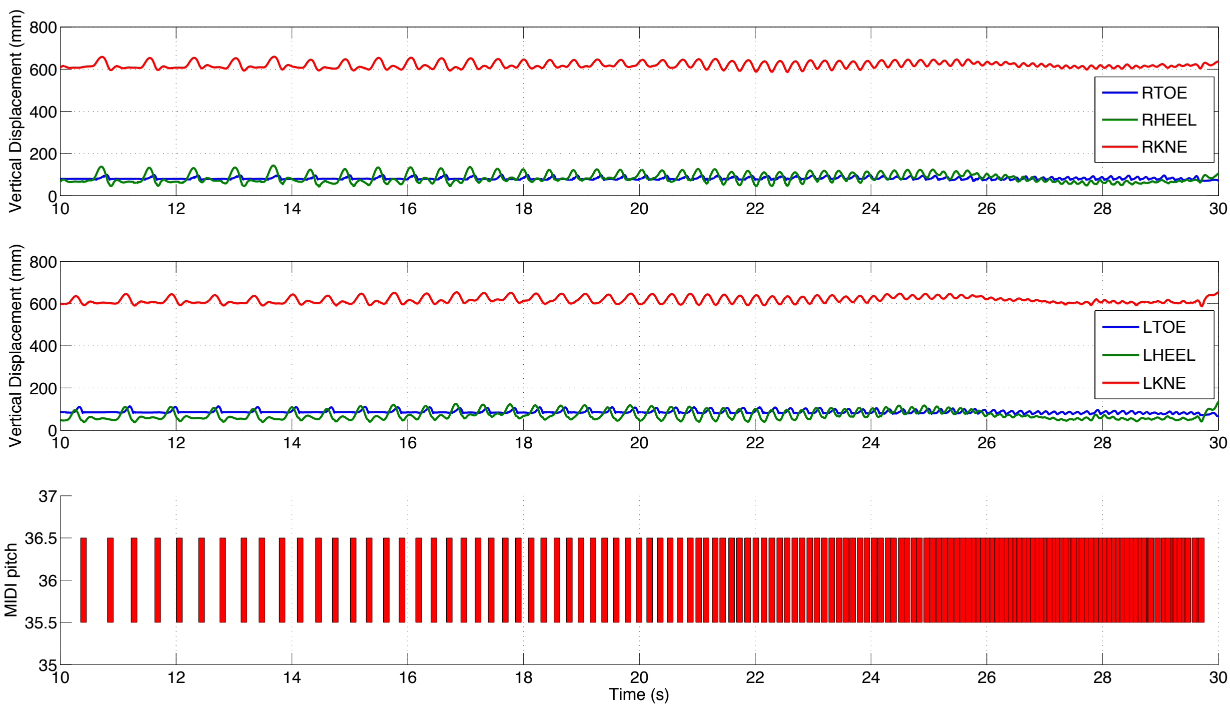

Figure 3. The increasing density of motion events leads to phase-transition, similarly to how event proximity may lead to coarticulatory fusion. Here we see how a repeated and accelerated right foot – left foot bass drum pedal motion leads to a phase-transition after approximately 20 seconds with the disappearance of the dip after the impact as well as a diminishing of the amplitude of motion, something that seems reasonable given the speed constraints of the human body.

In addition to fusion by coarticulation, we can also find instances of fusion by so-called *phase-transitions* in the sound-producing motion [9]. Phase-transition means that a series of otherwise independent events may fuse into what is perceived as a continuous stream because of increased event density, and conversely, a continuous stream of events may change into a series of distinct events with a decrease in event density. The transition from single strokes to a drum roll, or from single tones to a tremolo or trill, are common examples of this. In Figure 3, we see an example of such phase transition in the bass drum foot pedals of the drum set. With an acceleration, we see the change in the motion shape, and at the fastest tempo, also a decrease in the amplitude of the motion.

With both coarticulation and phase-transition we have cases of fusion, what we in general refer to as *chunking*, that seem to emerge from a combination of biomechanical and motor control constraints (for the moment, it seems not possible to say exactly what is due to what), i.e. gives us a bottom-up factor in the shaping of sound-motion textures.

Additionally, it seems that skill in performance is also about minimization of effort, and that virtuoso instrument performance in general gives an overall impression of ease, something that seems related to the exploitation of motion hierarchies.

5. HIERARCHIES

Using both hands and both feet in at times very dense and rhythmically complex drum set passages, is clearly demanding both in terms of effort and motor control. From what is known of human motor control (see e.g. [11]), such skillful behavior necessitates that the motion be partially automatic, i.e. need some kind of control hierarchy. Likewise, the layout of the human body will inherently result in some motion hierarchies, i.e. the fingers, attached to hands, attached to arms, shoulders, torso, and whole body, hence, we have hierarchies both in the spatial and in the temporal domain, similar to having coarticulation in both the spatial and temporal domain.

Spatial hierarchies are evident in task-dependent effector mobilization, e.g. for soft and slow textures, there is usually only a need for the most distal effectors, e.g. hand and wrist, whereas in more loud and fast and dense textures, it may be necessary to recruit more proximal effectors, e.g. elbow, shoulder, and even torso.

As for temporal hierarchies, these are probably the most crucial for achieving high levels of performance skill. Such hierarchies are again clearly dependent on extensive practice, practice resulting in exploitation of various synergies (i.e. cooperation of muscle groups) and hierarchies, i.e. top-down 'commands' at intermittent points in time [12]. Hierarchies then go together with a basic discontinuity in human motor control, and is associated with anticipatory motion [13], as well as with high levels of preprograming, i.e. with what has been called *action gestalts* [14]. The turn towards discontinuity in human motor control in some recent research is interesting for musical applications, because the demands for very rapid motion would indeed go better with intermittent motor control than with more traditional models of so-called 'closed loop', i.e. continuous, control because of its slowness [15].

More specifically, we believe there is evidence for how seemingly complex bimanual tasks can be carried out by a human performer provided a hierarchical approach. As suggested in [3], a polyrhythmic passage may be thought of as a singular rhythmic pattern, e.g. a pattern of 3 against 4 quarter tones may be thought of as a series of one punctured eight note, one sixteenth note, two eight notes, one sixteenth note, and one punctured eight note. This very simple example may be seen as what in [2, p. 103] is called a case of when "a dual task becomes a single task", and which the authors believe works because "the spatial patterns produced by the 2 hands form a geometric arrangement that can be conceptualized as a unified representation."

Another aspect of facilitating hierarchies is that of alternations between effectors and/or effector positions. It is well known that for instance a tremolo on a keyboard or with two mallets on a percussion instrument is much easier using a left-right-left-right-etc. hand rolling motion than a series of up-down motions of the whole hand. And likewise, in the vocal apparatus, it is possible to make a very fast articulation of saying *ta-ka-ta-ka-tam*, whereas saying *ta-ta-ta-ta-tam* is only possible at a slower rate. In the drum set, this alternation between effectors can lead to very complex passages, and although the motor control factors enabling such virtuosity remains to be explored, the idea of some kind of hierarchical and intermittent control scheme does seem quite plausible.

On the perceptual side, there are probably also *sound hierarchies*, i.e. that there is the *reverberation* of the instruments contributing to the basic *smearing*, the *phase-transition* leading to *fusion* (e.g. iterative rather than impulsive sound) and that the *coarticulatory inclusion* of successive sounds (sometimes also simultaneous sounds, e.g. bass drum + the other drums) contribute to holistically experienced chunks of sound-motion textures.

6. SOUND-MOTION OBJECTS

From a combined sound and motion perspective, it seems clear that sound-motion textures in drum set performance are both perceived, and in their production, conceived, as chunks, gestalts, or holistic entities, entities that may vary in content, e.g. between single slow strokes and ferocious fills, but typically experienced as units, as what we like to call *sound-motion objects*. The main reasons for the idea of sound-motion objects are the following:

- *Intermittent control*, based on the need for anticipation and on the possibilities of action gestalts in human motor control [12, 14, 15].
- *Intermittent energy infusion*, in particular with ballistic motion, i.e. biomechanics in combination with instrument physics (requiring impact excitation), and biomechanical demands for rests [9].
- *Coarticulation*, which is a constraint-based phenomenon that results in object level fusion, also related to *phase-transition* in cases of repetitive motion [9].
- *Chunk timescale musically most salient*, meaning that the timescale of approximately between 0.5 and 5 seconds is the most salient for most musical features, cf. the work of Pierre Schaeffer on sonic objects and similar work on timescales in music [8].

The notion of sound-motion objects is then not only in accordance with some basic features of perception and motor control, but also advantageous in view of various music theory and/or analytic perspectives. With such a central perspective of sound-motion objects, we believe we are in a better position to interpret the various sound and motion data that we collect in our research:

- Regard sound-motion textures as holistic objects, often repeated, often with variations, but variation-tolerant in retaining identity, cf. Bernstein's idea of "repetition without repetition" mentioned above [7].
- Also in cases of gradually increasing density of fills, e.g. from none by way of various upbeats and syncopations to very dense and energetic fills, a hierarchical scheme of salient points in the music, i.e. what could be called "anchoring" [7], seems to be at work.
- Focusing on sound-motion objects could also be useful for studying the aesthetic and affective aspects of drum set music, i.e. for studying how the various motion features, in particular the quantity of motion, the velocity, and jerk (derivative of velocity) may contribute to the overall experience of the music.

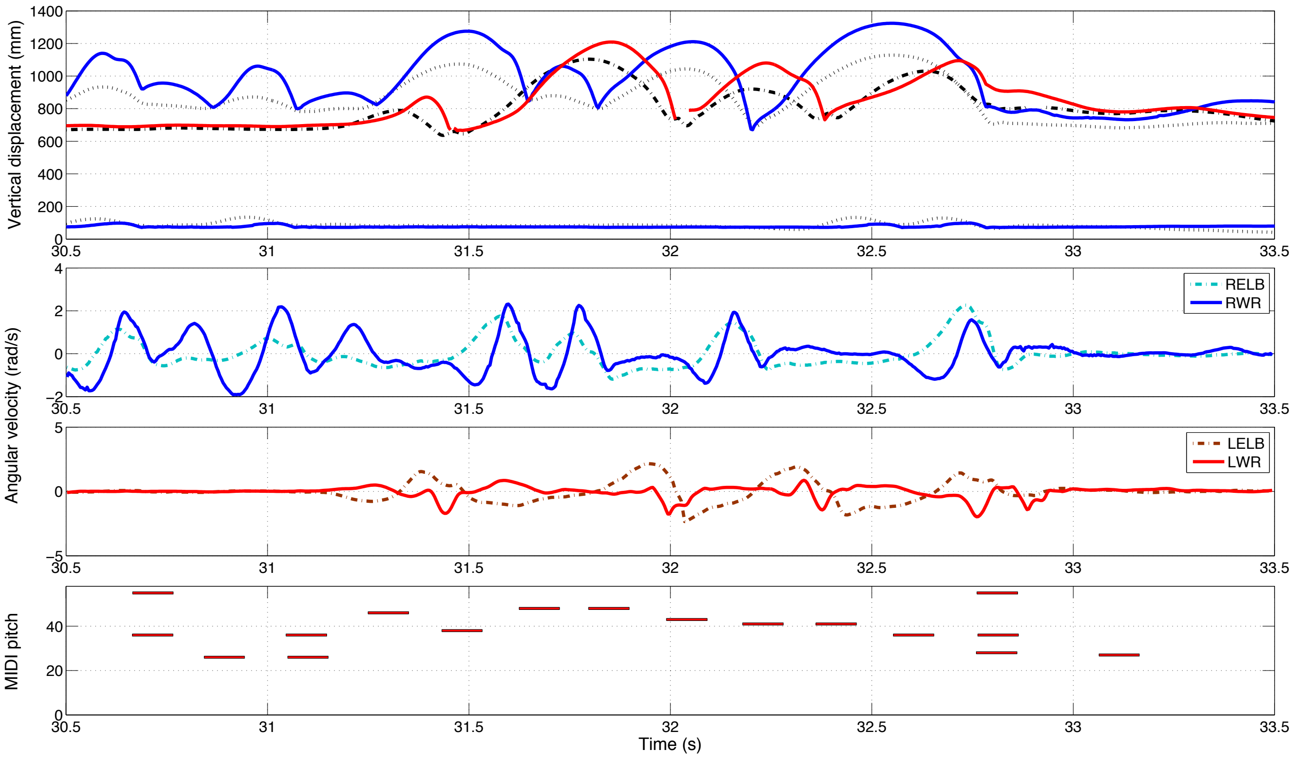

Figure 4. Motion of markers and MIDI onsets vs. time during the end fill after playing a steady slow groove. Top panel: The vertical displacement of markers on the player's right ankle (lower dotted line), right toe (lower blue line), right hand (upper dotted trace), left hand (dash-dotted line), right stick (upper blue line) and left stick (red line). As can be seen, the traces of the hand markers tend to precede the stick movements slightly, but otherwise maintain similar shape albeit with lower amplitude. The ankle marker is also preceding the toe marker, but this ankle movement is larger. Middle panels: the angular velocities of the right and left wrists and elbows. Bottom panel: MIDI onset times and drum info.

In our studies of sound-motion textures, we have seen how rather demanding passages may be performed seemingly with ease and elegance, and after quite extensive reviews of our recordings, we believe that the principles of sound-motion objects are crucial for both the performer and for the listener. As an example of this, consider the three-second fill passage from the end of a slow eight measure groove in Figure 4 and 5. Subjectively, the passage is a different object from the main pattern of the slow groove, but it is right on the beat of the groove. In the course of the fill, the drummer also makes a right torso rotation, probably in order to have the effectors in the optimal position for the final impacts of the fill.

In Figure 4, we see the motion of the hands and the feet in this three-second fill, as well as a zoomed in image of the angular velocity of the right and left elbows and wrists, indicative of the motion to the impact-points in the fill, and the MIDI onset points of these impact-points.

In Figure 5, we see a 3-D rendering of the right and left drumsticks and hands in the same three-second groove, demonstrating the more large-scale motion also involved in this fill.

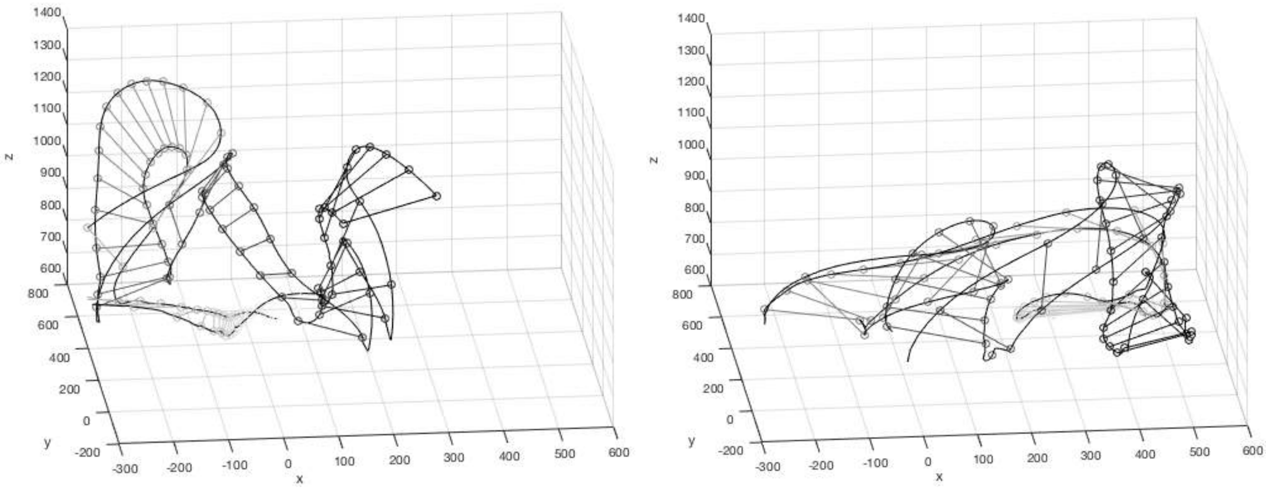

Figure 5. The movement for markers attached on the drummer's right/left hand and drumsticks during a final fill depicted in Figure 4 (from 31.4s to 33.5s). Every 8th sample point is marked with a circle and a line has been drawn between the marker at the stick and the hand, connecting the two. The movement start in the (upper) right hand side of the figures, where the right hand and stick are lifted in preparation for the first stroke in the fill while the left hand is at a lower amplitude (compare Figure 4). Thereafter the arms move to other drums in the left of the figure, and, finally, back to the snare.

7. CONCLUSIONS AND FURTHER WORK

Clearly, drum set music is a multimodal art with its combination of sound and motion, the latter in turn a combination of effort-related, visual, proprioceptive, etc. sensations. Sound and motion are so intertwined in both production and perception that it may be difficult to separate these two main elements, and should be a good reason for using the term *sound-motion textures*.

Our studies of drum set sound-motion textures have a number of issues in common with sound-motion textures on other instruments, and in particular rapid textures such as typically encountered in ornaments. We believe these rapid figures are important to study because they could shed light on how skilled musical performance can work around various constraints by anticipatory cognition, and also shed light on how small-scale sonic events fuse into sound-motion objects with emergent features not found on the small-scale level. In view of these aims, we hope to in the future be able to work on following topics:

- Enhanced motion capture methods that give us more precise recordings of motion trajectories.
- Motion capture recordings supplemented with so-called *electromyographic* (EMG) recordings of muscle activity of the effectors, giving us more information about both the level of effort and the timing of muscle contraction in relation to the visible motion as well as the auditory output, hence also shed light on issues of chunking.
- Continue our studies of sound-motion textures on other instruments, i.e. extend our previous studies on other percussion instruments, piano, violin, and cello.
- Develop enhanced methods for visualization of both motion capture and EMG data, so as to better represent the multimodal nature for sound-motion textures.
- Design models and studies for intermittency in production control, production effort, and even perception of musical sound.

Acknowledgments

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