The Sounding Object

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The Sounding Object

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Chapter 11

Complex gestural audio control: the case of scratching

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11.1 Introduction

To scratch means to drag a vinyl record forwards and backwards against the needle on an ordinary turntable along the grooves, not across, though it might sound like it. This way of producing sounds has during the last two decades made the turntable become a popular instrument for both solo and ensemble playing in different musical styles, still mostly in the hip-hop style where Disk Jockeys (DJs) first started to scratch. However, all musical genres seem to be able to adopt the turntables into their instrumental setups. Composers in traditions like rock, metal, pop, disco, jazz, experimental music, film music, contemporary music and numerous others have been experimenting with DJs the past years. Experimental DJs and most hip-hop DJs now frequently call themselves “turntablists”, and the music style of scratching and extensive cut-and-paste mixing is called “turntablism”. These terms, derived from the word turntable, are now generally accepted. It is also generally accepted that a turntablist is a musician and that the turntable is to be considered an instrument. The acoustics of scratching has been barely studied until now. On the other end the business market of DJs equipment is quite large. It is therefore interesting to study the phenomenon of turntablism from a scientific point of view.

In this chapter three experiments are presented. Aim of these experiments is to model scratching based on analysis of an experienced performer. For this purpose scratching as an expressive musical playing-style is looked at from different views. Experiment 1 investigates the musical fundamentals of scratching, and explains the most common playing-techniques in more detail. Experiment 2 investigates a real performance with aid of sensors on the equipment in order to understand what kinds of problems and parameter variation a model will need to deal with. Experiment 3 investigates what happens to the record that is being scratched, as it is apparent that some heavy damage will be done to the vinyl and this can therefore affect the sound quality.

11.1.1 Common set-up for experiments

All the experiments shared part of the equipment and methods, as explained in this section. Setups and methods specific to each experiment are explained in the respective sections.

11.1.2 Method

In all the experiments presented in the following, the same method was used. Small exceptions in the equipment are presented in Table 11.1[1].

Subject

Only one subject performed during experiments 1 and 2, examining expressive playing. He is Alexander Danielsson, *DJ 1210 Jazz*, a professional DJ from Sweden. He volunteered for the experiments. 1210 Jazz (as he will be called throughout the paper) has no formal musical training, but has for almost 15 years been considered to be among the best turntablists in Sweden and Europe, a reputation he has defended in DJ-battles (as competitions for DJs

[1]The audio recorded in Experiment 2 was only intended to illustrate what happened to the sound, and acoustical properties were not analyzed in this investigation.

<table>
<tr><th>Equipment</th><th colspan="3">Description</th></tr>
<tr><td>Turntable</td><td colspan="3">Technics SL-1210 Mk2 with felt slip-mat</td></tr>
<tr><td>Cartridge</td><td colspan="3">Stanton 500 (Experiment 1 only) and Shure M44-7</td></tr>
<tr><td>DJ-mixer</td><td colspan="3">Vestax PMC-06 Pro</td></tr>
<tr><td>Faders</td><td colspan="3">Vestax PMC-05 Pro</td></tr>
<tr><td>Record</td><td colspan="3">1210 Jazz - Book of Five Scratches. Book 2 [125]</td></tr>
<tr><td>Potentiometer</td><td colspan="3">Bourns 3856A-282-103A 10K (Experiment 2 only)</td></tr>
<tr><td rowspan="4">DAT-recorders</td><td rowspan="3">Teac RD-200T Multichannel (Exp. 2 only)</td><td>Channel 1 (20 kHz)</td><td>Potentiometer</td></tr>
<tr><td>Channel 2 (10 kHz)</td><td>Crossfader</td></tr>
<tr><td>Channel 3 (10 kHz)</td><td>Sound</td></tr>
<tr><td>Sony TCD-D10 (Exp. 1 and 3)</td><td colspan="2">2 channels (44.1 kHz)</td></tr>
<tr><td rowspan="2">Wave analysis software</td><td colspan="3">Soundswell Signal Workstation [64]</td></tr>
<tr><td colspan="3">Wavesurfer [221]</td></tr>
</table>

Table 11.1: Equipment used for the experiments.

are called) as well as on recordings, in concerts, and in radio and television appearances. He has made three records for DJ use, so-called *battle records*, one of which was used during the recording sessions.

For experiment 3, the first author performed the test.

Material

All the recordings used in these experiments were done at KTH during 2001. The equipment used for the experiments is summarized in Table 11.1.

Instrument line-up

Mixer and turntable were placed in a normal playing-fashion with the mixer to the left. The turntable was connected to stereo-in on the mixer. The right channel was output to a DAT recorder, while the left channel was output to a headphone mixer so the DJ could hear himself. See Figure 11.1.

Calibration

We needed to have a turntable with constant rotation speed for the experiments. The spikes (labelled 1-10 in Figure 11.2) in the waveform in the lower

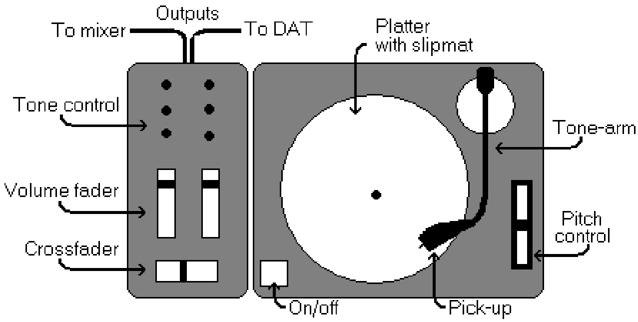


Figure 11.1: Instrument set-up with mixer on the left and turntable on the right side.

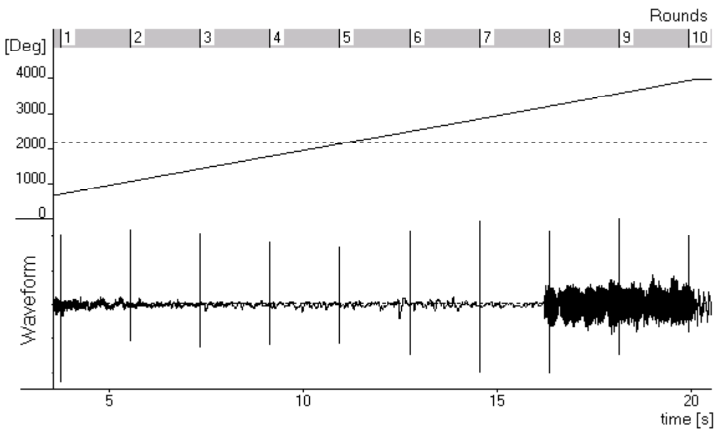


Figure 11.2: Calibration of turntable motor. The upper panel shows the record angle in degrees from the potentiometer. The lower panel shows the waveform from a prepared vinyl record.

panel come from a cut made across the record, marking every 360° with a pop. Since the distance between each spike was equal, the turntable motor by assumption generates a constant speed. The upper panel in Figure 11.2 shows the readout from a 10-rounds potentiometer in degrees.

11.1.3 Background - Playing the turntable

Introduction to scratch music

Turntablism includes both *scratching*, using one turntable, and *beatjuggling*, using two turntables. Scratching is a typical solo-playing style, comparable to that of electric guitar. The musician expresses himself in intricate rhythmical and in tonal structures. Beatjuggling sometimes has a rhythmical backing function to hip-hop *rapping*, but is also often played in expressive solo-acts, typically with a groove on one turntable. A history of turntablism and overview of the practice of using turntables as instruments has been reported in a previous paper [114].

In the early eighties, scratching DJs and the entire hip-hop community got the attention of the record-buying generation, gradually spreading their sounds to the rest of the musical world. Since then, DJs have appeared on recordings by artists as diverse as John Zorn [259], Herbie Hancock [112], Mr Bungle [41], Portishead [196], David Byrne [45] and Tom Waits [248]. The first experiments with use of phonograph to create music started about 1915 and were carried on through the next three decades by Stephan Wolpe, Paul Hindemith, Ernest Toch, Percy Grainger, Edgar Varèse, Darius Milhaud and Laszlo Moholy-Nagy [56]. None of these composers were turntable artists, nor did they write compositions for turntable that still exist (although some compositions may be reproduced by memory). John Cage [47] and Pierre Schaeffer [213] composed what are considered to be the first pieces for turntables, but they are recognized mainly for their approach to sounds, not to the turntable. Pierre Schaeffer's concept of *musique concrete* is as much a result of tape-manipulation as vinyl-manipulation, and his practices would probably have been commenced even without the phonograph technology [107, 136].

Instrumentalists must learn to incorporate a variety of techniques and methods for tone manipulation in their playing, and DJs have established a fundamental ground with an almost compulsory assortment of techniques [115]. All new ways of playing and scratching are persistently explained and debated on, especially on Internet discussion forums on sites devoted to turntablism [215]. Some of the accepted techniques will be described and analyzed in Experiment 1. Numerous techniques more or less resemble, and often originate, from those described, but they will not be included in this study. Many ways to scratch do not fit into the general scheme, and are not widely used. They are, however, all explained on turntablism Internet sites as soon as they surface. The overview in Experiment 1 will not deal with the more unconventional scratches.

11.1.4 Equipment and instruments

Any turntable might be used for scratching, but the standard is a direct-driven machine with the platter mounted on the motor. Scratching also utilizes an audio mixer with a volume control that is mostly used for controlling the onsets and offsets of tones. Therefore, the turntable as a musical instrument includes the turntable with pick-up, slip-mat, mixer and a vinyl record. Relatively few manufacturers have succeeded to enter the market with highly qualitative equipment, considering the massive interest in DJing and the prospective of good sales. Turntablists seem to be skeptical to adapt to radical innovations, especially those that oversimplify and trivialize playing. One example is the production of a mixer that allows for some of the hardest techniques to be played with ease. This particular mixer, Vestax Samurai [241], never got much positive attention from the professionals, even though it could inspire to the development of new techniques. Why this is so and which consequences this inflict on the evolution of the scene would bring us to an extensive discussion. In brief, displacement technology could be considered to cheapen the musician's skill, and this explains the hesitation to switch to such a technology [104].

Low budget equipment fails to convince users. At a professional level there are several brands to choose from, that have comparable qualities. The standard line-up for many turntablists is a set made of two Technics SL-1200 Mk2 turntables with Shure M44-7 pick-ups, and a scratch mixer without unnecessary controllers, e.g. the Vestax PMC-06 Pro. In the following, "Technics" will refer to the Technics SL-1200 Mk2 or its black counterpart SL-1210 Mk2. Normally this equipment is organized with one turntable placed on either side of the mixer, and even rotated 90° with the tone-arms away from the body to avoid hitting the tone-arm with a botched arm movement.

The quartz direct-driven Technics (Figure 11.3) has advantages to the belt-driven turntables in terms of pick-up speed and motor strength (the starting torque of a Technics is 1.5 kg/cm). When pushing the start-button, a mere third of a revolution (0.7 s) is needed to reach full speed at $33\frac{1}{3}$ revolutions per minute (rpm), and stopping the record goes even faster [224].

With a felt slip-mat lying between the platter and the record, moving the record in both directions with the motor on and the platter still going is fairly easy. In rougher moves and when maintaining a heavier touch, the platter might follow the record movement, but because of the pick-up speed, that is not a problem.

The *pick-up* mechanism is specially designed for scratching to prevent the

Figure 11.3: Technics SL-1200 Mk2 turntable (SL-1200 is silver gray and SL-1210 is black).

diamond stylus tip from skipping from one groove to another, and even the stylus tip is designed to make scratching easier. “Needle” is the popular term for both the stylus tip and the bar or tube that holds it, called the *cantilever*. Normal high fidelity styli are often elliptical at the end to follow the groove better, while scratch styli are spherical and made stronger as the force on the needle can get so high that both the reels and the needle are in hazard of being damaged. An M44-7 can handle three times the tracking force (the force holding the needle in the groove) of the hi-fi cartridge Shure V15 VxMR—up to 3.0 g (grams) on the M44-7 compared to 1.00 g on the V15 [220]. Output voltage from the scratch cartridges is 3-4 times higher (9.5 mV) than the hi-fi cartridge. The hi-fi cartridge has better frequency response, from 10 to 25 000 Hz, compared to M44-7’s 20 to 17 000 Hz. On scratch cartridges the cantilever holding the stylus has high mass and stiffness, and the high frequency range is much affected and poorly reproduced. M44-7 has twice the cantilever diameter compared to the V15.

The *mixer*, see Figure 11.4, has other features than just amplifying, the most important ones are the volume controls and fader. DJ mixers were originally designed for switching smoothly between two turntable decks when doing beat mixing[2], and all mixers have for both stereo channels at least a volume fader and tone controls (bass, mid and treble ranges). The fader was developed during the late seventies to make beat mixing easier, and is positioned

[2]Eventually, better mixers allowed the traditional beat mixing of two different songs to evolve into the practise of making one section of a record last for as long as wanted by cross mixing between two identical records

Figure 11.4: Rane TTM56 scratch mixer with a close-up on crossfader and volume controls.

at the front end of the mixer. In Figure 11.4 the close-up shows crossfader and volume faders.

The crossfader glides seamlessly from letting in sound from channel 1 (left turntable), through mixing signals from channel 1 and channel 2, to channel 2 (right turntable) only. Whether a left-positioned crossfader shall let in sound from the left or right turntable is now adjustable with a special switch called *hamster switch*. Fading curves for crossfader and volume faders can be customized on most mixers. Several varieties in how the crossfader operates are fabricated, such as using optics or Rane's *non-contact magnetic faders* [198]. "Fader" might, however, be a misguiding term as the fading curve on the crossfader normally is adjusted to be very steep, making it act as an on-off switch.

Any vinyl record might be used for scratching, but during the last ten years sounds with certain qualities have dominated. Only fragments of original recordings are being manipulated, often shorter than one second. Isolated musical incidents like drumbeats, guitar chords, orchestra hits and especially sung, spoken or shouted words represent the majority of sounds used. To simplify playing, and for obvious economical reasons, a number of popular sounds are compiled on one record pressed for DJ use, commonly called a *battle record* (copyrighting is understandably an abiding but disconcerting question). The sound samples come without long gaps in one track. Longer sentences are often scratched one word or syllable at the time.

Sounds can be given different onsets and offsets depending on the technique used by the DJ. These variations on the sounds and the results of different techniques applied to the sounds will be described and analyzed in the following section presenting the Experiment 1.

11.2 Experiment 1 - The techniques of scratching

11.2.1 Introduction

The aim of this first experiment was to investigate and explain some of the different scratch techniques.

11.2.2 Method

Material

DJ 1210 Jazz was asked to perform some typical techniques, both independently and in a natural musical demonstration, and he also included more unusual examples. Further he was restricted to one frequently used sound, the breathy-sounding *Fab Five Freddie* "ahhh"-sample from "Change the beat"(a chorused voice sings "ahhh" with a falling *glissando* in the end [81]). The recordings lasted for about 30 minutes, out of which long sections (several seconds) of continuous playing of a single technique were extracted. About twenty different techniques were recorded in this session.

11.2.3 Techniques

Basic movements

Basic DJ hand movements are naturally distinguished in two separate entities; record movement and mixer (crossfader) movement. Most scratching techniques derive from fast but rather simple movements. Record control and mixer control depend strongly on one another, analogous to right- and left-hand movements in guitar playing. Both hands can operate on both devices, and most players switch hands effortlessly, both for playing purpose and for visual showing-off purpose. Even techniques where both hands go to the same device are performed. A general rule has been to have the strong hand on the vinyl, but with a more intricate use of crossfader, learners now tend to use their strong hand on the mixer instead. The volume controls (first and foremost the crossfader) are handled with fingertips and are often bounced swiftly between the thumb and the index finger. The record is pushed forwards and backwards

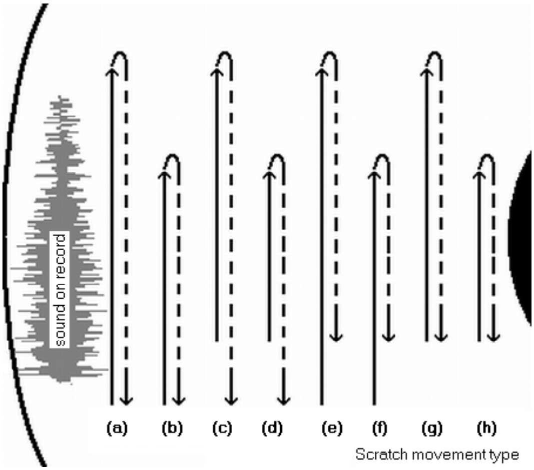


Figure 11.5: 8 ways of starting and ending a movement over a sound on the record.

in every imaginable manner. Travelling distance for the vinyl varies from less than 10° to more than 90° in each direction.

Onsets and offsets depend on the position of the sample when starting a scratch, the use of crossfader, and the speed of the movement. Three fundamentally different onsets are possible to achieve. First, a scratch movement can start before the sound sample, and the acceleration then completes before the sound cuts in. The crossfader will have no effect. In the second kind of onset, the scratch movement starts within the sound sample without use of the crossfader; the record will speed up from stand still and produce a very fast glissando from the lower limit of auditory range to desirable pitch, often above 1 kHz. A third onset category occurs when the crossfader cuts in sound from within the sample, creating an insignificant *crescendo*-effect, as if it was switched on. Any sound can be deprived of its original attack by cutting away the start with the crossfader.

Figure 11.5 shows a sector of a record with a sampled sound on it. The y-axis represents the position in the sample. There are eight different forms of a forward-backward motion, marked (a)-(h). All movement types are permutations of starting, turning and stopping either within or without the sampled sound. Movement types (a)-(b) and (e)-(f) start before the sound, and movements (c)-(d) and (g)-(h) start within the sound. Movements (a), (c), (e) and (g)

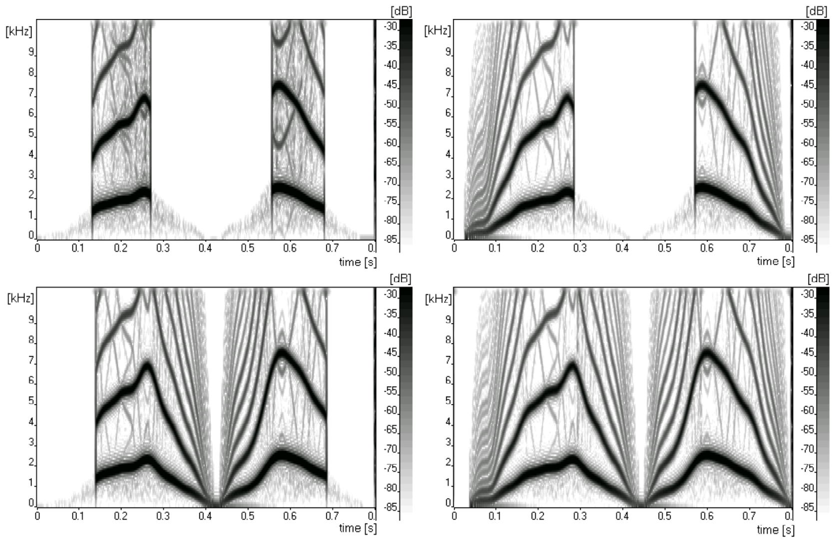


Figure 11.6: Spectrograms of 4 different types of scratch movement.

have the change of direction outside the borders of the sound, while (b), (d), (f) and (h) change direction within the sound. Movements (a)-(d) end outside the sound border, while (e)-(h) end before the sound has finished.

Four of the possible movement types have been generated with the scratch model described in section 11.A. A simple forward and backward gesture is applied to a sound file, producing examples of types (a)-(b) and (g)-(h). Spectrograms of these examples are drawn in Figure 11.6, and demonstrates how the onsets and offsets will vary from each case. The sound used is a flute-like sound with the fundamental at 500 Hz. Spectrograms are cut at 9 kHz as the most interesting part is the shape of the fundamental and the added noise band that simulates groove wearing in the model. All four gestures represented in the spectrograms are identical.

Besides the starting, turning and stopping points, several other factors have influence on the output sound of a simple forward and backward movement: Direction, or whether to start with a push or a pull, is an effective variable. The speed changes the pitch, and can be fast or slow, steady or shifting. In addition to controlling sounds with the record-moving hand, the crossfader gives the DJ the option to produce alternative onsets and offsets. The kind of sound sample

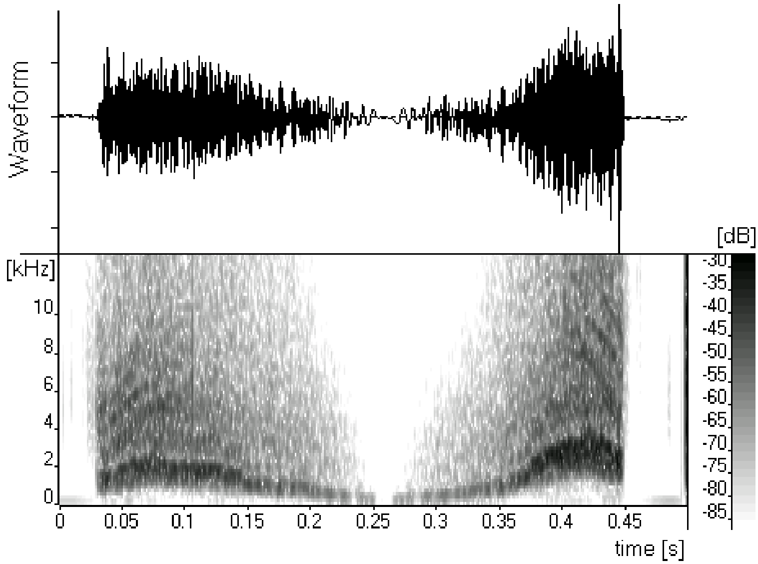


Figure 11.7: Waveform (upper panel) and spectrogram (lower panel) of simple forward and back motion, called baby-scratching

on which all variables are executed greatly affects the result.

Figure 11.7 shows the waveform and spectrogram of the sound being scratched. All the other figures presented in the following do not include the waveform plot, as the spectrogram contains all information about the interesting characteristics of the sound examples discussed here. Figure 11.7 is an illustration of a very simple scratch (this specific one will be explained as *baby-scratching*) similar to type (b) in Figure 11.5. The scratch is approximately 0.4 s long and can in traditional musical notation resemble two sixteenth notes at about 75 bpm (beats per minute). The original sound ("ahhh") has a noise band with a broad maximum, inducing the perception of some pitch. Arguably the first sixteenth has a broad maximum around 1200 Hz and the second sixteenth around 2400 Hz, or an octave higher, but it is hard to establish a definite tonal phrase because of the *glissando* effects that can be observed in the spectrogram in Figure 11.7. The first sixteenth starts abruptly when the sound cuts in (this is evident on the amplitude level figure), while the second sixteenth has a smoother attack with an increase of both frequency and amplitude.

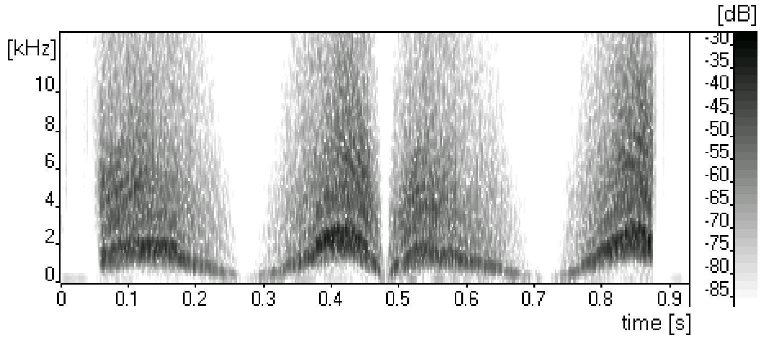


Figure 11.8: Spectrogram of two simple forward and backward movements.

Ending of tones can equally be divided into three categories, with the quick slowing down to a halt perhaps being the most interesting one. During a scratch performance, a big portion of the onsets and offsets come from directional changes of the record movement within the boundaries of a sound sample. Figure 11.8 shows a combination of movement type (e) followed by type (c) (see Figure 11.5), where the turns from going forward to backward are made just beyond the ending of the sound. The 0.8 s long scratch is built up by four sixteenth notes at 75 bpm. The first sixteenth has an abrupt attack, while the second and fourth sixteenths have a more smooth attack. The third sixteenth has a faster attack than the second and the fourth, but the sound is still achieved in the same way. The explanation of these differences lies in the speed of the turn of record direction. In the example in Figure 11.7, the turn when going from forward to backward movement is quicker than the turn when going from backward to forward again—the initial move from the body is faster than the initial move towards the body. All the endings except the last one are results of slowing down the record to change the direction, producing a fast drop in frequency.

The pitch we perceive from the broad maximum of the noise band is determined by the original recording and by the speed by which it is played back. Normally $33\frac{1}{3}$ rpm is used for scratching, but also 45 rpm. These numbers can be adjusted by a certain percentage in both directions depending on the product: a Technics affords a detuning of the rotation speed by at most 8% [224]. 8% creates a span of almost a musical major sixth (from $30\frac{2}{3}$ to $48\frac{3}{5}$ rpm, a factor of 1.58). Perceived pitch is most influenced by the playback speed on the sample caused by the hand movements. There are no musical restrictions

Figure 11.9: Different hand positions taken from a performance by DJ 1210 Jazz.

(i.e. tonally or melodically) to which audible frequencies can be used, and no concerns about preserving the original pitch of the source recording. For a 500 Hz tone to reach 15 kHz, however, playback at 30 times the original speed, or 1000 rpm, is required, which is impossible for a human DJ to accomplish. Different source recordings cover the whole frequency range, and may even exceed the pick-up's range.

Hand motion

Each DJ has a personal approach to moving the record, even though the aim is a well-defined technique. There seems to be an agreement among performers on how it should sound, but not so much on how it is accomplished. Since the record has a large area for positioning hands and fingers, and the turntable can be rotated and angled as preferred, the movements can be organized with great variety (Figure 11.9).

The characteristics of the hand movements associated with different types of scratches will be examined in a future investigation.

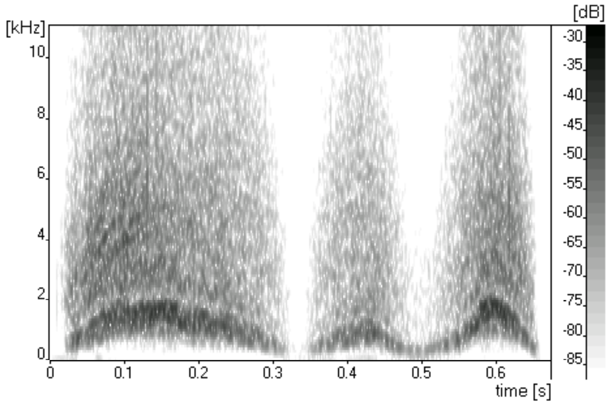


Figure 11.10: Spectrogram of tear-scratch.

Without crossfader

The most fundamental technique, also recognized as the first scratch, is done by pushing the record forward and backward, and without using the crossfader. When done in a steady rhythmical pattern of for example sixteenth-notes it is called *baby-scratch*. Movement types number (b) and (e) and the combination of (e) and (c) from Figure 11.5 are most frequent in baby-scratching. How fast the turntablist turns the record direction influences both attacks and decays. A long slowdown or start gives a noticeable glissando-like sound. In addition, the frequency-drop will make the listener experience volume decrease—this is thoroughly explained by Moore [179]. This evidence can also be extrapolated from equal loudness contours and *Fletcher-Munson* diagrams [75, 110].

Another fundamental technique is the *tear-scratch* that divides one stroke, usually the backstroke, in two separate strokes. The division is kind of a halt before returning the sample to the starting point. It is not necessary that the record stops entirely in the backstroke, but the fall in frequency and volume will give an impression of a new tone attack. Figure 11.10 shows how the simple division affects the sound.

Two techniques take advantage of a tremble-motion on the record. Tensing the muscles on one arm to perform a spasm-like movement is called a *scribble-scratch*. Dragging the record with one hand while holding one finger of the other hand lightly against the direction, letting it bounce on the record, make a stuttering sound called *hydroplane-scratch*.

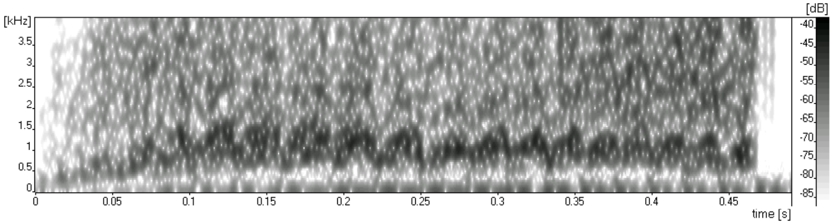


Figure 11.11: Spectrogram of hydroplane-scratch.

Both hydroplane- and scribble-scratches produce continuous breaks in the sound. On a spectrogram of a hydroplane-scratch, Figure 11.11, it is possible from the tops and valleys around 1 kHz to trace how the finger bounces on the vinyl. The slowdowns at a frequent rate, here about 30 per second, produce a humming sound. The broad maximum makes jumps of about 1 kHz in these slowdowns.

With crossfader

The volume controls can cut a sound in or out at will, which was also the technique behind the experiments of Pierre Schaeffer conducted during the early fifties [191]. He discovered that when removing the attack of a recorded bell sound, the tone characteristics could change to that of a church organ, for instance. Normally the turntablists let the crossfader abruptly cut the sound, in this way cutting the transition. The sound can easily be turned on and off several times per second, making the scratches sound very fast. This is probably one reason why scratching sounds so recognizable and inimitable. Some techniques are just baby-scratching with varying treatment of the crossfader. Others use longer strokes with quick crossfader cutting.

Forwards and *backwards*, *chops* and *stabs* all hide one of the two sounds in a baby-scratch, either the forward push or the backward pull. In *chirps* only two snippets of sounds are heard from a very fast baby-scratch. On every movement forward, the fader closes fast after the start, cutting the sound out, and going backwards only the last bit of the sound is included (cut in). At these points of the scratch, the vinyl speed is high and so the broad maximum of the noise band is high, 2 kHz in Figure 11.12. The drawn line, adapted from the baby-scratch spectrogram in Figure 11.7, shows the probable broad maximum curve of the forward and backward movement with 0.1 s silenced, hiding the

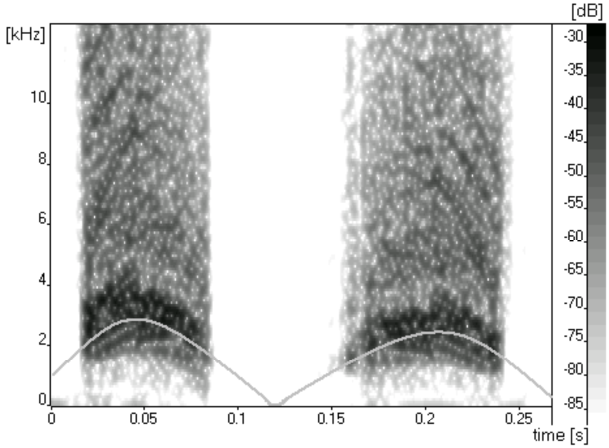


Figure 11.12: Spectrogram of chirp-scratch. The overimposed grey curved-line shows the assumed record movement.

change of record direction.

The most debated technique is the *flare*-scratch, with all its variations. Flaring means cutting out sound during the stroke, but discussions among the performers concern how many times and how regular these cuts should occur. In a relatively slow forward movement that starts with the sound on, the sound is quickly clicked off and back on by bouncing the crossfader between thumb and index finger. Various flares are given names based on the number of such clicks. A *2-click flare* is one stroke with two clicks, or sound-gaps, producing a total of three onsets. An *orbit* or *orbit flare* is the same type of scratch on both forward and backward strokes. In a *2-click orbit flare* there will be a total of six onsets; three on the forward stroke, one when the record changes direction and two on the backward stroke. The flaring-technique generates many other techniques.

Twiddle and *crab* further take advantage of the possibility to bounce the light crossfader between thumb and other fingers, making a rapid series of clicks. The superficial similarity with the *tremolo* in flamenco-guitar is evident. Figure 11.13 comes from a twiddle, where the index and middle fingers on the left hand thrust the crossfader on the thumb. The short gaps are easily audible even in a very short scratch.

Because the numerous clicks are done in one single stroke, the frequency

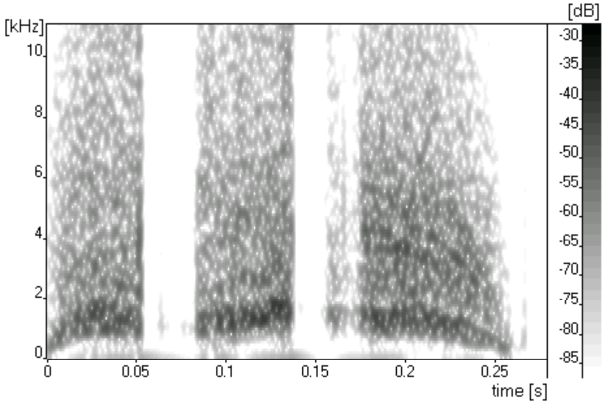


Figure 11.13: Spectrogram of twiddle scratch.

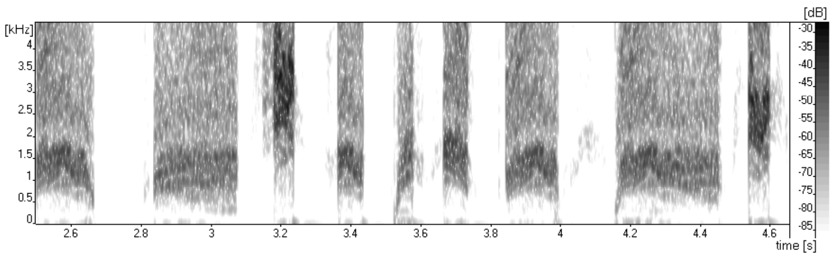


Figure 11.14: Spectrogram of transformer-scratch.

of each attack or tone will be quite stable. Roughly speaking, *flutter-tongue* playing on brass instruments and flutes produces a similar sound [175].

The old technique called *transformer*-scratch is often compared to strobe lights, as the crossfader is pushed on and off fast and rhythmically during relatively long and slow strokes, or even at original playback speed. Now *transforming* is often performed with varying but simple rhythmical patterns on the crossfader, and thus controlling the record speed can be given more attention. Transforming generally attains greater tonal variety than the techniques where the main musical purpose is producing short tones by rapid fader clicks, as, for instance, it happens in the twiddle-scratch. Figure 11.14 shows a spectrogram of a typical transformer-scratch section.

11.2.4 Discussion: Relevance in music

Techniques are seldom played individually for longer periods; conversely they are blended and intertwined for greater expression and musical substance. For instance, it might be difficult to distinguish one technique from the other during a two-click flare-scratch and a twiddle-scratch in succession. Indeed, the turntablists do not want to emphasize this. Rather, they often refer to the different playing styles and scratch solos in terms of *flow*, which, considered as a whole, seems to be more important than the components. Mastering one single scratch should be compared to mastering a scale (or, rather, being able to take advantage of the notes in the scale during a performance) in tonal improvisation. Without the sufficient skill, complicated patterns will not sound good at least to experienced and trained ears. Aspiring DJs, like all other musicians, have to devote hours to everyday training to get the right timing.

11.3 Experiment 2 - Analysis of a genuine performance

11.3.1 Introduction

In order to acquire knowledge about how scratching is performed and how it works and behaves musically, an analysis of several aspects of playing was necessary. Results from this analysis can be used as a starting point for implementing future scratch-models. By only looking at the individual technique taken from the musical context, it is easy to get an impression of scratching as a clean and straightforward matter to deal with. This is not always the case. Techniques are not often played individually, but rather shortened, abrupted, and mixed one with the other. Also many gestures are not necessarily classified as valid techniques, but as variations or combinations of existing ones.

11.3.2 Method

In the DJ 1210 Jazz recording sessions eight performances were executed, all of which without a backing drum track. Since 1210 Jazz is an experienced performer, the lack of backing track was not considered a restrictive or unnatural condition even though scratching often is performed to a looped beat.

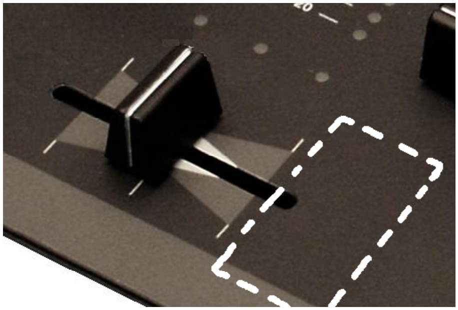


Figure 11.15: Potentiometer set-up with top and lateral views of the turntable.

Equipment

A potentiometer was used to track the vinyl movement. The $3\frac{3}{4}$ rounds 10 kOhm potentiometer was mounted to the vinyl with the help of a stand, and a cylinder attached to the record center. The output was recorded by a multichannel DAT. The potentiometer was chosen based on how easily it turned. No effect could be noticed in the performance and friction on the vinyl when it was attached, and the DJ felt comfortable with the set-up. See Figure 11.15.

Modern mixers give the DJ the opportunity to change the fading curves of the crossfader. To get a reliable signal we decided to find the slider position from reading the output voltage, not the physical position. Two cables connected from the circuit board to the multichannel DAT recorder tracked the slider movement, but not automatically the sound level. The crossfader run is 45 mm, but the interesting part, from silence to full volume, spans only a distance of 2-3 millimeters, a few millimeters away from the (right) end of the slider run. Because the crossfader did not respond as the DJ wanted to, he glued a credit card to the mixer, thus shortening the distance from the right end to where the crucial part (the so-called cut-in point) is located (see Figure 11.16). Positioned to the right, the crossfader completely muted all sound, and it let through all sound when moved a few millimeters (to the left).

Only the right channel of the stereo sound output signal was recorded to the multichannel DAT, but that was sufficient for evaluating the record movement output against the sound output. The original sound from the record had no significant stereo effects, and both right and left channel appear similar.

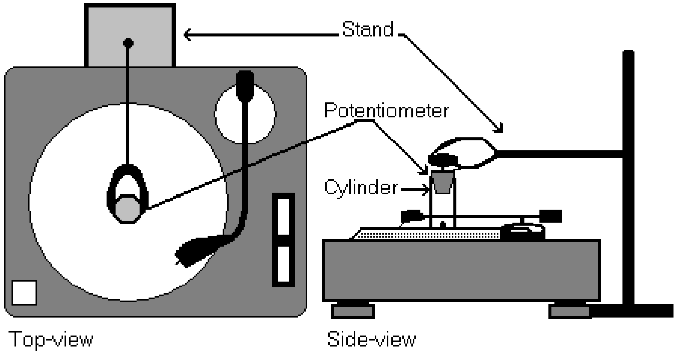


Figure 11.16: Crossfader adjustment. The white stapled-square marks the position occupied by a credit card used to shorten the slider range.

Calibrations

Both the crossfader and the potentiometer had to be calibrated.

To read the approximate sound output level from the position of the crossfader, every millimeter position was mapped to a dB level. A problem occurred as the slider had some backlash (free play in the mechanics). By using two different methods, both with step-by-step and continuous moving of the crossfader, the sound levels on a defined sound (from a tone generator) could be found and used as calibration for the output level. See Figure 11.17.

The potentiometer had a functional span of about 1220° or $3\frac{1}{2}$ rounds. Unfortunately it was not strictly linear, but we succeeded in making a correction to the output values so that the adjusted output showed the correct correspondence between angle and time. See Figure 11.18.

The dotted line in Figure 11.18 is the original reading from the potentiometer doing 3 rotations in 6 seconds, using the same method as for calibrating the turntable mentioned earlier. The dashed line is the correction-curve used to calibrate the readings. The solid line is the corrected original signal later applied to all recordings. The voltage was adjusted to rounds, expressed in degrees.

Material

The DJ was asked to play in a normal way, as he would do in an ordinary improvisation. He was not allowed to use other volume-controllers than the

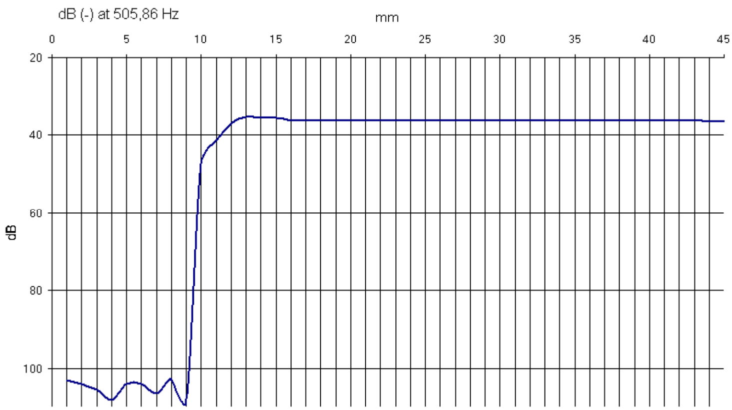


Figure 11.17: Crossfader calibration. The X axis shows the whole travelling distance of the slider in mm.

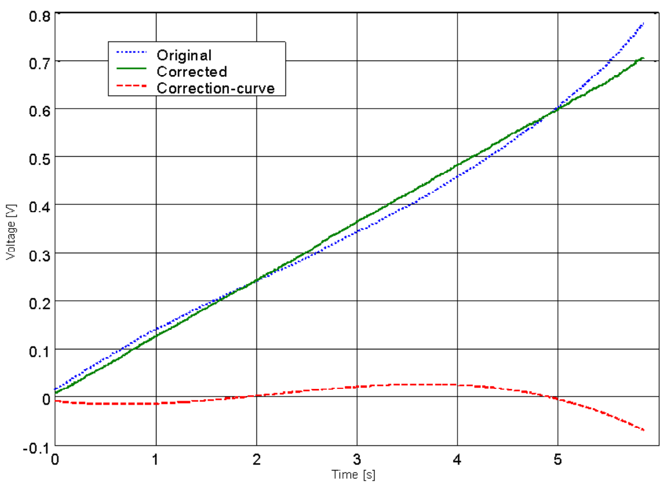


Figure 11.18: Calibration of potentiometer.

crossfader, but as the crossfader is by far the most used control during in a performance, and the other controllers are used to achieve the same sounding results, this does not affect the experiment. The performances from that session were by all means representative examples of improvised solo scratching with a clearly identifiable rhythmic structure; one of those examples is used here. 30 seconds of music were analyzed. All sounds were originated from the popular “ahhh” sound from “Change the beat” [81]. This sampled part is found on most battle-records, including the 1210 Jazz [125] record we used.

The analysis was done on the basis of three signals; the crossfader, the record movement and a waveform of the recorded sound, and for comparison even the audio track. Comparisons with previous recordings of the separate techniques provide valuable information on the importance of these techniques.

We decided to describe the music in terms of *beats* and *bars* in addition to looking at time. This description necessarily calls for interpretations, and especially at the end of the piece it is questionable if the performance is played strictly metrically or not. In this analysis, however, that is a minor concern. With our interpretation the piece consist of 12 bars in four-fourth time. The tempo and rhythm is fairly consistent throughout with an overall tempo of just under 100 beats per minute. Figure 11.19 shows an excerpt of the readings and illustrates how the structuring in beats and bars was done. The upper panel is the low pass-filtered signal from the crossfader in volts, the middle panel is the audio signal and the lower panel is the potentiometer signal in degrees. This excerpt is from bar 7.

11.3.3 Measurements outline

Vinyl movement

One of the things we wanted to measure was the movement of the vinyl record itself without considering the turntable platter or motor. The slip-mat, placed between the platter and the record, reduces friction depending on the fabric and material. For these measurements the DJ used his preferred felt slip-mat, which allowed to move the record quite effortlessly regardless of the platter and motor movement.

Crossfader movement

The second element we measured was the movement of the crossfader. To get a reliable signal we measured it directly on the circuit board.

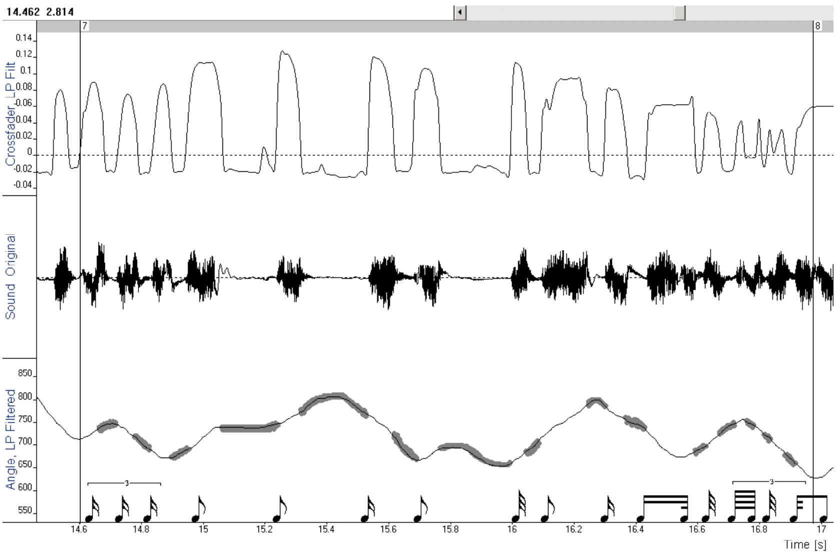


Figure 11.19: Bar 7 transcribed to musical notation. The grey areas mark where the crossfader silences the signal. The upper panel is the low pass-filtered signal from the crossfader in volts, the middle panel is the audio signal, and the lower panel shows the rotation angle in degrees.

Sound output

The third signal we recorded was the sound output from the manipulated record. In order to let the musician play in a realistic manner he was allowed to choose the sound to work with.

11.3.4 Analysis

In the following analysis some key elements will be considered; namely the work with the vinyl in terms of directional changes, angles and areas, speed and timing; the activity on the crossfader and the volume; the occurrences of predefined techniques; and finally the occurrences of different kinds of patterns. The three variables considered in the measurements are: (1) crossfader movements, (2) record movements, and (3) associated sound signal.

Sounding directional changes

Sound is obtained from scratching by moving the record forward and backward. This implies that the record will change direction continuously during playing. Directional changes can be grouped in three categories:

- changes which are silenced with the crossfader;
- silent changes, where the change happens outside a sound;
- changes where the sound is heard, here called *turns*.

Turns can be further categorized in terms of *significant* and *insignificant* turns, according to how well we can hear the directional change.

A significant turn will produce the attack of the next tone. An insignificant turn appears when only a little part of the sound from the returning record is heard, either intentionally or by imprecision, also producing a kind of attack (although less audible).

The record direction was changed 135 times, in average 4.5 times per second. Of such changes, 21.5% were heard: 18.5% of them were significant turns; 6% were insignificant. A technique like *scribble* would influence this result considerably, as it implies fast and small forward and backward movements (about 20 turns per second) with sound constantly on. This excerpt had two instances of short *scribble*-scratches, representing 36% of the significant turns. It seems that in a normal scratch-improvisation (at least for this subject), about 70-90% of the directional changes are silenced.

Further investigation is needed to explain why so many directional changes are silenced. More data from other DJs needs to be collected and analyzed. However, one possible reason could be that the characteristic and recognizable sound of a record changing direction is no longer a desirable sound among DJs wanting to express themselves without too much use of clichés. These characteristic sounds are typically associated with the early, simple techniques.

Angles and area

The length of a sample naturally limits the working area on the record for the musician, and moving the record forward and backward can be made difficult by the turntable's tone-arm. About a quarter of the platter area is taken up by the tone-arm in the worst case. Big movements are difficult to perform fast with precision, resulting in a narrowing down, as the technical level evolves, to an average of about 90° (although not measured, recordings of DJs from mid-eighties seem to show generally longer and slower movements). We consider long movements those that exceed 100°. A little less than 50% were long movements.

The occurrence of equally long movements in both directions was quite low, about 30% of the pairing movements covered the same area. Only 25% of the forward-backward movements started and ended on the same spot.

Issues concerning rhythm and timing

An attempt to transcribe the piece to traditional notation will necessarily mean that some subjective decisions and interpretations have to be made. Nevertheless, some information can be seen more easily from a musical analysis. This transcription allows an analysis of timing in relation to the various scratching techniques, by looking at both the record and the crossfader speed and their relation to the corresponding waveform.

Speed

About half of all movements, both forwards and backwards, were done slower than the original tempo in this recording. The backward moves were often performed faster than the forwards moves (33% compared to 26%). Due to different factors, as inertia and muscle control, and the fact that scratching implies a rounded forward and backward stroke, it is hard to perform a movement with constant speed. Hence, most of the movements have unstable speeds and do not result in straight lines appearing at the potentiometer output.

Sound position

Even though a DJ has a great control over the record position, in this helped also by visual marks such as colored stickers, nevertheless a minor inaccuracy can affect the result greatly. 1210 Jazz had only one sound (and position) to focus on, so he did not make any serious mistakes resulting in unexpected attacks or silences. The sound sample was also quite simple to deal with. With continuous change of sound samples, or with sharper sounds such as drumbeats and words with two or more syllables, this issue becomes more problematic.

Crossfader

This analysis did not distinguish extensively between crossfader movements done with the hand or by bouncing with the fingers, but some evident cases can be pointed out. It is likely that the crossfader should be left open for performing a number of certain techniques, but the longest constant openings in this performance had durations which were shorter than half a second. The crossfader was turned or clicked on about 170 times in 30 seconds (more than 5 times per second). The total amount of sound and silence was approximately equal.

53.3% of the draws had one sound only, and 11.8% of the draws were silenced. Among the remaining draws, 24.4% had two sounds, 6.6% had three sounds and 3.7% of the draws had four separate sounds. Multiple sounds per draw were distributed quite evenly on backward and forward draws, except for the five draws carrying four tones; all were done on the backward draw.

Techniques

The aesthetics of today's musicians roots in a mutual understanding and practice of attentively explained techniques. However, the improvising does not necessarily turn out to be a series of well-performed techniques. So far, research on scratching has considered the performing techniques separately. A run-down on which techniques are used in this piece clearly shows the need for a new approach considering the combination of techniques and basic movements. All recognized techniques are here associated to the bar number they appear in. The duration of a bar is approximately 2.5 s, i.e. the DJ played with a tempo of about 96 bpm.

Forwards appear in the same position in almost every bar. There are 9 *forwards* in 12 bars; 7 land on the fourth beat (in bars 1, 2, 3, 4, 6, 10 and 12) and 2 *forwards* land on the first beat (in bars 6 and 9). All *forwards* on the fourth beat are followed by a pickup-beat to the next bar, except for the last *forward*.

Tear-like figures occurred from time to time when the sound was clicked off during the backward draw, but they do not sound as *tears* because the breakdown in the backward draw was silenced. 3 of these *tear*-likes are executed, in bars 6, 10 and 11. Normally, several *tears* are performed in series, and the sound is left on all the time. None of the *tears* here were clean in that sense, or perhaps even intended to be *tears*.

Chops normally involve a silenced return. Prior to 10 silences, a *chop* was performed. It happened in bars 3, 4, 5, 7, 8 and 11. A *chop* can be followed by another technique (but the whole forward move is used by the chop) as it happened during the experiment in bars 5, 7 and 11.

Stabs and *drags* are similar to *chops*, but performed with more force (faster).

They both appeared in bar 8. Many movements (35%) had a swift crossfader use. There are two states of crossfader position during scratching: With the sound initially off, sound is temporarily let in; conversely, with the sound initially on, the sound is temporarily cut out. Main techniques of sound-off state are different *transform*-scratches, while *chirps*, *crabs* and especially *flares* are typical for sound-on state. Sound-on state should give more significant turns. Most of the significant (and insignificant) turns happened with variations on the *flare* scratch.

Some common techniques were not found in the recording of the performance under analysis, including *baby*, *hydroplane*, *chirp* and *tweak*. The reasons for this could be many; *baby* scratching will often seem old-fashioned while *tweaking* can only be performed with the motor turned off, so it is more demanding for the performer to incorporate it in a short phrase. The absence of *hydroplane* and *chirp* can be explained as artistic choice or coincidence, as they are widely used techniques.

Patterns

Some movements and series of movements are repeated frequently. Patterns are not considered to be valid techniques, and they are not necessarily so-called "combos" either. A combo is a combination of two or more techniques, performed subsequently or simultaneously.

Often a significant turn was followed by a silenced change and a new significant (or insignificant) turn in the experiment. This particular sequence was performed 6 times (in bars 1, 4, 6, 11, 12).

In the performance analyzed only 5 long (more than 100°) forward strokes were followed by another long forward stroke, and there were never more than 2 long strokes in a row. On the backward strokes, long strokes happened more frequently. 16 long strokes were followed by another long stroke; on three occasions 3 long strokes came in a row, and once 6 long strokes came in a row.

No forward stroke was silenced, while 16 backward strokes were silenced with the crossfader. As the *chop* technique involves a silenced return, this technique was often evident around the silences.

Two bars, bars 4 and 5, started almost identically, the major difference is that bar 4 had a *forward* on the fourth beat while bar 5 had a *chop* on the third offbeat.

Twin peaks

One returning pattern was a long forward stroke with a slightly shorter backward stroke followed by a new long forward stroke (shorter than the first) and the backward stroke returning to the starting point. This distinctive sequence looks in the record angle view like two mountain peaks standing next to each other, the left one being the highest, and as it returned 8 times in 30 seconds in this experiment, it was for convenience named *twin peaks*[3].

The *twin peaks* pattern was repeated 8 times with striking similarity. The first peak was the highest in all cases, ranging from 100° to 175° (132.5° in average) going up, and from 85° to 150° (120° in average) going down. The second peak ranges from 50° to 100° (77.5° in average) going up, and from 75° to 150° (128.75° in average) going down. All had about 10 crossfader attacks (from 7 to 11), and more on the second peak than the first. The second peak was always a variant of a *flare* scratch. The 8 *twin peaks*-patterns take up almost one third of the performance in time.

11.3.5 Discussion

The division and structuring of the recording into bars reveals that the techniques are used taking into account timing and rhythmical composition, such as fourth beats. For a better understanding of musical content in scratching, more recordings should be analyzed as only 12 bars and one subject do not suffice for formulating general conclusions.

11.4 Experiment 3 - Wearing of the vinyl

This experiment is a quite simple test to find the extent of wearing on a vinyl record used for scratching. During the first minute of scratching, a record groove will be drastically altered by the needle and start carrying a broad white noise signal.

11.4.1 Method

On 1210 Jazz's record [125] there is a set of sounds from Amiga and Commodore 64 games. One of these sounds, with a bright flute-like character, has

[3]After the TV-series by David Lynch called "Twin Peaks", with a picture of a mountain in the opening scene.

a fundamental frequency at 600 Hz and a harmonic spectrum (harmonics at n·F0). This sound is repeated on the record in a short rhythmic pattern with small silent gaps.

On the very first playback of the record, high-end equipment was used to ensure highest possible quality. Second playback was done on the equipment used in the experiments, but with a brand new scratch needle. Third playback, which is used as reference in this paper, was made with the same needle after a few weeks of use (which should mean the needle is in close to perfect condition). After playing back the short segment of the record at normal speed, the record was dragged forward and backward over the sound for one minute, and then the segment was played back at normal speed again. The forward and backward movement was done none-expressive at a constant speed and with approximately 2 cm run on each side of the point on the record. This procedure was repeated over and over, so the final test covers 15 minutes of scratching (dragging the record forward and backward corresponds to normal scratch movements) and 15 playbacks of the same sound in different stages of wearing. All playbacks and scratching was recorded in stereo to DAT at 44 kHz sample rate.

Noise from the equipment

The noise coming from the equipment (especially the hum from mixer and turntable) is about 10 dB lower up to 4 kHz than the total noise emitted from a blank place on the record and the equipment. Figures 11.20 and 11.21 show the noise level from the record and the equipment with the first axis cut at 22 kHz and 6 kHz respectively.

11.4.2 Results

The following figures show a selection of the spectrograms and line spectrum plots that were taken from every minute of the recording. Deterioration happens gradually, but only the most illustrating events are included here.

Spectrograms

Figure 11.22 show the original sound with surrounding silence before the scratching begins, and after 1 , 2 and 15 minutes of scratching. After one minute of dragging the record forward and backward, the signal clearly has

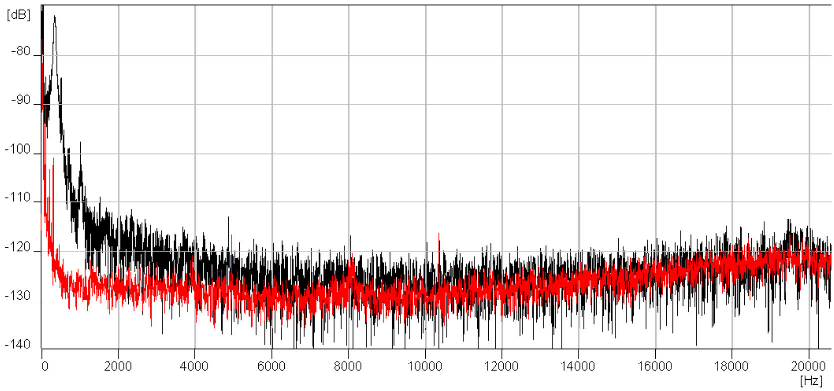


Figure 11.20: Noise levels of recording (upper plot) and equipment (lower plot).

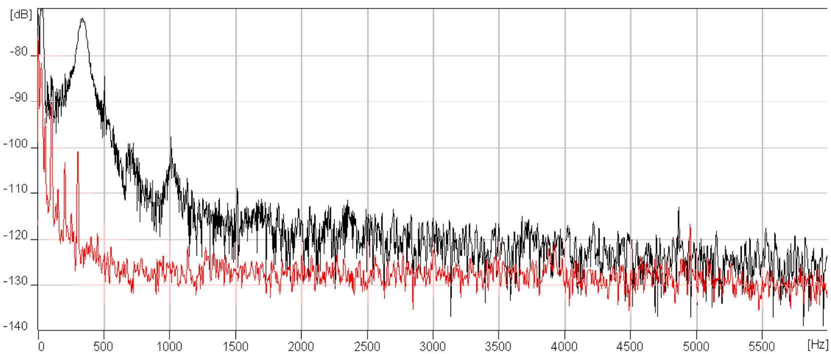


Figure 11.21: Noise levels of recording (upper plot) and equipment (lower plot) up to 6 kHz.

deteriorated. Even the silent parts on each side of the sound signal start to carry a noise signal.

After 2 minutes of scratching, Figure 11.22, the whole surrounding silent part carries the noise signal. The broad noise band seems to a have higher level of energy between 2 and 6 kHz. The upper harmonics (from the fourth harmonic upwards) that could still be seen reasonably clearly after one minute are from now on masked in the noise signal.

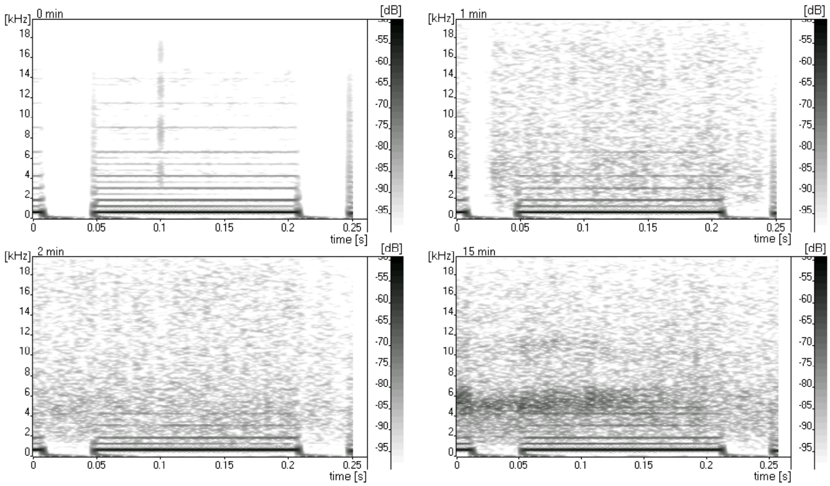


Figure 11.22: Spectrogram of the tone and surrounding silence after 0, 1, 2 and 15 minutes of scratching.

No big changes are detected at the following one-minute intervals until around the twelfth minute. After that, the tendency from the second minute spectrogram in Figure 11.22 of a stronger noise band between 2 and 6 kHz shifts toward being a narrower noise band (approximately 1 kHz) around 5 kHz.

After 15 minutes of scratching (Figure 11.22), the appearance of a narrower noise band is more evident. Below 2 kHz, however, not much happens to the original audio signal and the first two harmonics are strong.

Line spectrum plots

In the line spectrum plots in the following, only the pre- and post-scratching state (0 respectively 15 minutes) are considered. Line spectra taken before (Figure 11.23) and after (Figure 11.24) scratching show the same segment on the record. The harmonic peaks have approximately the same power, but a broad noise band is gaining strength.

The noise signal is more than 20 dB stronger after 15 minutes of scratching, which result in a masking of the harmonics above 5 kHz. From the last spectrograms it seems that the wearing generates louder noise between 4 and 6 kHz. This noise band may be perceived as being part of the sound, especially

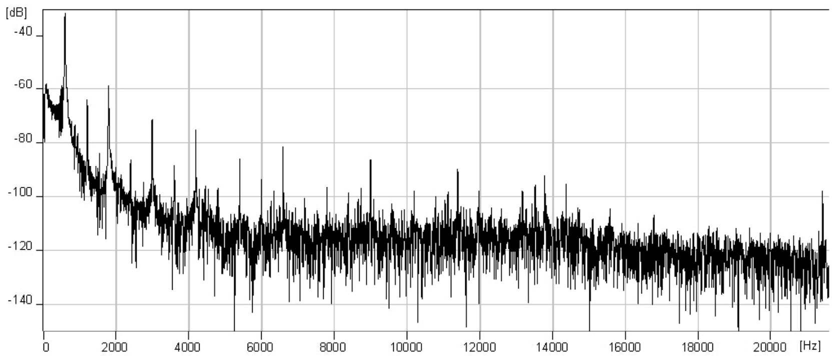


Figure 11.23: Line spectrum of the tone after 0 minutes of scratching (0-20 kHz).

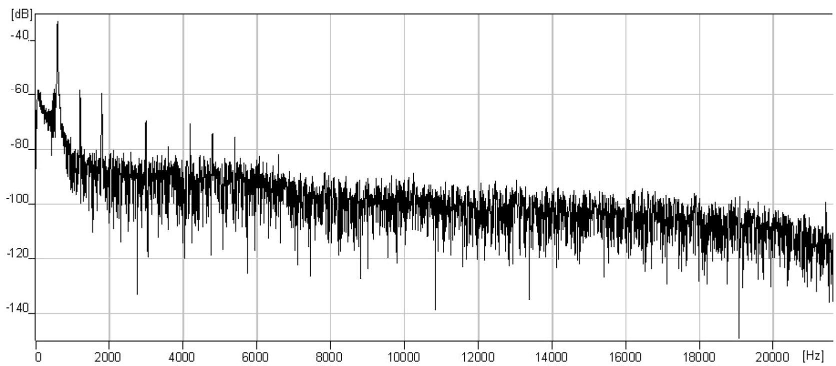


Figure 11.24: Line spectrum of the tone after 15 minutes of scratching (0-20 kHz).

with standard scratch sounds as “ahhh”.

The silent parts

The most interesting issue is the constant level of noise that will mask the audio signal, and the best place to look at the level and appearance of noise is in the silent parts surrounding the audio signal. The following line spectrum plots of silence before and after scratching illustrates to what extent the needle

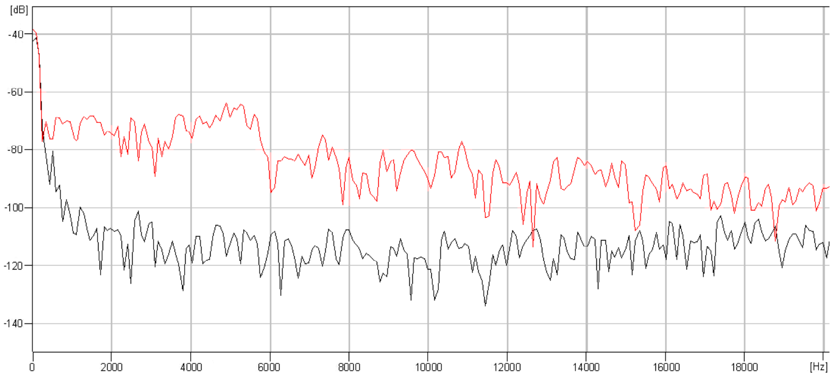


Figure 11.25: Line spectra of the silent part before (lower plot) and after (upper plot) scratching.

damages the vinyl record.

Silence is also affected when tearing down the grooves, in the sense that silence is replaced by a noise signal. Figure 11.25 shows the line spectra of the small silent gaps seen in Figure 11.22. Because the gap was short, less than 30 ms, a high bandwidth had to be chosen for the analysis. It seems that the noise is about 40-50 dB louder after 15 minutes for frequencies below 6 kHz, and about 20-30 dB louder for frequencies above that.

11.4.3 Discussion

As noise seem to be generated in the groove already during the first minute of scratching, it seems unnecessary to consider a signal to be noiseless and perfect, at least if the level of realism strived for is that of vinyl being manipulated. A thing like a 'clean' signal will never be an issue in real scratching, which maybe also gives scratching its characteristic sounds. This same noise that appears in real performances can be implemented in a model for scratching, and maybe prove helpful in masking audible errors connected to resampling, which is often a problematic concern in today's models.

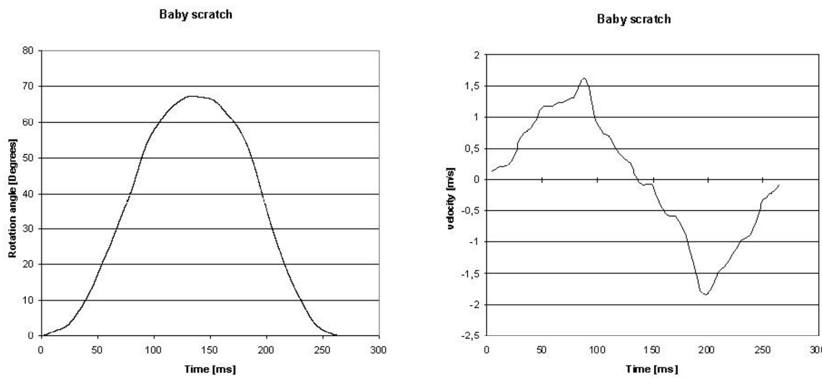
11.5 Design issues for a control model for scratching

Considering the analysis from experiment 2, a scratch simulator must include a volume on/off function, as almost none of the scratches are performed with the volume constantly on. There is no need to be able to control bigger scratch areas than 360°, and 180° should be easily controlled. Probably a touch sensitive pad could be efficient for controlling the vinyl part. These are fairly inexpensive and have advantages compared other controllers. Finding some controller to match a real turntable will perhaps prove difficult and expensive due to the strong motor, heavy platter and the inertia.

To simulate the record playing, the sample to scratch should be looped. A sample prepared to be altered from a standstill state does not correspond to any real scratch situation, the closest would be a comparison with *tweak*-scratching, where the motor of the turntable is turned off, but then the platter spins easily with low friction. Many simulators today have the standstill approach. When the sample is running in a loop, a mouse may be used for dragging the "record" forward and backward. It will not feel much like scratching for real, however, as you have to press the mouse button on the right place on the screen and move the mouse simultaneously. Even if the ability to do this smoothly and efficiently can be trained, there are hopefully better ways. A touch sensitive pad is more suited to this task than both keyboards and mice. Since it registers touch, hold-down and release, it can be programmed to act as the vinyl would upon finger touch; a finger on the vinyl slows down the record easily to a halt without too much pressure, and the same can be achieved with touch sensitive pads.

From the analysis and data of the two first experiments a model of scratching was built using `pd`[4]. The readings of the potentiometer and the crossfader recorded in experiment 1 were used to control an audio file. By first using the output from the potentiometer to change the sample-rate of the audio file that was played back, and then using the output from the crossfader circuit board to change the playback volume level, we successfully resynthesized the few techniques we tested on. 3 techniques involved record movement only; *baby*, *tear* and *scribble*, while 2 techniques, *chirps* and *twiddle*, also involved crossfader movement. In the following, the measurements of these 5 techniques are analyzed in detail and some algorithms for their simulations are proposed.

[4]Pure Data, or `pd`, is a real-time computer music software package written by Miller Puckette (http://pure-data.org).



(a) (b)

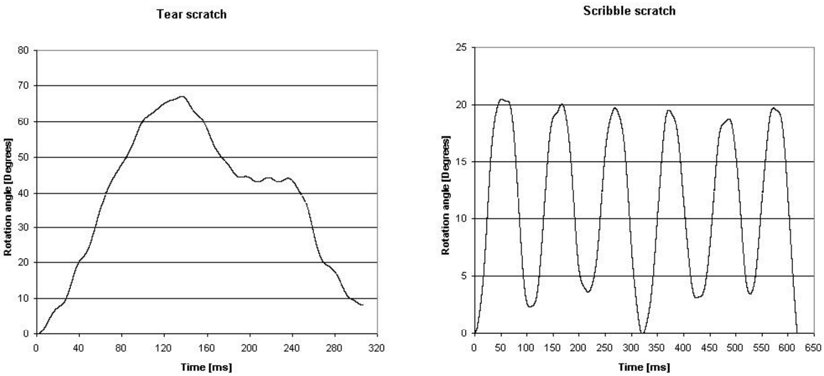
Figure 11.26: Baby scratch: rotation angle of the record during one cycle (a); velocity of the record during one cycle (b).

11.5.1 Baby scratch model

An analysis of the data related to one baby scratch cycle (see Figure 11.26) shows that the DJ moves the record forward and backward to its starting position ($0°$ in Figure 11.26a) in about 260 ms. The track used for the experiment was positioned at a distance of 9 cm from the center of the record. Thus it was possible to calculate the distance travelled by the record and the velocity of the record itself (Figure 11.26b). The velocity of this movement has the typical shape of target approaching tasks [74]. In the DJ pulling action, the velocity reaches its maximum when the record has travelled a little over half of the final distance, then velocity decreases to 0 value when the DJ starts to push the record forward. During the pushing action, the record increases in velocity (see the negative values of Figure 11.26b) in a shorter time than in the pulling phase. It thus reaches maximum velocity before having travelled through half the distance covered in the pushing action.

11.5.2 A general look at other scratching techniques

The Same observations and measurements can be done for the other scratching techniques taken in consideration in Experiment 2. In the following only the signals produced by the sensors are shown for each scratching type.



(a) (b)

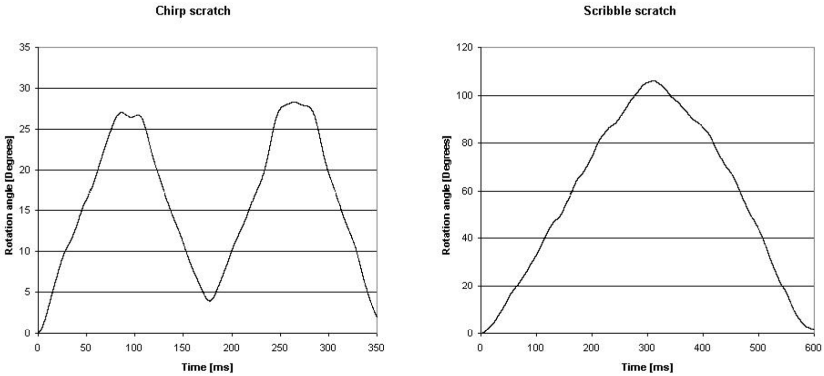
Figure 11.27: Tear scratch: displacement of the record during one cycle (a). Scribble scratch: displacement of the record during six cycles (b).

Both *chirps* and *twiddle* scratch models use *baby* scratch as the basic movement as do most scratches where the crossfader is the main feature. Still the record movement varies from the simpler *baby*.

11.5.3 Existing scratching hardware and software

Expensive equipment and hard-to-learn playing techniques are motivations for developers of turntable-imitating hardware and software. Several scratch simulators have emerged during the last ten years, but none have so far proven to be successful among the professionals. This is about to change, and one of the promising products today is the scratchable CD players that simulate record players by playing the CD via a buffer memory. This memory can be accessed from a controller. In the early stages of scratch CD players this controller was in the shape of a jog wheel, now it often is a heavy rubber platter that can freely be revolved. Recent models have a motor that rotates the rubber platter at an adjustable speed, making it resemble turntables even further. Buffer memory and scratch pad controllers are used for other media formats such as MP3 and MiniDisc as well.

The turntable itself is also used for controlling a buffer memory, either by attaching sensors or using the signal from the record. For the latter, standard pick-ups can be used, but the record signal must be specially coded. Attaching



(a) (b)

Figure 11.28: Chirp scratch: displacement of the record during two cycles (a). Twiddle scratch: displacement of the record during one cycle (b).

sensors to turntables has not yet been implemented in commercial products.

Software for performing scratching, often simulating turntables or making virtual turntables, is interesting above all for its low expenses and high versatility. The controllers are standard computer input devices or MIDI, but customable.

The game industry develop both simple and advanced applications and accompanying hardware that profit from the popularity of scratching. A common ground for all of this hardware and software, from the simplest on-line Flash-wave game to the coded vinyl records, is the turntable. The inclusion of a crossfader-like volume manipulator should seem to be obvious, but so far it has not been dealt with satisfyingly.

11.5.4 Reflections

It is not obvious to see whether models of scratching will hold a comparison to vinyl technology. All simulators have in common their digital approach, which is quite natural, but there are benefits and catches with vinyl that are either overlooked or even sidestepped. One specific example of a vinyl-typical feature is the deterioration of the vinyl; a few minutes of dragging the needle continually over the same spot on the record has devastating consequences for the sound quality, and quoting experiences of DJs, the needle even responds differently to movement over that spot. CD players will not wear out grooves the same way a record player does, and this might take the edge off a sound the same way a producer in a recording studio can polish a rough performance to the nearly unbearable.

To simulate every aspect of the turntable, the vinyl, the needle *and* the more remote aspects like wearing, will probably turn out to be the only suitable option for making an acceptable replacement for today's instrument set-up. An approach built on physics-based modelling technique seems therefore appropriate and worth to experiment with in the future [206].

Arguably, the most characteristic quality in scratching is the big range of recognizable and universally agreed-upon playing techniques. Future research can reveal interesting issues regarding these. Also, technology aiming to replace the turntable should take into consideration the role and practises of scratch techniques. The techniques and characteristics of the hand movements associated with different types of scratches will be examined in future investigations.

11.A Appendix

The measurements conducted in the experiments reported in chapter 11 were used for the design of a model of scratching. The environment for this model is `pd`[5]. Sound models of friction sounds can be controlled by the scratch software, but it can also control recorded sounds in the same manner as turntables. The `pd` patch is open and customizable to be controlled by various types of input devices. We have tested the patch with both recorded sounds and physically modelled friction sounds, and we have controlled the model by use of computer mice, keyboards, MIDI devices, the Radio Baton, and various sensors connected to a Pico AD converter[6].

[5]Pure Data http://pure-data.org.

[6]Pico Technology. The ADC-11/10 multi channel data acquisition unit, http://www.picotech.com/data-acquisition.html.

11.A.1 Skipproof - a pd patch

Skipproof[7] has three main functions. It is an interface for manipulating the playback tempo of a sound-file by using a computer input device, and it is an interface for triggering models of single scratching techniques. With these two functionalities, Skipproof acts as both a virtual turntable and a scratch sampler/synthesizer. In addition, the output volume can be controlled manually or by the models of scratching as a significant part of some of the techniques. With this third functionality, Skipproof also simulates the scratch audio mixer.

Method

In addition to pd, Skipproof uses a GUI front-end program written for pd, called GrIPD[8]. pd processes all sounds, and GrIPD controls the different options made possible in pd.

Material

The sounds manipulated in Skipproof are 16 bit 44.1 kHz and 88.2 kHz mono wave-files, but other formats should easily be supported. Sounds, or 'samples' in analogy to DJ-terms, are meant to be 1.6 s long in order to imitate a real skip-proof record, yet there is no restriction to the length.

Apart from direct manual "scratch control" of a sound-file, it can be accessed via recorded scratch movements. These recordings originate from the measurements reported in the presented experiments.

Control concepts

Skipproof can be controlled by different sensors and hardware, and is easy to adjust to new input objects. Sensors, MIDI input and computer inputs (keyboard and mouse) are used both to trigger the scratch models and manipulate the virtual turntable and audio mixer.

[7] The name Skipproof is taken from a feature found on DJ-tools records called a skip-proof section, where a sound (or set of sounds) are exactly one rotation long and repeated for a couple of minutes. If the needle should happen to jump during a performance, chances are quite good that it will land on the same spot on the sound, but in a different groove. The audience must be very alert to register this jump.

[8] GrIPD, or Graphical Interface for Pure Data, is written by Joseph A. Sarlo (http://crca.ucsd.edu/~jsarlo/gripd/).

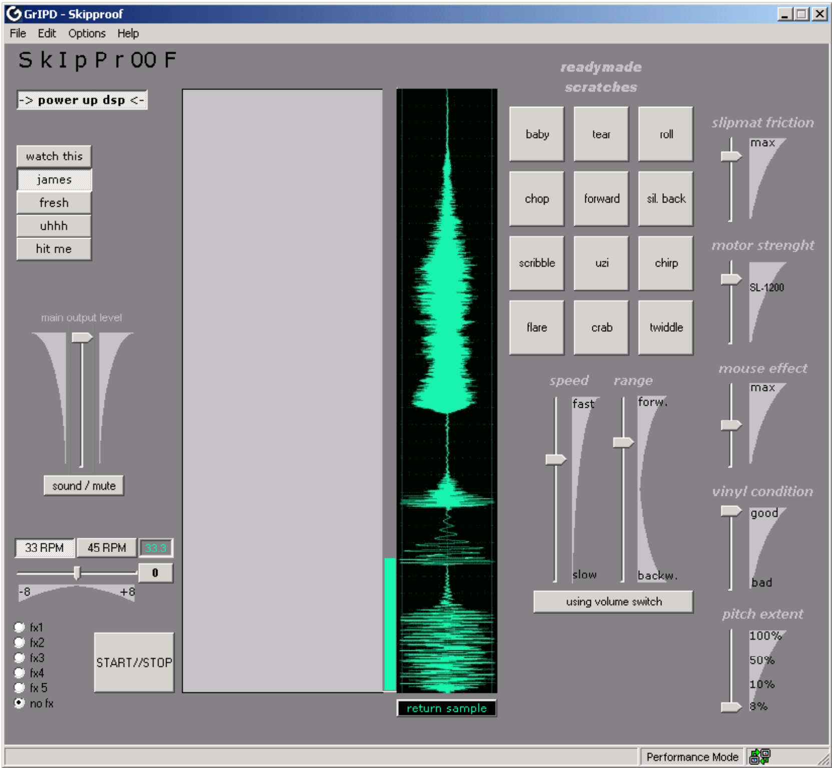


Figure 11.29: Graphical interface for Pure Data, `GrIPD` with turntable and audio mixer controls.

Implementation

In the following, selected screenshots from the `pd` patch will be commented, explaining briefly how Skipproof is designed. `pd` allows the user to build complex patches with sub-patches and references to other patches. Skipproof is built up by many subpatches that send and receive control signals from and to one another.

`GrIPD`

Figure 11.29 shows the performance window in Skipproof. One main focus designing the graphical interface was to some extent copy a turntable and a mixer. There are also a number of other buttons and sliders not found on the standard hardware, enabling the DJ to change parameters of, amongst others, motor strength. The user will not have to open any other window than this interface just to play.

Turntable and mixer

The large light grey rectangle in Figure 11.29 is the part that registers mouse action (when left mouse button is held down). The meter next to the grey area displays sound progression marked with each quarter round (90°, 180°, 270° and 360°). Around this 'vinyl record part' all the standard turntable buttons are collected; start/stop, two buttons for toggling 33 and 45 rpm, and a pitch adjustment slider. On a turntable there is also a power switch that lets the platter gradually stop rotating by its own low friction. When stopping the turntable with the stop-button it is the motor that forcefully breaks the rotation speed. The power-switch is sometimes used to produce a slow stop, but is omitted as a controller here.

Only two controllers are chosen from the audio mixer's many possibilities. The up-fader is a logarithmic master-volume slider. Normally the crossfader is far more utilized than the up-fader, but a slider is not an advantageous way to control volume when the mouse is occupied with record speed. Under the slider is a push-button which shuts out the sound (or turns on the sound) when activated. This button mixes the functions of the line/phono switch and the crossfader.

Other controllers

Top left in Figure 11.29, there is a main power-button "power up dsp" starting the audio computation and resetting or initializing some start values in the patch. Under this there are 5 buttons for selecting the playback sound (sample).

Under the heading "readymade scratches" there are several buttons for triggering the recorded techniques. Below, two sliders define the speed and the depth these techniques will have. The speed range is a bit broader than what is normally performed. The depth slider goes from long backward movements to long forward movements, also making exaggerated performances possible.

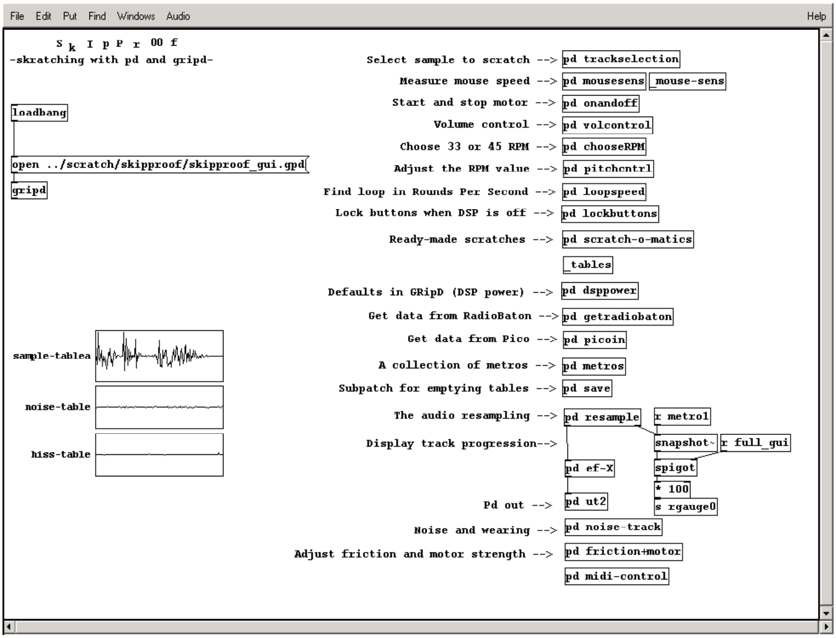


Figure 11.30: Main patch for Skipproof.

The button labelled "using volume switch" decides whether the recorded scratches should be performed with crossfader or an on-off switch.

The `pd` patches

The main window, Figure 11.30, opens the GUI and lists all the subpatches. The right side of the window receives the playback speed of the sound in rounds per second (rps). This information is sent to the progression meter in `GrIPD`.

The `pd trackselection` subpatch lets the user choose sounds and sample rates. All sounds will be read into the same table, "sample-table a", to reduce the CPU load.

"Metro" in `pd` is a metronome object counting at a defined speed. Here in `pd mousesens` the metro counts every 100 ms, and at every count registers changes in relative mouse position. Too slow or too fast movements (often caused by long time of no action or by inaccuracy in the mouse sensors) are filtered out. Both horizontal and vertical mouse activity is measured. The

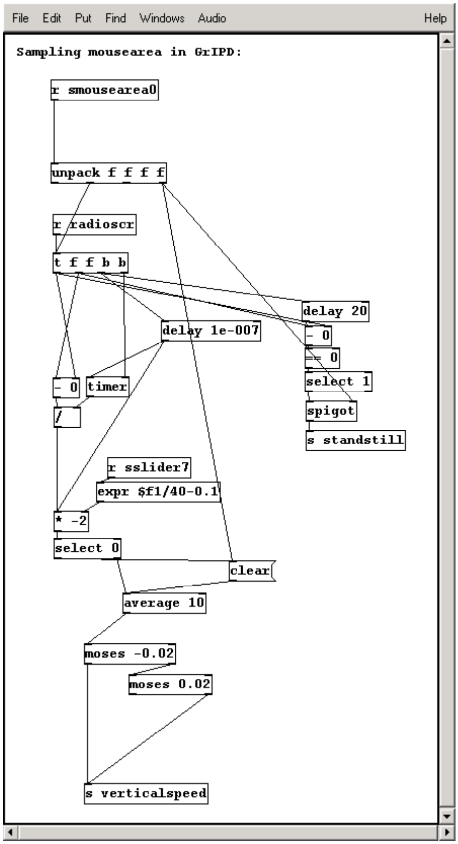


Figure 11.31: Mousesens: Calculating the mouse movement.

mouse speed value is sent to subpatch `pd loopspeed` for adjusting the playback sample rate.

The `pd loopspeed` is sent to the table-reader as seconds per round and can be altered by receiving the mouse speed, the pitch control value and on-and-off messages. When the motor is turned off, the turntable will respond differently to movement caused by mouse activity. Some kind of inertia can be simulated, as in “Return to loop speed” in the top right corner of the window in Figure 11.32.

All the recorded scratches used for synthesizing single techniques are col-

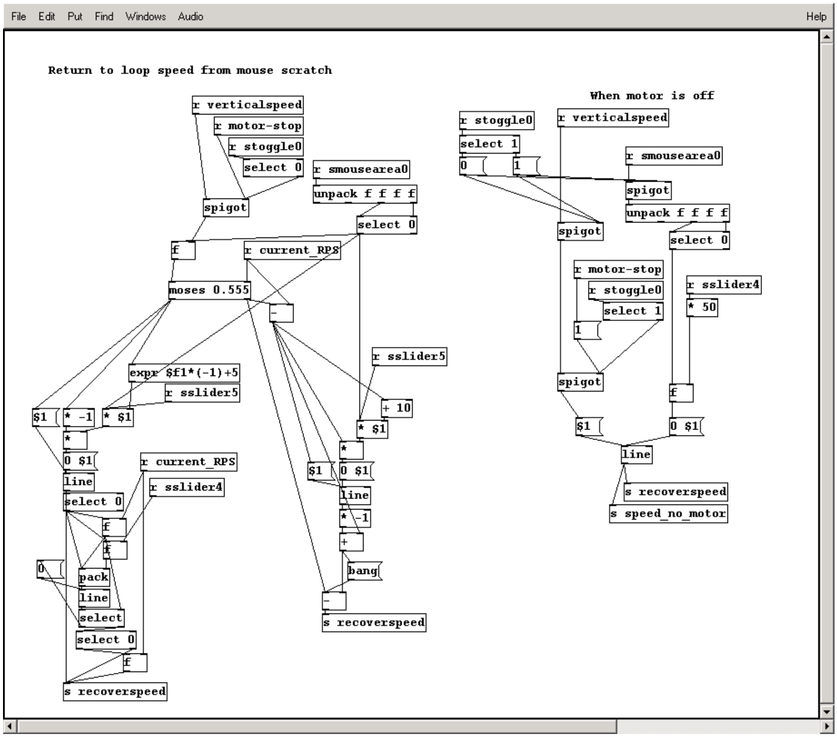


Figure 11.32: The `loopspeed` subpatch.

lected in `pd tables` for simplicity. Tables are read in `pd scratch-o-matics`. The empty “table11” is for techniques where the crossfader is not utilized, in this way all techniques can follow the same procedure in the subpatch described next.

Signals from crossfader and record movements are low-pass filtered at 30-50 Hz before implemented in Skipproof. Each of the techniques is picked out from a series of constantly performed single techniques, and so represent an idealized model. Apart from techniques where the main idea consists of many small movements on the record, as with chirps and scribble, only one stroke forward and backward is included for all scratches. The scratches vary in length.

In future versions, most of the tables will be substituted by algorithms for

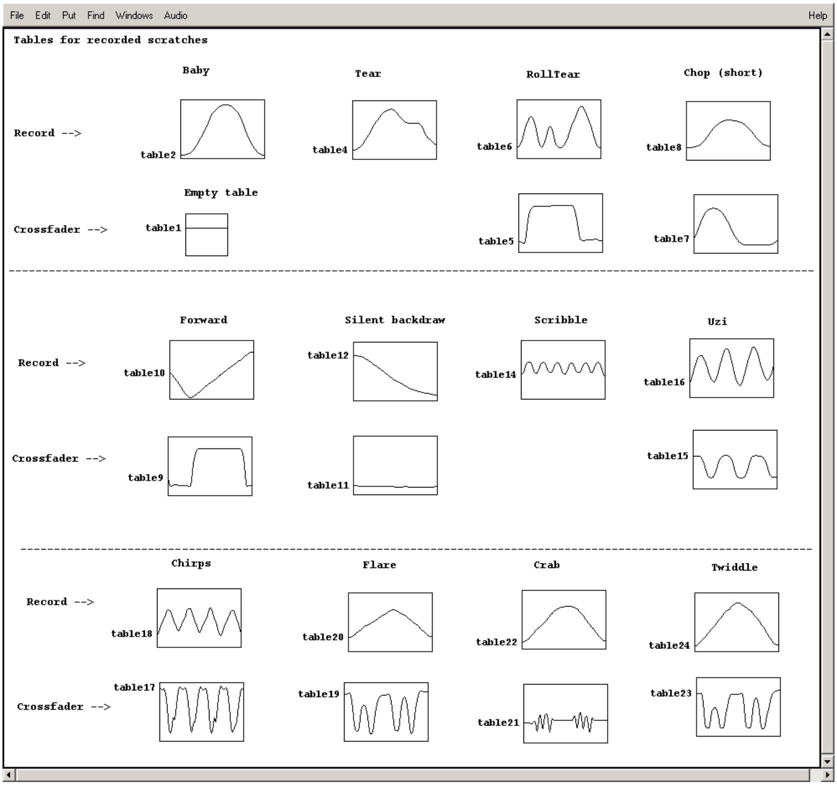


Figure 11.33: `pd` tables: The recordings of the techniques in tables.

both record and crossfader movement.

The subpatch in Figure 11.34 reads the tables in `pd tables` using the same procedure, but since the tables are of different sizes, some adjustments must be done to the computations. The record-movement table readings are sent to the main patch and replace the value from `pd loopspeed` in seconds per round. The crossfader-movement table readings are sent to `pd volcontrol` as both up-fader values and volume push-button values depending on which method is selected.

After a performed scratch, the turntable continues in the set rpm.

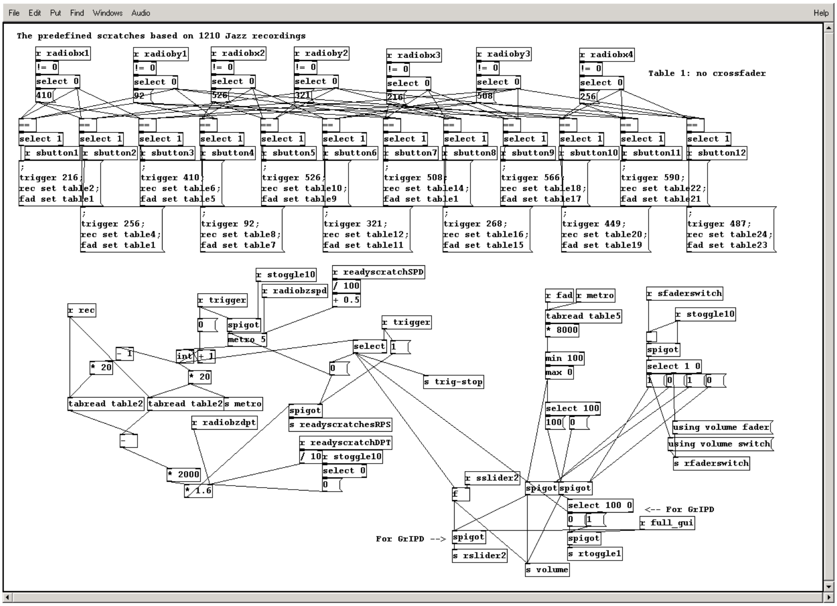


Figure 11.34: Scratch-o-matics: Reading the recorded techniques.

Noise and wearing

To simulate the wearing of the vinyl, as explained in experiment 3, a simple noise model was implemented, see Figure 11.35. Following several notions, it generates low-level white noise, narrow-band noise and vinyl defects as cracks and hiss. All the noise signals are recorded to a 1.6 s long table, so the vinyl defects always occur at the same spot on the record when it is looped.

11.A.2 Controllers

Here are some alternatives to standard MIDI and computer input controllers that we use. The model is controlled in 4 different areas. An analogue-digital converter from Pico sends the signals from the control objects to the computer. The voltage output is then read in pd, controlling the described parameters.

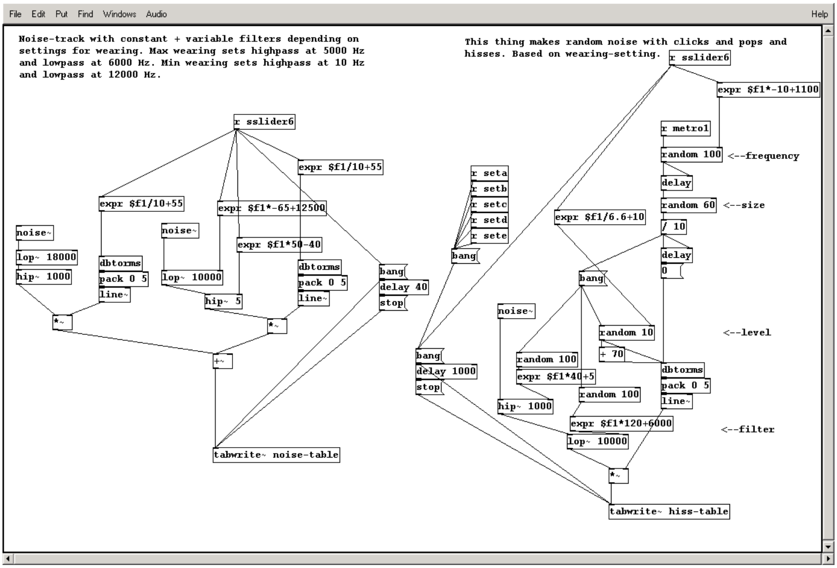


Figure 11.35: Noise generator.

Substituting the turntable

The Max Mathews' Radio Baton was used as gestural controller for Skipproof. The drumstick like batons were substituted by a newly developed radio sender that fits the fingertips. This new radio sender allows users' interaction based on hand gestures (see Figure 11.36).

Substituting the mixer

The crossfader on modern scratch mixers is becoming easier and easier to move; now some models have friction-free faders. Still it takes a lot of training to accurately jump the fader over the critical break-in point. To make it easier to accomplish fast clicks, a light sensor replaces the crossfader.

Substituting the record

Sounds in Skipproof are sampled sounds. The user can add her/his own choice of sounds to be scratched. Skipproof can also be applied to the control

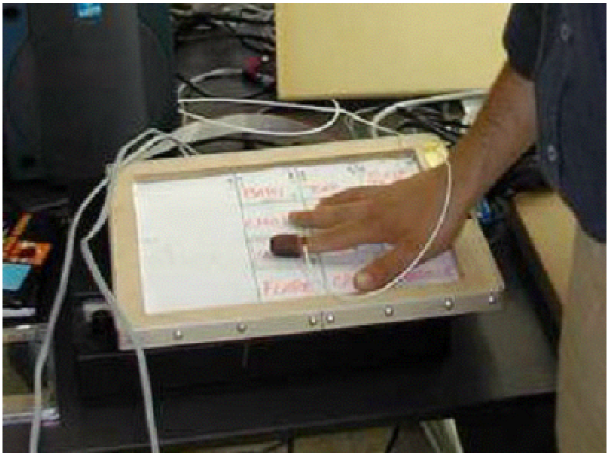


Figure 11.36: The finger-based gestural controller for the Max Mathews' Radio Baton.

of the sound model, such as for friction.

Substituting the DJ

Max Mathews Radio-baton is divided into nine sectors, each sector hosting a pre-recorded scratch technique. Treated gloves (with wiring equivalent to the drumstick used with the Radio-baton) manipulate a 3D (xyz-plane) signal received by the antennas.

References

[1] Adc-11. Pico Technology Limited, registered trademark, http://www.picotech.com.

[2] J. M. Adrien. The missing link: Modal synthesis. In G. De Poli, A. Piccialli, and C. Roads, editors, *Representations of Musical Signals*, pages 269–297. MIT Press, Cambridge, MA, 1991.

[3] C. Ahlberg and B. Shneiderman. The Alphaslider: A rapid and compact selector. In *Proc. ACM CHI*, pages 365–371, Boston, MA, 1994.

[4] C. Ahlberg and B. Shneiderman. Visual information seeking: Tight coupling of dynamic query filters with starfield displays. In *Proc. ACM CHI*, pages 313–317, Boston, MA, 1994.

[5] A. Akay. Acoustics of friction. *J. of the Acoustical Society of America*, 111(4):1525–1548, 2002.

[6] M. C. Albers. The Varese system, hybrid auditory interfaces, and satellite-ground control: Using auditory icons and sonification in a complex, supervisory control system. In G. Kramer and S. Smith, editors, *Proc. Int. Conf. on Auditory Display*, pages 3–14, Santa Fe, NM, November 1994.

[7] F. Altpeter. *Friction Modeling, Identification and Compensation*. PhD thesis, École Polytechnique Fédérale de Lausanne, 1999.

[8] F. Avanzini. *Computational issues in physically-based sound models*. PhD thesis, Università degli Studi di Padova, 2001.

[9] F. Avanzini, M. Rath, and D. Rocchesso. Physically–based audio rendering of contact. In *Proc. IEEE Int. Conf. on Multimedia & Expo*, Lausanne, August 2002.

[10] F. Avanzini and D. Rocchesso. Controlling material properties in physical models of sounding objects. In *Proc. Int. Computer Music Conference*, La Habana, Cuba, September 2001.

[11] F. Avanzini and D. Rocchesso. Modeling Collision Sounds: Non-linear Contact Force. In *Proc. Conf. on Digital Audio Effects*, pages 61–66, Limerick, December 2001.

[12] F. Avanzini and D. Rocchesso. Efficiency, accuracy, and stability issues in discrete time simulations of single reed instruments. *J. of the Acoustical Society of America*, 111(5):2293–2301, May 2002.

[13] J. A. Ballas. Common factors in the identification of an assortment of brief everyday sounds. *J. of Experimental Psychology: Human Perception and Performance*, 19(2):250–267, 1993.

[14] J. A. Ballas and J. H. Howard. Interpreting the language of environmental sounds. *Environment and Behaviour*, 9(1):91–114, 1987.

[15] A. Barr. Superquadrics and angle-preserving transforms. *IEEE Computer Graphics and Applications*, 1(1):11–23, 1981.

[16] S. Barrass. *Auditory Information Design*. PhD thesis, Australian National University, 1997.

[17] L. L. Beranek. Concert hall acoustics - 1992. *J. of the Acoustical Society of America*, 92(1):1–39, 1992.

[18] L. Berio and N. Bernardini. Incontro con Luciano Berio. In *La passione del conoscere*. AA.VV., Laterza Ed., Bari, Italy, 1993.

[19] M. M. Blattner. Investigations into the use of earcons. Technical report, Lawrence Livermore National Laboratory, University of California, Davis, CA, 1996.

[20] M. M. Blattner, D. Sumikawa, and R. Greenberg. Earcons and icons: Their structure and common design principles. *Human-Computer Interaction*, 4(1), Spring 1989.

[21] J. Blauert. *Spatial Hearing: the Psychophysics of Human Sound Localization*. MIT Press, Cambridge, MA, 1983.

[22] M. T. Boren and J. Ramey. Thinking aloud: Reconciling theory and practice. *IEEE Trans. on Professional Communication*, 43(3):261–278, September 2000.

[23] G. Borin and G. De Poli. A hysteretic hammer-string interaction model for physical model synthesis. In *Proc. Nordic Acoustical Meeting*, pages 399–406, Helsinki, June 1996.

[24] G. Borin, G. De Poli, and D. Rocchesso. Elimination of delay-free loops in discrete-time models of nonlinear acoustic systems. *IEEE Trans. on Speech and Audio Processing*, 8(5):597–605, 2000.

[25] R. Boulanger and M. Mathews. The 1997 Mathews radio-baton and improvisation modes. In *Proc. Int. Computer Music Conference*, pages 395–398, 1997.

[26] L. H. Boyd, W. L. Boyd, and G. C. Vanderheiden. The graphical user interface: Crisis, danger, and opportunity. *Visual Impairment & Blindness*, pages 496–502, 1990.

[27] L. D. Braida. Development of a model for multidimensional identification experiments. *J. of the Acoustical Society of America*, 87, 1988.

[28] E. Brazil and M. Fernström. Let your ears do the browsing - the Sonic Browser. *The Irish Scientist*, 2001.

[29] E. Brazil, M. Fernström, G. Tzanetakis, and P. Cook. Enhancing sonic browsing using audio information retrieval. In *Proc. Int. Conf. on Auditory Display*, Kyoto, Japan, 2002.

[30] A. Bregman. *Auditory Scene Analysis*. The MIT Press, Cambridge, MA, 1990.

[31] R. Bresin. Articulation rules for automatic music performance. In *Proc. Int. Computer Music Conference*, La Habana, Cuba, September 2001.

[32] R. Bresin and G. U. Battel. Articulation strategies in expressive piano performance. Analysis of legato, staccato, and repeated notes in performances of the andante movement of Mozart's sonata in G major (K 545). *J. of New Music Research*, 29(3):211–224, 2000.

[33] R. Bresin and A. Friberg. Emotional coloring of computer-controlled music performances. *Computer Music J.*, 24(4):44–63, 2000. MIT press.

[34] R. Bresin and G. Widmer. Production of staccato articulation in mozart sonatas played on a grand piano. Preliminary results. Speech Music and Hearing Quarterly Progress and Status Report 4, Speech Music and Hearing, Stockholm: KTH, 2000.

[35] S. A. Brewster. Sound in the interface to a mobile computer. In Lawrence Erlbaum Associates, editor, *Proc. of HCI International*, pages 43–47, Munich, Germany, 1999.

[36] S. A. Brewster. Overcoming the lack of screen space on mobile computers. *Personal and Ubiquitous Computing*, 6(3):188–205, 2002.

[37] S. A. Brewster, P. C. Wright, A. J. Dix, and A. D. N. Edwards. The sonic enhancement of graphical buttons. In K. Nordby, P. Helmersen, D. Gilmore, and S. Arnesen, editors, *Proc. of Interact'95*, pages 43–48, Lillehammer, Norway, 1995. Chapman & Hall.

[38] S. A. Brewster, P. C. Wright, and A. D. N. Edwards. The design and evaluation of an auditory-enhanced scrollbar. In S. Dumais B. Adelson and J. Olson, editors, *Proc. ACM CHI*, pages 173–179, Boston, MA, 1994. ACM Press, Addison-Wesley.

[39] S. A. Brewster, P. C. Wright, and A. D. N. Edwards. A detailed investigation into the effectiveness of earcons. In G. Kramer, editor, *Auditory Display: Sonification, Audification and Auditory interfaces*, pages 471–498. Addison-Wesley, Reading, MA, 1994.

[40] D. S. Brungart, N. I. Durlach, and W. M. Rabinowitz. Auditory localization of nearby sources. II. localization of a broadband source. *J. of the Acoustical Society of America*, 106:1956–1968, 1999.

[41] Mr Bungle. Mr Bungle. CD, 1991: 2-26640. New York: Warner.

[42] W. Buxton and W. W. Gaver. Human interface design and the handicapped user. In *ACM CHI'86*. ACM Press, 1986.

[43] W. Buxton and W. W. Gaver. The use of non-speech audio at the interface. In *CHI'89*, Austin, Texas, 1989. ACM Press.

[44] W. Buxton, W. W. Gaver, and S. Bly. Non-speech audio at the interface. Unfinished book manuscript, http://www.billbuxton.com/Audio.TOC.html, 1994.

[45] D. Byrne. Feelings®. CD, 1997: 46605. New York: Luaka Bop/Warner Brothers.

[46] P. A. Cabe and J. B. Pittenger. Human sensitivity to acoustic information from vessel filing. *J. of Experimental Psychology: Human Perception and Performance*, 26(1):313–324, 2000.

[47] J. Cage. Imaginary landscape no 1, 1939. Edition Peters - New York.

[48] J. W. Cannon, W. J. Floyd, R. Kenyon, and W. R. Parry. Hyperbolic geometry. In S. Levy, editor, *Flavors of Geometry*, pages 59–115. Cambridge University Press, Cambridge, 1997.

[49] C. Carello, K. L. Anderson, and A. J. Kunkler-Peck. Perception of object length by sound. *Psychological Science*, 9(3):211–214, May 1998.

[50] C. Carello, J. B. Wagman, and M. T. Turvey. Acoustical specification of object properties. In J. Anderson and B. Anderson, editors, *Moving image theory: Ecological considerations*. Southern Illinois University Press, Carbondale, IL, 2003.

[51] P. Cederqvist. *Version Management with CVS*, 2003. Version 11.3 web available at http://www.cvshome.org/docs/manual.

[52] A. Chaigne and C. Lambourg. Time-domain simulation of damped impacted plates: I. theory and experiments. *J. of the Acoustical Society of America*, 109(4):1422–1432, April 2001.

[53] A. Chaigne, C. Lambourg, and D. Matignon. Time-domain simulation of damped impacted plates: II. numerical models and results. *J. of the Acoustical Society of America*, 109(4):1433–1447, April 2001.

[54] P. R. Cook. *Real Sound Synthesis for Interactive Applications*. A. K. Peters Ltd., 2002.

[55] G. Corsini and R. Saletti. A $1/f^{\gamma}$ power spectrum noise sequence generator. *IEEE Trans. on Instrumentation and Measurement*, 37(4):615–619, December 1988.

[56] C. Cutler. Plunderphonia. http://www.l-m-c.org.uk/texts/plunder.html, 1994. MusicWorks 60, 6-20. Toronto: MusicWorks.

[57] S. Dahl. Spectral changes in the tom-tom related to striking force. Speech Music and Hearing Quarterly Progress and Status Report 1, Dept. of Speech Music and Hearing, Stockholm: KTH, 1997.

[58] S. Dahl. The playing of an accent. preliminary observations from temporal and kinematic analysis of percussionists. *J. of New Music Research*, 29(3):225–234, 2000.

[59] S. Dahl and R. Bresin. Is the player more influenced by the auditory than the tactile feedback from the instrument? In *Proc. Conf. on Digital Audio Effects*, pages 194–197, Limerick, 2001.

[60] R. Dannenberg and I. Derenyi. Combining instrument and performance models for high-quality music synthesis. *J. of New Music Research*, 27(3):211–238, 1998.

[61] ddrum4. Registered trademark of Clavia Digital Musical Instruments AB, http://www.clavia.se/ddrum.htm.

[62] C. Canudas de Wit, C. H. Olsson, K. J. Åström, and P. Lischinsky. A new model for control of systems with friction. *IEEE Trans. Autom. Control*, 40(3):419–425, 1995.

[63] D. Deutsch. *The Psychology of Music*. Academic Press, San Diego, 1999.

[64] Hitech Development. Soundswell signal workstation . http://www.hitech.se/development/products/soundswell.htm.

[65] P. Djoharian. Shape and material design in physical modeling sound synthesis. In *Proc. Int. Computer Music Conference*, pages 38–45, Berlin, 2000.

[66] P. Dupont, V. Hayward, B. Armstrong, and F. Altpeter. Single State Elasto-Plastic Friction Models. *IEEE Trans. Autom. Control*, (5):787–792, 2002.

[67] N.I. Durlach, B.G. Shinn-Cunningham, and R.M. Held. Supernormal auditory localization. I. General background. *Presence: Teleoperators and Virtual Environment*, 2(2):89–103, 1993.

[68] S. A. Van Duyne and J. O. Smith. A simplified approach to modeling dispersion caused by stiffness in strings and plates. In *Proc. Int. Computer Music Conference*, pages 407–410, Aarhus, Denmark, September 1994.

[69] S.A. Van Duyne and J.O. Smith. Physical modeling with the 2-D digital waveguide mesh. In *Proc. Int. Computer Music Conference*, pages 40–47, Tokyo, Japan, 1993.

[70] T. Engen. Psychophysics. I. Discrimination and detection. II. Scaling. In *Woodworth & Schlosberg's Experimental Psychology*, pages 11–86. J.K. Kling and L.A. Riggs (ed.), Methuen, London, 3rd edition, 1971.

[71] M. Fernström and C. McNamara. After direct manipulation - direct sonification. In *Proc. Int. Conf. on Auditory Display*, Glasgow, Scotland, 1998.

[72] S. A. Finney. Auditory feedback and musical keyboard performance. *Music Perception*, 15(2):153–174, 1997.

[73] W. T. Fitch and G. Kramer. Sonifying the body electric: Superiority of an auditory display over a visual display in a complex, multivariate system. In G. Kramer, editor, *Auditory Display: Sonification, Audification and Auditory interfaces*, pages 307–326. Addison-Wesley, Reading, MA, 1994.

[74] T. Flash and N. Hogan. The coordination of arm movements: an experimentally confirmed mathematical model. *The J. of Neuroscience*, 5(7):1688–1703, 1985.

[75] H. Fletcher and W. A. Munson. Loudness, its definition measurements and calculation. *J. of the Acoustical Society of America*, 5:82–108, 1933.

[76] N. H. Fletcher and T. D. Rossing. *The Physics of Musical Instruments*. Springer-Verlag, New York, 1991.

[77] F. Fontana and R. Bresin. Physics-based sound synthesis and control: crushing, walking and running by crumpling sounds. In *Proc. Colloquium on Musical Informatics*, Florence, Italy, May 2003.

[78] F. Fontana, D. Rocchesso, and E. Apollonio. Using the waveguide mesh in modelling 3D resonators. In *Proc. Conf. on Digital Audio Effects*, pages 229–232, Verona - Italy, December 2000.

[79] C. A. Fowler. Sound-producing sources of perception: Rate normalization and nonspeech perception. *J. of the Acoustical Society of America*, 88(6):1236–1249, June 1990.

[80] C. A. Fowler. Auditory perception is not special: we see the world, we feel the world, we hear the world. *J. of the Acoustical Society of America*, 89(6):2910–2915, June 1991.

[81] Fab Five Freddie. Change the beat. 12" Celluloid Records CEL 156, 1982.

[82] D. J. Freed. Auditory correlates of perceived mallet hardness for a set of recorded percussive events. *J. of the Acoustical Society of America*, 87(1):311–322, January 1990.

[83] A. Friberg. Generative rules for music performance: A formal description of a rule system. *Computer Music J.*, 15(2):56–71, 1991.

[84] A. Friberg, V. Colombo, L. Frydén, and J. Sundberg. Generating musical performances with director musices. *Computer Music J.*, 24(3):23–29, 2000.

[85] A. Friberg and J. Sundberg. Time discrimination in a monotonic, isochrounous sequence. *J. of the Acoustical Society of America*, 98(5):2524–2531, 1995.

[86] A. Friberg and J. Sundberg. Does music performance allude to locomotion? a model of final ritardandi derived from measurements of stopping runners. *J. of the Acoustical Society of America*, 105(3):1469–1484, 1999.

[87] A. Friberg, J. Sundberg, and L. Frydén. Music from motion: Sound level envelopes of tones expressing human locomotion. *J. of New Music Research*, 29(3):199–210, 2000.

[88] G. Furnas. Generalised fisheye views. In *Proc. ACM CHI*, Massachusetts, USA, 1986.

[89] G. Furnas. Space-scale diagrams: Understanding multiscale interfaces. In *Proc. ACM CHI*, Denver, CO, USA, 1995.

[90] W. G. Gardner. Reverberation algorithms. In M. Kahrs and K. Brandenburg, editors, *Applications of Digital Signal Processing to Audio and Acoustics*, pages 85–131. Kluwer Academic Publishers, Dordrecht, The Netherlands, 1998.

[91] A. Gates, J. Bradshaw, and N. Nettleton. Effect of different delayed auditory feedback intervals on a music performance task. *Perception and Psychophysics*, 14:21–25, 1974.

[92] W. W. Gaver. *Everyday listening and auditory icons*. PhD thesis, University of California, San Diego, 1988.

[93] W. W. Gaver. The sonic finder: An interface that uses auditory icons. the use of non-speech audio at the interface. In *Proc. ACM CHI*, Austin, Texas, 1989.

[94] W. W. Gaver. Sound support for collaboration. In *Proc. of ECSCW'91*, Amsterdam, The Netherlands, September 1991. Kluwer. Reprinted in R. Baecker, (ed.), Readings in groupware and CSCW: Assisting human-human collaboration. Morgan Kaufmann, San Mateo, CA, 1993.

[95] W. W. Gaver. How do we hear in the world? explorations in ecological acoustics. *Ecological Psychology*, 5(4):285–313, 1993.

[96] W. W. Gaver. Synthesizing auditory icons. In *INTERCHI '93, 24-29 April 1993*, pages 228–235, 1993.

[97] W. W. Gaver. What in the world do we hear? an ecological approach to auditory event perception. *Ecological Psychology*, 5(1):1–29, 1993.

[98] W. W. Gaver. Using and creating auditory icons. In G. Kramer, editor, *Auditory Display: Sonification, Audification and Auditory interfaces*, pages 417–446. Addison-Wesley, Reading, MA, 1994.

[99] W. W. Gaver. Auditory interfaces. In M. G. Helander, T. K. Landauer, and P. Prabhu, editors, *Handbook of Human-Computer Interaction*. Elsevier Science, Amsterdam, The Netherlands, 2nd edition, 1997.

[100] W. W. Gaver, R. Smith, and T. O'Shea. Effective sounds in complex systems: the arkola simulation. In *Proc. ACM CHI*, New Orleans, Louisiana, 19991.

[101] J. J. Gibson. A theory of pictorial perception. *Audio-Visual Communication Review*, 1:3–23, 1954.

[102] J. J. Gibson. The useful dimension of sensitivity. *American Psychologist*, 18:115, 1963.

[103] J. J. Gibson. *The ecological approach to visual perception*. Houghton Mifflin, Boston, 1979.

[104] S. Godlovitch. *Musical Performance: A philosophical study*. Routledge, London, UK, 1998.

[105] S. Granqvist. Enhancements to the visual analogue scale, VAS, for listening tests. Speech Music and Hearing Quarterly Progress and Status Report 4, Speech Music and Hearing, Stockholm: KTH, 1996.

[106] J. M. Grey and J. W. Gordon. Perceptual effects of spectral modifications on musical timbres. *J. of the Acoustical Society of America*, 63:1493–1500, 1978.

[107] P. Griffiths. *Modern music and after*. Oxford University Press, 1995.

[108] R. Guski. Auditory localization: effects of reflecting surfaces. *Perception*, 19:819–830, 1990.

[109] B. Gygi. *Factors in the identification of environmental sounds*. PhD thesis, Indiana University, Department of Psychology, 2001.

[110] D. E. Hall. *Musical Acoustics*. Wadsworth, 1980.

[111] D. E. Hall. Piano string excitation VI: Nonlinear modeling. *J. of the Acoustical Society of America*, 92:95–105, July 1992.

[112] H. Hancock. Future shock. CD, reissue 2000: 65962. New York: Columbia/Legacy.

[113] S. Handel. Timbre perception and auditory object identification. In B.C.J. Moore, editor, *Hearing*. Academic Press, San Diego, CA, 1995.

[114] K. F. Hansen. Turntable music. In L. Jonsson, K. Oversand, and M. Breivik, editors, *Musikklidenskapelig Årbok 2000*, pages 145–160. Trondheim: NTNU, 2000. http://www.speech.kth.se/˜hansen/turntablemusic.html.

[115] K.F. Hansen. Turntablisme - his master's voice: The art of the record player. Master's thesis, NTNU, Trondheim: NTNU, 1999.

[116] H. M. Hastings and G. Sugihara. *Fractals: A User's Guide for the Natural Sciences*. Oxford University Press, 1993.

[117] V. Hayward and B. Armstrong. A new computational model of friction applied to haptic rendering. In P. Corke and J. Trevelyan, editors, *Experimental Robotics VI*, pages 403–412. Springer-Verlag, 2000.

[118] D. Van Heesch. *The Doxygen Manual*, 2003. Version 1.3-rc3 web available at http://www.stack.nl/˜dimitri/doxygen/manual.html.

[119] F. Heider and M. Simmel. A study of apparent behavior. *American J. of Psychology*, 57:243–256, 1944.

[120] M. M. J. Houben, A. Kohlrausch, and D. J. Hermes. Auditory cues determining the perception of size and speed of rolling balls. In *Proc. Int. Conf. on Auditory Display*, pages 105–110, Espoo, Finland, 2001.

[121] P. A. Houle and J. P. Sethna. Acoustic emission from crumpling paper. *Physical Review E*, 54(1):278–283, July 1996.

[122] K. H. Hunt and F. R. E. Crossley. Coefficient of Restitution Interpreted as Damping in Vibroimpact. *ASME J. Applied Mech.*, pages 440–445, June 1975.

[123] J. Huopaniemi, L. Savioja, and M. Karjalainen. Modeling of reflections and air absorption in acoustical spaces: a digital filter design approach. In *IEEE Workshop on Applications of Signal Processing to Audio and Acoustics*, pages 19–22, Mohonk, NY, 1997. IEEE.

[124] E. L. Hutchins, J. D. Hollan, and D. A. Norman. Direct manipulation interfaces. In D. A. Norman and S. W. Draper, editors, *User Centered System Design: New Perspectives on Human-Computer Interaction*, pages 87–124. Lawrence Erlbaum Associates, Hillsdale, NJ, 1986.

[125] DJ 1210 Jazz. Book of five scratches. Book 2. Snickars Rec., SR1206, 2001.

[126] G. Johansson. Studies on visual perception of locomotion. *Perception*, 6:365–376, 1977.

[127] B. Johnson and B. Shneiderman. Tree-maps: A space filling approach to the visualization of hierarchical information structures. In *IEEE Visualization '91*, San Diego, CA, 1991.

[128] J.-M. Jot. An Analysis/Synthesis Approach to Real-Time Artificial Reverberation. In *Proc. Int. Conf. on Acoustics, Speech, and Signal Processing*, San Francisco, CA, 1992. IEEE.

[129] J.-M. Jot. Real-time spatial processing of sounds for music, multimedia and interactive human-computer interfaces. *Multimedia systems*, 7:55–69, 1999.

[130] W. B. Joyce. Exact effect of surface roughness on the reverberation time of a uniformly absorbing spherical enclosure. *J. of the Acoustical Society of America*, 64(5):1429–1436, 1978.

[131] N.P. Juslin, A. Friberg, and R. Bresin. Toward a computational model of expression in music performance. The GERM model. *Musica Scientiae*, 2002.

[132] G. Kanizsa. Condizioni ed effetti della trasparenza fenomenica [conditions and the effects of perceptual transparency]. *Rivista di Psicologia*, 49:3–19, 1955.

[133] G. Kanizsa and G. B. Vicario. La perception de la réaction intentionnelle. *Bulletin de Psychologie*, 234:1019–1039, 1970.

[134] D. Katz. Die erscheinungsweisen der farben und ihre beeinflussung durch die individuelle erfahrung. *Zeitschrift für Psychologie*, 1911. (special number 7). *The world of color*, Paul Kegan, London 1921.

[135] M. Kennedy. *Oxford Concise Dictionary of Music*. Oxford University Press, Oxford, 1996.

[136] R. Khazam. Electroacoustic alchemist. *The Wire Magazine*, pages 36–40, 1997.

[137] R. L. Klatzky, D. K. Pai, and E. P. Krotkov. Perception of material from contact sounds. *Presence: Teleoperators and Virtual Environment*, 9(4):399–410, August 2000.

[138] K. Koffka. *Principles of Gestalt Psychology*. Routledge & Kegan, London, 1935. (1935/1962 5).

[139] G. Kramer. Some organizing principles for representing data with sound. In G. Kramer, editor, *Auditory Display: Sonification, Audification and Auditory interfaces*, pages 185–222. Addison-Wesley, 1994.

[140] M. Kubovy and D. Van Valkenburg. Auditory and visual objects. *Cognition*, 80:97–126, 2001.

[141] A. Kulkarni and H. S. Colburn. Role of spectral detail in sound-source localization. *Nature*, 396:747–749, December 1998.

[142] A. J. Kunkler-Peck and M. T. Turvey. Hearing shape. *J. of Experimental Psychology: Human Perception and Performance*, 26(1):279–294, 2000.

[143] H. Kuttruff. *Room Acoustics*. Elsevier Science, Essex, England, 1973. Third Edition, 1991.

[144] S. Lakatos. A common perceptual space for harmonic and percussive timbres. *Perception & Psychophysics*, 62:1426–1439, 2000.

[145] S. Lakatos, S. McAdams, and R. Caussé. The representation of auditory source characteristics: simple geometric form. *Perception & Psychophysics*, 59(8):1180–1190, 1997.

[146] J. D. Lambert. *Numerical Methods for Ordinary Differential Systems*. John Wiley & Sons, Chichester, UK, 1993.

[147] J. Lamping, R. Rao, and P. Pirolli. A focus+context technique based on hyperbolic geometry for visualizing large hierarchies. In *Proc. ACM CHI*, Denver, CO, USA, 1995.

[148] S. J. Lederman. Auditory texture perception. *Perception*, 8:93–103, 1979.

[149] D. N. Lee. A theory of visual control of breaking based on information about time-to-collision. *Perception*, 5:437–459, 1976.

[150] G. Leplatre and S. A. Brewster. An investigation of using music to provide navigation cues. In *Proc. Int. Conf. on Auditory Display*, Glasgow, UK, 1998. British Computer Society.

[151] Y. K. Leung and M. D. Apperley. A review and taxonomy of distortion-oriented presentation techniques. *ACM Trans. on Computer-Human Interaction*, 1:126–160, 1994.

[152] H. Levitt. Transformed up-down methods in psychoacoustics. *J. of the Acoustical Society of America*, 49(2):467–477, 1970.

[153] X. Li, R. J. Logan, and R. E. Pastore. Perception of acoustic source characteristics: Walking sounds. *J. of the Acoustical Society of America*, 90(6):3036–3049, December 1991.

[154] A. L. Liberman and I. G. Mattingly. The motor theory of speech perception revised. *Cognition*, 21:1–36, 1985.

[155] B. Libet. Cerebral processes that distinguish conscious experience from unconscious mental functions. In J.C. Eccles and O. Creutsfeldt, editors, *The principles of design and operation of the brain*, pages 185–202. Pontificia Academia Scientiarum, Roma, 1990.

[156] B. Lindblomm. Explaining phonetic variation: a sketch of the h&h theory. In Hardcastle & Marchal, editor, *Speech production and speech modeling*, pages 403–439. Kluwer, Dordrecht, 1990.

[157] J. M. Loomis, R. L. Klatzky, and R. G. Golledge. Auditory distance perception in real, virtual, and mixed environments. In Y. Ohta and H. Tamura, editors, *Mixed Reality: Merging Real and Virtual Worlds*, pages 201–214. Ohmsha, Ltd., Tokio, Japan, 1999.

[158] K. Lorenz. *Die Rückseite des Spiegels. Versuche einer Naturgeschichte menschlichen Erkennens*. Piper & Co., München, 1973.

[159] R. A. Lutfi. Informational processing of complex sound. I: Intensity discrimination. *J. of the Acoustical Society of America*, 86(3):934–944, 1989.

[160] R. A. Lutfi. Informational processing of complex sound. II: Cross-dimensional analysis. *J. of the Acoustical Society of America*, 87(5):2141–2148, 1990.

[161] R. A. Lutfi. Informational processing of complex sound. III: Interference. *J. of the Acoustical Society of America*, 91(6):3391–3401, 1992.

[162] R. A. Lutfi. Auditory detection of hollowness. *J. of the Acoustical Society of America*, 110(2), August 2001.

[163] R. A. Lutfi and E. L. Oh. Auditory discrimination of material changes in a struck-clamped bar. *J. of the Acoustical Society of America*, 102(6):3647–3656, December 1997.

[164] W. E. Mackay. Using video to support interaction design. Technical report, INRIA DISC multimedia, 2002.

[165] C.L. MacKenzie and D.L. Van Erde. Rhythmic precision in the performance of piano scales: Motor psychophysics and motor programming. In M. Jeannerod, editor, *Proc. Int. Symposium on Attention and Performance*, pages 375–408, Hillsdale, 1990. Lawrence Erlbaum Associates.

[166] G. Madison. Drumming performance with and without clicktrack - the validity of the internal clock in expert synchronisation. In *Proc. Fourth Workshop on Rhythm Perception & Production*, pages 117–122, Bourges, France, 1992.

[167] D. W. Marhefka and D. E. Orin. A compliant contact model with nonlinear damping for simulation of robotic systems. *IEEE Trans. on Systems, Man, and Cybernetics - Part A: Systems and Humans*, 29(6):566–572, November 1999.

[168] M. Marshall, M. Rath, and B. Moynihan. The Virtual Bhodran — The Vodhran. In *Proc. Int. Workshop on New Interfaces for Musical Expression*, Dublin, May 2002.

[169] W. L. Martens. Psychophysical calibration for controlling the range of a virtual sound source: Multidimensional complexity in spatial auditory display. In *Proc. Int. Conf. on Auditory Display*, pages 197–207, Espoo, Finland, July 2001.

[170] S. C. Masin. *Foundations of perceptual theory*. North-Holland, Amsterdam, 1993.

[171] S. McAdams. Recognition of sound sources and events. In S. McAdams and E. Bigand, editors, *Thinking in sound: the cognitive psychology of human audition*, pages 146–198. Oxford University Press, 1993.

[172] R. McGrath, T. Waldmann, and M. Fernström. Listening to rooms and objects. In *Proc. AES Conf. on Spatial Sound Reproduction*, pages 512–522, Rovaniemi, Finland, April 1999.

[173] M. Mellody and G. H. Wakefield. A tutorial example of Stimulus Sample Discrimination in perceptual evaluation of synthesized sounds: discrimination between original and re-synthesized singing. In *Proc. Int. Conf. on Auditory Display*, Espoo, Finland, July 2001.

[174] F. Metelli. The perception of transparency. *Scientific American*, 230(4):90–98, 1974.

[175] J. Meyer. *Akustik und musikalische Aufführungspraxis*. Verlag das Musikinstrument, 1972.

[176] A. Michotte. The emotions regarded as functional connections. In M. L. Reymert, editor, *Feeling and emotions*, pages 114–126. McGraw-Hill, New York, 1950.

[177] S. K. Mitra. *Digital Signal Processing: A computer-Based Approach*. McGraw-Hill, New York, 1998.

[178] M. R. Moldover, J. B. Mehl, and M. Greenspan. Gas-filled spherical resonators: Theory and experiment. *J. of the Acoustical Society of America*, 79:253–272, 1986.

[179] B. C. J. Moore. *An introduction to the Psychology Of Hearing*. Academic Press, 4th edition, 1997.

[180] P. M. Morse. *Vibration and Sound*. American Institute of Physics for the Acoustical Society of America, New York, 1991. 1st ed. 1936, 2nd ed. 1948.

[181] P. M. Morse and K. U. Ingard. *Theoretical Acoustics*. McGraw-Hill, New York, 1968.

[182] A. Mulder. Getting a grip on alternate controllers. *Leonardo Music J.*, 6:33–40, 1996.

[183] E. D. Mynatt. Auditory presentation of graphical user interfaces. In G. Kramer, editor, *Auditory Display: Sonification, Audification and Auditory interfaces*, pages 533–555. Addison-Wesley, 1994.

[184] J. G. Neuhoff, G. Kramer, and J. Wayand. Sonification and the interaction of perceptual dimensions: Can the data get lost in the map? In *Proc. Int. Conf. on Auditory Display*, Atlanta, Georgia, USA, 2000.

[185] J. Nilsson and A. Thorstensson. Adaptability in frequency and amplitude of leg movements during human locomotion at different speeds. *Acta Physiol Scand*, 129:107–114, 1987.

[186] J. Nilsson and A. Thorstensson. Ground reaction forces at different speeds of human walking and running. *Acta Physiol Scand*, 136:217–227, 1989.

[187] E. G. Noik. Encoding presentation emphasis algorithms for graphs. In *Proc. Graph Drawing*, 1994.

[188] J. O'Brien, P. R. Cook, and G. Essl. Synthesizing sounds from physically based motion. In *Proc. ACM SIGGRAPH*, pages 529–536, Los Angeles, CA, 2001.

[189] H. Olsson, K. J. Åström, C. Canudas de Wit, M. Gäfwert, and P. Lischinsky. Friction models and friction compensation. *European J. of Control*, 4:176–195, 1998.

[190] C. E. Osgood. On the nature and measurement of meaning. *Psychological bulletin*, 49:197–237, 1952.

[191] C. Palombini. Pierre Schaeffer - from research into noises to experimental music. *Computer Music J.*, 17(3):14–19, 1993.

[192] A. Papoulis. *Probability, Random Variables, and Stochastic Processes*. McGraw-Hill, New York, NY, 1984. 2nd edition.

[193] A. P. Pentland. Fractal-based description of surfaces. In W. Richards, editor, *Natural Computation*, pages 279–298. MIT Press, Cambridge, MA, 1988.

[194] P. Q. Pfordresher and C. Palmer. Effects of delayed auditory feedback on timing of music performance. *Psychological Research*, 66(1):71–79, 2002.

[195] A. Pirhonen, S. A. Brewster, and C. Holguin. Gestural and audio metaphors as a means of control for mobile devices. In *Proc. ACM CHI*, pages 291–298, Minneapolis, MN, 2002. ACM Press, Addison-Wesley.

[196] Portishead. Dummy. CD, 1994: 828 553. London: Go! Discs.

[197] M. Puckette. Pure Data. In *Proc. Int. Computer Music Conference*, pages 269–272, San Francisco, 1996.

[198] Rane ttm 56, 2001. http://www.rane.com/djcat.html#mixersttm56.html.

[199] M. Rath, F. Avanzini, N. Bernardini, G. Borin, F. Fontana, L. Ottaviani, and D. Rocchesso. An introductory catalog of computer-synthesized contact sounds, in real-time. In *Proc. Colloquium of Musical Informatics*, Florence, Italy, May 2003.

[200] B. H. Repp. The sound of two hands clapping: an exploratory study. *J. of the Acoustical Society of America*, 81(4):1100–1109, April 1987.

[201] B. H. Repp. Acoustics, perception, and production of legato articulation on a computer-controlled grand piano. *J. of the Acoustical Society of America*, 102(3):1878–1890, 1997.

[202] S. Resnick. *Adventures in Stochastic Processes*. Birkhäuser Boston, 1992.

[203] J. C. Risset and D. L. Wessel. Exploration of timbre by analysis and synthesis. In D. Deutsch, editor, *The psychology of music*, pages 113–169. Academic Press, 2nd edition, 1999.

[204] D. Rocchesso. The ball within the box: a sound-processing metaphor. *Computer Music J.*, 19(4):47–57, Winter 1995.

[205] D. Rocchesso. Spatial effects. In U. Zölzer, editor, *DAFX: Digital Audio Effects*, pages 137–200. John Wiley & Sons, Chichester, UK, 2002.

[206] D. Rocchesso, R. Bresin, and M. Fernström. Sounding objects. *IEEE Multimedia*, 10(2), april 2003.

[207] D. Rocchesso and P. Dutilleux. Generalization of a 3D resonator model for the simulation of spherical enclosures. *Applied Signal Processing*, 1:15–26, 2001.

[208] D. Rocchesso and L. Ottaviani. Can one hear the volume of a shape? In *IEEE Workshop on Applications of Signal Processing to Audio and Acoustics*, pages 115–118, NewPaltz, NY, October 2001. IEEE.

[209] V. Roussarie, S. McAdams, and A. Chaigne. Perceptual analysis of vibrating bars synthesized with a physical model. In *Proc.* 135^{th} *ASA Meeting*, New York, 1998.

[210] R. Saletti. A comparison between two methods to generate $1/f^{\gamma}$ noise. In *Proc. IEEE*, volume 74, pages 1595–1596, November 1986.

[211] L. Savioja, J. Backman, A. Järvinen, and T. Takala. Waveguide Mesh Method for Low-Frequency Simulation of Room Acoustics. *Proc. Int. Conf. on Acoustics*, pages 637–640, June 1995.

[212] G.P. Scavone, S. Lakatos, and C.R. Harbke. The Sonic Mapper: an interactive program for obtaining similarity ratings with auditory stimuli. In *Proc. Int. Conf. on Auditory Display*, Kyoto, Japan, 2002.

[213] P. Schaeffer. Etude aux chemins de fer, 1948.

[214] M. R. Schroeder. *Fractal, Chaos, Power Laws: Minutes from an Infinite Paradise*. W.H. Freeman & Company, New York, NY, 1991.

[215] Scratchdj. http://www.scratchdj.com, 2002. American turntablism site with forum, 2002.

[216] J. P. Sethna, K. A. Dahmen, and C. R. Myers. Crackling noise. *Nature*, (410):242–250, March 2001.

[217] B. Shneiderman. Direct manipulation: A step beyond programming languages. *IEEE Computer*, 16(8):57–69, 1983.

[218] B. Shneiderman. *Designing the User Interface: Strategies for Effective Human-Computer Interaction*. Addison-Wesley, MA, USA, 2 edition, 1992.

[219] B. Shneiderman. Tree visualization with tree-maps: A 2-D space-filling approach. *ACM Trans. on Computer Graphics*, 11:92–99, 1992.

[220] Shure m44-7 cartridge & v15 vxmr cartridge. http://www.needlz.com/m44-7.asp, http://www.shure.com/v15vxmr.html.

[221] K. Sjölander and J. Beskow. Wavesurfer - an open source speech tool. http://www.speech.kth.se/wavesurfer/.

[222] M. Slaney and R. F. Lyon. On the importance of time – a temporal representation of sound. In M. Cooke, S. Beete, and M. Crawford, editors, *Visual Representations of Speech Signals*, pages 409–429. John Wiley & Sons, Chichester, UK, 1993. Available at http://www.slaney.org/malcolm/pubs.html.

[223] J. O. Smith. Physical modeling using digital waveguides. *Computer Music J.*, 16(4):74–91, 1992.

[224] R. Smith. *Online 1200*. Technics SL1200 Mk2 specifications.

[225] The Sounding Object web site, 2001. Containing software, demonstrations, and articles, http://www.soundobject.org.

[226] E. Somers. Abstract sound objects to expand the vocabulary of sound design for visual and theatrical media. In *Proc. Int. Conf. on Auditory Display*, Atlanta, Georgia, April 2000. Georgia Institute of Technology.

[227] R. D. Sorkin, D. E. Robinson, and B. G. Berg. A detection-theoretic method for the analysis of visual and auditory displays. In *Proc. Annual Meeting of the Human Factors Society*, volume 2, pages 1184–1188, 1987.

[228] R. Stallman. *Free Software, Free Society: Selected Essays of Richard M. Stallman*. The GNU Press, Boston, MA, 2002.

[229] J. Strikwerda. *Finite Difference Schemes and Partial Differential Equations*. Wadsworth & Brooks, Pacific Grove, CA, 1989.

[230] A. Stulov. Hysteretic model of the grand piano hammer felt. *J. of the Acoustical Society of America*, 97(4):2577–2585, Apr 1995.

[231] J. Swevers, F. Al-Bender, C. G. Ganseman, and T. Prajogo. An Integrated Friction Model Structure with Improved Presliding Behavior for Accurate Friction Compensation. *IEEE Trans. Autom. Control*, 45:675–686, 2000.

[232] S. Targett and M. Fernström. Audio games: Fun for all? all for fun? In *Proc. Int. Conf. on Auditory Display*, Boston, MA, July.

[233] M. Tirassa, A. Carassa, and G. Geminiani. A theoretical framework for the study of spatial cognition. In S. O'Nuallain, editor, *Spatial cognition. Fondations and Applications*. Benjamins, Amsterdam, 2000.

[234] T. Tolonen and H. Järveläinen. Perceptual study of decay parameters in plucked string synthesis. In *Proc. 109-th AES Convention*, Los Angeles, September 2000. Available from http://www.acoustics.hut.fi/publications/.

[235] B. Truax. *Acoustic communication*. Ablex, Norwood, NJ, 84.

[236] P. Valori. *Fenomenologia*. Sansoni, Firenze, 1967. Entry of the Encyclopedia of Philosophy.

[237] K. van den Doel, P. G. Kry, and D. K. Pai. Foleyautomatic: Physically-based sound effects for interactive simulation and animation. In *Proc. ACM SIGGRAPH*, August 2001.

[238] K. van den Doel and D. K. Pai. The sounds of physical shapes. *Presence*, 7(4):382–395, August 1998.

[239] N. J. Vanderveer. Acoustic information for event perception. In *Paper presented at the celebration in honor of Eleanor J. Gibson*, Cornell University, Ithaca, NY, 1979.

[240] N. J. Vanderveer. *Ecological Acoustics: Human perception of environmental sounds*. PhD thesis, 1979. Dissertation Abstracts International, 40, 4543B. (University Microfilms No. 80-04-002).

[241] Samurai series mixers. http://www.vestax.com/products/samurai.html.uk/, 2002.

[242] G. B. Vicario. On Wertheimer's principles of organization. *Gestalt Theory*, (20), 1998.

[243] G. B. Vicario. *Psicologia generale [General Psychology]*. Laterza, Roma, 2001.

[244] G. B. Vicario. Breaking of continuity in auditory field. In L. Albertazzi, editor, *Unfolding perceptual continua*. Benjamins, Amsterdam, The Netherlands, 2002.

[245] G. B. Vicario. La fenomenologia sperimentale esiste. *Teorie e modelli*, (7), 2002.

[246] G. B. Vicario. Temporal displacement. In R. Buccheri and M. Saniga, editors, *The nature of time: geometry, physics and perception*, Tatránska Lomnica, May 2003. NATO, Kluwer, Amsterdam, The Netherlands. In press.

[247] J. von Uexküll. *Streifzüge durch Umwelten der Tieren und Menschen*. Rowohlt, Reinbeck bei Hamburg, 1956.

[248] T. Waits. Mule variations. CD, 1999: 86547. Los Angeles, CA:Anti/Epitaph.

[249] S. Wake and T. Asahi. Sound retrieval with intuitive verbal expressions. In *Proc. Int. Conf. on Auditory Display*, Glasgow, Scotland, 1998.

[250] W. H. Warren, E. E. Kim, and R. Husney. The way the ball bounces: visual and auditory perception of elasticity and control of the bounce pass. *Perception*, 16:309–336, 1987.

[251] W. H. Warren and R. R. Verbrugge. Auditory perception of breaking and bouncing events: a case study in ecological acoustics. *J. of Experimental Psychology: Human Perception and Performance*, 10(5):704–712, 1984.

[252] C. A. Wert. Internal friction in solids. *J. of Applied Physics*, 60(6):1888–1895, 1986.

[253] R. Wildes and W. Richards. Recovering material properties from sound. In W. Richards, editor, *Natural Computation*, pages 356–363. MIT Press, Cambridge, MA, 1988.

[254] C. Williamson and B. Shneiderman. The dynamic homefinder: evaluating dynamic queries in a real estate information exploration system. In *Special Interest Group on Information Retrieval (SIGIR)*, 1992.

[255] F. Winberg and S.-O. Hellström. Qualitative aspects of auditory direct manipulation - a case study of the towers of hanoi. In *Proc. Int. Conf. on Auditory Display*, Espoo, Finland, July 2001.

[256] G. W. Wornell. Fractal signals. In V. K. Madisetti and D. B. Williams, editors, *The Digital Signal Processing Handbook*, chapter 73. CRC Press and IEEE Press, 1998.

[257] P. Zahorik. Assessing auditory distance perception using virtual acoustics. *J. of the Acoustical Society of America*, 111(4):1832–1846, 2002.

[258] P. Zahorik. Auditory display of sound source distance. In *Proc. Int. Conf. on Auditory Display*, Kyoto, Japan, July 2–5 2002.

[259] J. Zorn. Locus solus. CD Reissue, 1995: 7303. New York: Tzadik.