Manipulating Music: Multimodal Interaction for DJs

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ABSTRACT
In this paper we consider the general goal of supporting physical manipulation of digital audio in a specific context: the performance disk jockey (DJ) seeking to migrate from vinyl to digital media. We classify both the DJ's traditional processes and tools and the field's newest technology.

D'Groove, our own technological contribution, is a force feedback turntable used to manipulate digital audio in novel ways. We present an observational study of professional DJ's using D'Groove, and discuss this approach's attributes and directions for future augmentation. Finally, we extend our conclusions about the DJ's emerging needs to the broader domain of digital audio manipulation.

Author Keywords
Tangible & physical interfaces, manual media manipulation, digital audio, disk jockey, DJ, turntable, music, haptic, force feedback, audio control.

ACM Classification Keywords
H.5.2: User Interfaces (H.1.2: User/Machine Systems)

INTRODUCTION

The need to manually control digital media streams is growing apace with the vast availability of material, live and stored, public and personal. Applications involving media browsing, manipulation and in particular, creative expression require both tight temporal coupling and creation of new interactive techniques and hardware to facilitate a sense of control [16, 21]. In this paper, we address a specific off-the-desktop instance of this need.

A disc jockey (DJ)'s primary job is to play pre-recorded music at social occasions such as dances or weddings, and in performance venues like dance clubs. It was once sufficient to simply play one song after another, but at least one branch of DJing has evolved into an expressive art form where DJs mix song fragments using special interactive techniques, creating entirely new music in a live performance that is an auditory and visual spectacle.

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Today's DJ uses archaic tools: vinyl records, a pair of turntables and an audio mixing board. This direct analog interface has survived because of its tight manual connection to the music and visual appeal, despite the limitations of turntables and vinyl. Many contemporary DJs would like to make use of digital media and explore new creative outlets with new tools. However, since DJs have invested so much time perfecting their skills with a turntable, any new technology must maintain the main virtues of this device.

Figure 1. An experienced DJ scratching with D'Groove

This paper begins with an analysis of DJs using conventional tools and procedures, and a discussion of previous attempts to upgrade DJ technology. These findings led to our first prototype controller, D'Groove, a novel digital DJ system with haptic, visual and auditory interaction. We designed these multi-modal feedback paths to serve the twin primary goals of reducing a DJ's cognitive load and providing new opportunities for expression. Experienced DJs from a variety of specializations tested our prototype, resulting in useful feedback and the discovery of some exciting new expressive uses that we had not intended. They discussed the technological needs and wants of the next generation of DJs, providing input to our user-centered design strategy. While D'Groove is for DJs, the experiences of our experts provide insight to the general problem of interacting with digital media streams.

CURRENT STATE-OF-THE-ART IN DJ TECHNOLOGY

A DJ-driven desire to control digital content has fueled primarily commercial development. For example, a number of DJ-targeted CD players have become available in the past two years. The most notable is the CDJ-1000 released by Pioneer in 2001 [3], which provides a 7-inch dial to manipulate the music as if it were a record. When in "vinyl" mode, rotating the dial causes a corresponding movement

of the CD's playback point as well as the characteristic 'scratch' sound. The unit does not have a motor and thus, when the DJ releases the dial, the music continues to play but the dial is motionless. This lack of synchronization breaks the sensation of direct control over the music, and has not been well received by turntable enthusiasts.

Numark will soon release the CDX1, a CD player with a full-sized (12-inch) motorized platter [4]. This product has the greatest potential to faithfully recreate the attributes of a conventional turntable; however, the authors have not yet been able to evaluate it.

In 2001, turntable manufacturer Stanton took a different approach with a product called FinalScratch, composed of two encoded records used with unmodified turntables [14]. Each record sends an audio-encoded position signal through the needle to a computer, which then plays a digital song in accordance with the record's movements. This approach takes advantage of digital media and has excellent manual control properties, including random access with the needle, but retains some of the old problems: vinyl wears out and needles skip and break. Our approach differs significantly in that we control the turntable's motor, providing feedback and effects through visual and haptic channels.

Researchers at academic institutions have also investigated various ways to control digital audio content. Halderman *et al.* modified a turntable by replacing the needle with an encoded wheel [22]. This system worked like FinalScratch but the wheel did not allow for groove selection within a song, thus eliminating random access.

Another interesting system, called *I Robot*, uses a robot to manipulate real turntables and vinyl to play music based on a preset script [10]. It is novel but the system lacks the nuances a human DJ provides when performing. There is no interaction between the robot and the audience.

Chu used a motorized haptic dial for navigation in an audio editing task [9]. He demonstrated some success in using haptic feedback generated directly from the audio stream to locate features within it. This is interesting as it can be applied to a DJ application.

Finally Hanson [15] studied the sound of scratching; produced when DJs manipulate traditional vinyl, and is working towards a physically based model of this sound. This may improve the authenticity of audio from future digital scratching devices.

THE DJ DOMAIN

We generated a detailed description of the processes involved in DJing from a number of sources: informal observations of over one hundred live DJ performances, interviews with over thirty DJs, DJ related films [19, 20] and websites [1, 2], and the input from the first author, a DJ of 13 years. Here we provide a summary but a more comprehensive accounting can be found online [5].

Types of DJ and Their Attitudes Toward Technology

We classify performance DJs into two categories: the *scratch* DJ and the *mix* DJ. Mix DJs control a dance floor's auditory ambience through artful choice of material and expert transitions. Scratch DJs employ a much wider and more personalized repertoire of interactive techniques, but the signature maneuver involves pushing a record back and forth to create a scrubbing sound as the needle rubs along the groove. Scratch DJs often use a "cut and paste" style of playing where songs switch abruptly, whereas mix DJs blend the music inconspicuously. Often elements of one style appear in the other.

Fast, highly practiced and dextrous hand movements make the scratch performance visually exciting. Both types of DJ rely on audience interaction and physical demeanor to build a unique visual experience.

Because of the time they've invested in turntables, scratch DJs are generally adverse to new technology. Conversely, mix DJs tend to be eager for new formats that could help distinguish their act. Some (usually scratch) DJs regard using tools that facilitate their job as "cheating": they will reject them as devaluing their skills and not requiring talent.

Traditional DJ Tools

A standard DJ setup consists of two turntables connected to an audio mixing board. The turntable can be deconstructed into three one-dimensional manual controls. The platter is a rotary controller that spins at a constant nominal speed, while allowing continuous manual modulation of rotation (and playback) speed including a complete stop. It provides haptic and visual feedback, both generated by the motor.

A record is a tangible interface with a visual representation of the music's mood/structure via the density of its grooves. A typical DJ's record has one song per side; songs are selected by changing records. The audio is decoded by moving the needle along the groove to advance the playback point. The directness of this interface supports intimacy leading to expressive play as discussed by Fels [13].

The needle and pitch slider are linear, limited-range controllers affording continuous access to the current play-point and platter speed respectively. Both provide visual feedback: the needle indicates temporal position within a song while the pitch slider denotes platter speed relative to the turntable's default setting.

Other important advantages of a turntable include:

1) A straightforward mapping and low latency between the movement of the record and the music's play-point.
2) An overall visual appeal based on the physical motion of the platter. This contributes to an accepted DJ "look" and showcases the DJ's effort as she manipulates the records.
3) Quick random access within a song via needle placement.
4) Auditory feedback through changes in the musical output when a record is accelerated, slowed or scratched.

However, the physical properties of turntables and records have disadvantages. Needles may skip, causing undesirable interruptions. The limited range of typical pitch/tempo adjustment sliders precludes mixing songs with extremely different tempos. Needles and vinyl, often expensive and/or rare, must be regularly replaced. Vinyl is cumbersome, heavy and generally impractical.

Specially designed CD players represent a digital alternative to turntables but have not been readily accepted. Existing CD players do not have large moving platters; the DJ produces music by pressing buttons or rotating small dials and it is hard to make this exciting to watch. Random access within a song is achieved by scrolling through the entire song or setting up cue points prior to a performance. Thus, DJs who have used both turntables and CD players express a lack of control intimacy when using the latter, a fault also identified by Moore with respect to MIDI [18].

Beatmatching: The Basis of Mixing Music

Every DJ must learn to beatmatch before she can perform. This task, the goal of which is to synchronize two or more tracks such that they have the same tempo and are in phase, is challenging since it requires management of divided attention. DJ music generally uses a 4/4 time signature. Thus to get two tracks to the same tempo, the DJ (while listening to a different track with each ear) adjusts the speed of one track using the pitch slider until the duration between successive beats in each track is the same. To get two tracks in phase, she synchronizes each song's *downbeat* (every 2^n beats where $n > 2$ and n is constant for each song) by directly touching the record to momentarily change the speed.

Many DJs require the entire duration of the outgoing song to synchronize the incoming song, suggesting that the audio channel may be overloaded.

Turntablism: The Art of Scratching and Beat Juggling

The combination of scratching and beat juggling is referred to as turntablism. When executed with skill and artistry, these techniques can promote a DJ from music player to music maker.

Beat juggling is the creation of unique new drum patterns by playing a small sample from one turntable while cuing up another pattern on the opposing turntable; then with an abrupt switch of the output, the second turntable plays its pattern while the first turntable is cued again and the process is repeated.

A DJ places a marker (usually a piece of tape or paint) on the inner rim of a record when beat juggling. This serves as a visual indicator for the playback point in the song with respect to the record's position. For example, a DJ might delimit an interesting sample in a 45º arc with the visual marker. In performance, he can then see how far to back-spin each beat without listening.

Beat juggling involves two one-dimensional tasks: re-cuing each record is continuous, but switching the output from one record to the next is binary.

In scratching, new sounds are created by rubbing the needle along (not across) the grooves of the vinyl while using the mixer's cross-fader to rapidly turn the sound on and off. DJ QBert, one of the world's most renowned scratch artists, has classified at least 25 different scratch patterns [20].

The process of scratching thus involves two one-dimensional tasks: moving a record back and forth and moving a cross-fader back and forth. The record movement is a continuous task but the cross-fader movement is usually done so quickly that it becomes a binary task – i.e. the music is either playing or not.

D'GROOVE: AN IMPROVED DIGITAL DJ SYSTEM

D'Groove represents a novel means for DJs to access digital media while facilitating – rather than inhibiting – creative and expressive performance. Its basic philosophy is to bring to digital music the same tight manual control offered by traditional turntables, along with new performance capabilities that analog media physically cannot provide. D'Groove's design process was both user-centric (it sought to embody the important characteristics of traditional DJ tools identified in the previous section, and to reduce cognitive load by matching the modern DJ's task space more closely than conventional DJ systems are able to) and technology-centric (it explores the new artistic and functional possibilities of new technology).

Figure 2. The D'Groove System

D'Groove's engineering design, audio player and haptic effects are fully described in previous publications [6, 7]. A summary is provided here. The system consists of three external user input/output devices connected to an audio engine built using van den Doel's JASS audio synthesis system [12]. The input devices control the playback of digital music on the computer, and the computer in turn controls the output devices via motor force commands in real time. We went to great lengths to achieve a motion-to-audio-output latency of under 10 msec, yielding a sense of tight manual control. Our approach is consequently able to maintain and extend the traditional turntable's visual, auditory and haptic communication with the user.

The Turntable Platter

D'Groove's main interface component is a real vinyl record driven/sensed by a 90 watt, 1070 nMn (stall) Maxon DC motor and a high-resolution (14,400 cpr) encoder (Figure 3). Moving this vinyl controls the computer's digital audio output in the same way that moving a record on a conventional turntable controls acoustic playback. The powered turntable allows D'Groove to satisfy the critical relationship between the platter's movements and the song's playback when the platter is not under manual control; but unlike a conventional turntable, its computer control also creates the opportunity for new kinds of haptically oriented interaction.

Figure 3. The Turntable Platter

Beatmatching Aid: Computer control of the turntable's motion and knowledge of the digital audio track's tempo allows us to make one revolution of the platter play exactly four beats (one bar in 4/4 time) in a song (Figure 4). On a normal turntable, the beats occur at a changing angular position as the needle moves inward on the record.

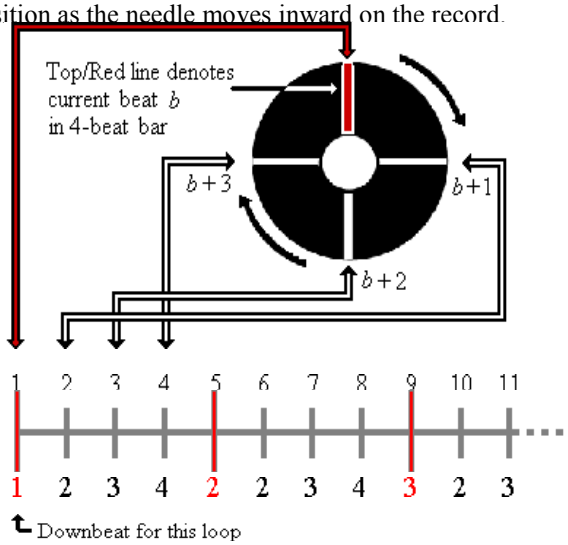

Figure 4. Lines on the turntable map to one bar. 12 o'clock marks the beginning of a bar.

We chose 4 beats per revolution because most DJ music is in 4/4 time. We assume that the song has a constant tempo, which in this version is supplied by the user at startup.

Many amateur DJs struggle to discern the tempo of one song relative to another using purely auditory means. Since beatmatching is still considered fun and part of the art form, we chose not to automate it, but instead tried transferring some of the auditory load to the underutilized visual sense.

With two D'Groove turntables, DJs could use the lines to visually compare tempos (now proportional to the turntables' rotational speeds) and phase (relative direction and magnitude of the offsets of the two red marks). With one D'Groove turntable, the multimodal quality of the feedback should still aid the user as information in one modality (vision) helps guide attention to information in another (audition) as discussed by McDonald [17] and Bertleson [8].

Interactive Haptics: On the theory that DJing has always been intensely physical and thus the haptic modality was a good candidate for broadening performance capabilities, we augmented the turntable with four haptic feedback modes. In the current prototype, the mode is set using a keyboard and GUI, and each one invokes a different motor controller.

In *spring* mode, a virtual spring makes the turntable oscillate around a set-point like a plucked string.

In *bumps-for-beats* mode, a virtual bump is generated at every beat. We theorized that feeling each beat when rotating the turntable manually would help with navigation through a song, and could also provide periodic "hills" of force to scratch against.

In *resistance* mode, the turntable becomes harder to move when it is playing an area of high-energy music (greater variations in amplitude) and easier to move when playing a *break* (relaxed and lower amplitude sections). Again, this was envisioned as a navigational feature.

In *textured-record* mode, the turntable produces many smaller detents, effectively making a bumpy road. If the turntable is pushed in either direction, it wobbles, causing an interesting jitter in the music as it winds to a halt.

Torque Limitation: Sizing the platter's motor drive was subject to conflicting demands. While it is desirable to match the significant torque levels provided by a conventional DJ turntable for satisfying interaction, the large motor and/or transmission required tends to respond less quickly and thus provides poor-quality haptic effects. The current prototype is a compromise between substantial but less than ideal torque and good dynamic response.

The Pitch Slider

The pitch slider (Figure 5) allows the DJ to control the song's coupled pitch and tempo. D'Groove's pitch slider range is extended infinitely through the use of a toggle-switch "scroller": if the DJ reaches the end of the slider's range, she can toggle the slider off, reset the slider, toggle it on and resume pitch modulation in the desired direction. Zhai refers to this as "clutching" [23], as in lifting a mouse and resetting it to increase its reach. The toggle adds a step but increases range without sacrificing precision.

The Q-Slider

The Q-slider (Figure 6) replaces the random-access cue function of the needle on the turntable. Both devices entail a one-dimensional linear task with visual feedback. Here, a digital song is mapped onto an actuated slider: left is the beginning and right is the end, and each revolution (and bar of the music) is mapped to a unique position in between. The slider moves as the song plays, visually indicating the playback position. It also provides haptic feedback when held, replacing the visual feedback of grooves on a record. Since DJs often work in dark spaces, we guessed they would find it useful to scan an upcoming track and search for different levels of activity in the music: exciting music feels heavy, and breaks feel light.

Figure 5. The Pitch Slider

Figure 6. The Q-Slider

EXPERT DJS USING D'GROOVE

We conducted an observational study of six experienced DJs who played with D'Groove for a single session and then answered questions in a structured interview. Much like Dix's Christmas Crackers [11], our goal was to see if we had successfully captured the "DJ experience". We therefore gathered only qualitative data. We were also interested in looking for emergent behaviour and encouraged free play. This helped us to better understand the features that DJs want in a new tool.

The DJs were recruited based on an enthusiasm for new DJ technology, and not otherwise compensated. The sessions were videotaped and the play portion lasted at least two hours; the DJs were encouraged to speak aloud.

Three of our participants were scratch DJs and three were mix DJs, hereafter referred to as Scratch1-Scratch3 and Mix1-Mix3. Scratch1 was a committed scratch artist; Scratch2 and Scratch3 were less experienced but keen on developing their skills. Mix1 was an adamant mix enthusiast with no interest in scratching. Mix2 was the only female participant recruited from this male-dominated discipline. Like the other mix DJs, she was familiar with the procedures of scratching but did not practice the art. All were between the ages of 21 and 30. Experience levels ranged from 3 to 12 years but all had ample experience performing in front of an audience and could beatmatch vinyl records in less than 10 bars.

A Technics 1200 turntable and D'Groove were connected to a common DJ mixing board (the Numark SM-3), completing a typical DJ setup. This allowed the DJs to make direct comparisons between D'Groove and the industry standard turntable. Full testing of D'Groove's beatmatching aid would require two D'Groove turntables and was thus deferred. Instead we anticipated that DJs would use auditory feedback (in the form of music) from D'Groove and the Technics 1200 as well as new visual feedback from D'Groove's beat markers to confirm the two turntables were beatmatched.

After a tour of D'Groove's features, the DJs were asked to mix and scratch and were encouraged to invent new tricks using D'Groove's features.

Evaluating the Turntable's Functional Features

Sound Quality & Latency: D'Groove's most popular feature was the ability to play digital music as if it were on vinyl. Scratch1 was the only DJ who found fault with the sound quality; however, he could discern degradation only when the turntable was moving at relatively slow speeds (dramatically slowing playback requires longer segments of interpolated sound).

Scratch1 was also the only user to detect any latency. He claimed that it occurred only when making a quick direction change from backwards to forwards, and felt it was slight enough to be compensated with practice. The remaining DJs were impressed with the reaction time.

Using the Beat Markers: The second most popular feature was the visual beatmatching aid (red and white lines) on the turntable. We had hypothesized that this feature would enable visual confirmation that the beats of D'Groove were matched to an opposing record, and thus expected DJs to watch the red line (the first beat in a bar) hit 12 o'clock, 3 o'clock, 6 o'clock and 9 o'clock for each of the four beats in a bar. In reality, the DJs continued to rely entirely on their ears for beatmatch confirmation, whether through habit, discomfort with the D'Groove feature or the fact that only one of the turntables offered it.

However, they found new uses for the red line: for example, when cueing D'Groove to the beginning of a bar. Mix2 came the closest to using the beat markers as intended when she used the red line at 12 o'clock to indicate the passing of a bar. Some of the DJs liked to interrupt the playback of D'Groove by grabbing the platter and scratching while it was playing alongside the conventional turntable. They could then easily resynchronize D'Groove with the conventional turntable by re-cueing it so that the red line was at 12 o'clock and then releasing it (so it plays on its own) at the next downbeat. Each DJ was asked if he/she envisioned the red line as a beat traveling around the turntable, and all replied negatively. The white lines (representing the remaining three beats in the bar) were not used at all.

Scratch1 and Scratch2 preferred to have a bar start with the red line at 9 o'clock instead of 12 o'clock; this is where they used tape on their vinyl records to denote the beginning of a song. Therefore we re-synchronized D'Groove for these DJs so that songs began at 9 o'clock.

All, especially the scratch DJs, noted that the red line would be extremely useful when beat juggling, where a DJ must memorize the position of a piece of tape (or paint) on a record in relation to the current bar. D'Groove's red line is an improvement as its position always signifies the same place in a bar. Backspinning to re-cue a bar is then simplified because DJs do not have to remember different distances for each bar in a song.

Power: The main concern was the turntable's lack of torque, which in the current prototype is considerably less than that of a Technics 1200. While all participants graciously said they could learn to cope, more power was clearly desirable. Scratch2 emphasized that a Technics 1200 turntable feels "almost alive" and "bursting with power". He wanted that feeling from D'Groove.

Evaluating the Turntable's Haptic Features

Spring: Of our haptic features, the spring was the most popular. All the DJs felt it would be fun to bounce the turntable like dribbling a basketball in a live performance. All agreed it would require practice but that that was customary – in fact desirable – for any good trick. Scratch2 and Scratch3 wanted the turntable to "ping-pong" back and forth between two predefined points. All of the DJs wanted stiffer springs – possible with more torque.

Scratch1 discovered how to automatically trigger a *scribble scratch*, a trick where normally the DJ tenses his record arm, quickly jerks the record and produces a short snappy sound. He found that when he overpowered D'Groove's spring-mode force, the turntable became unstable and overshot its target rest position, oscillating rapidly back and forth in a limit cycle that continued without intervention. The result was a short, snippety, helicopter-like sound.

Bumps-for-Beats: DJs found the bumps-for-beats mode more interesting for scratching than for navigating. They learned to dribble the platter and bounce it off the haptic hills that represented each beat. For example, Scratch2 played half a bass drum sample forwards (as the record went up a haptic hill) and then backwards (as the record fell back down). Scratch2 and Scratch3 wanted to control the frequency (and thus the tempo) of the platter bouncing constantly between two points. They also found the idea of placing the bump just *after*, rather than on, the beat exciting because the bounce would produce two distinct beat sounds – one as it went up the hill and another as it fell back down.

Textured Records: Scratch1 discovered how to perform a one-handed *hydroplane* scratch trick in textured-record mode. A hydroplane is normally done by moving the record with one hand and placing a finger from the opposite hand on the record such that it causes stick-slip friction, resulting in a bubbly scratchy sound. D'Groove can achieve the same effect by scratching over the textured bumps in this mode.

Scratch1 was also able to achieve very nice hydroplane sounds by setting the platter in normal turntable mode and using his friction finger on the underside of the platter as opposed to the top, as is normally done (Figure 7). He found this exciting because the underside of the platter gave him a whole new surface with which to play and his hands would never get in each other's way.

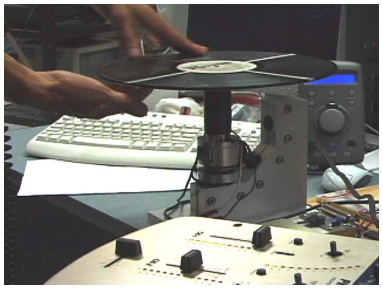

Figure 7: A hydroplane scratch performed on the underside of the turntable

Resistance: The resistance mode on the platter was thought to be interesting but not immediately useful. None of the DJs thought they needed mood change information on the platter as it rendered the platter difficult to use for playback.

Evaluating the Q-Slider

All of the DJs seemed to like the Q-slider. Mix2 liked our design but the other DJs asked for a graphical display of the song to be added to the slider so that they could visualize the layout of the music as well as feel it. All DJs were asked to locate a mood change in the music on the Q-Slider and Technics 1200. This is done on a conventional turntable by visually locating a difference in groove density, and placing the needle there. Surprisingly, it was done with equal if not better speed on the Q-slider with the use of the resistive haptics (the same mode that served little purpose on the turntable). Ironically, all of the DJs said they usually start their songs from the beginning and that it is uncommon (though not unheard of) to cue a song to start on one of these transitions.

Scratch2 discovered a fun way to use the Q-slider for *needle-dropping*. One needle-drops on a conventional turntable by picking up the needle and rapidly dropping it into a groove to produce a short sound. Scratch2 found he could quickly tap the Q-slider as the D'Groove turntable spun on its own, providing a stuttering effect. Because the turntable was still rotating, the music cut in and out but no change in musical time was made. Furthermore, a one-bar loop could be produced if the Q-slider was tapped once at the point of change between revolutions. If the DJ tapped the Q-slider at the very end of a revolution, then when the tap was complete, the turntable would remain on the same revolution, thus creating a loop.

This DJ also discovered that the Q-slider could be used for *jumping* to various locations in a song while remaining beatmatched with another song. The Q-slider increments the bar D'Groove plays but does not affect the playpoint within a bar – this is controlled exclusively by the turntable. Thus the song remains synchronized with the opposite

record when the D'Groove record is jumped via the Q-slider, a feature that is very useful for quick song remixes.

Evaluating the Pitch Slider

The pitch slider / toggle combination, used to extend the playback pitch/tempo range, was well received. All the DJs were excited to have the extra range, and did not object to the extra switch movement required to access it. They were asked to discuss two alternatives to D'Groove's mechanism: two sliders (one for large jumps in pitch and one for smaller jumps) in place of the switch, and a mouse wheel instead of a slider. All the DJs thought that the two-slider concept might be a suitable alternative to the current implementation but none liked the mouse wheel.

Evaluating D'Groove's Acceptance

When asked if any of D'Groove's new features would enable a DJ to "cheat" at certain tasks, the DJs had different responses. Scratch1 said he had spent hours perfecting certain moves and he valued showing these skills to an audience. If someone could use D'Groove to do a scribble scratch automatically or make a hydroplane easier, it would devalue his skills. Mix1, however, felt there was no point in making something harder than it needed to be. Such features made his job easier.

At the end of the sessions, the DJs were asked if they would replace their regular turntables with a pair of D'Groove turntables. They agreed that if D'Groove was more durable, had a higher turntable torque and combined all the components into a single device, they would use it on stage. All of the DJs, excluding Mix1, said they would keep at least one turntable around for nostalgic purposes and to make use of their existing record collection.

Interpreting the Responses

After reflecting on our initial study of DJ tasks and the observations of DJs using our system, we can extract a number of important observations.

Aid vs. Cheating: Using a performance aid is not necessarily "cheating" as long as the DJ (and the audience) still perceives the performer as a valuable contributor to the music and/or working hard. The DJ would like to feel she is in control over every aspect of the music. Thus, our decision to not automate the beatmatching process, but rather facilitate it with visual cues, seems to have been the right one since the DJs still felt a gratifying challenge in synchronizing the songs. We also note the possibility of a tool like D'Groove drastically changing the DJ art, not necessarily in a good way. Mix1 commented that he would not want to hear great amounts of scratching in a DJ set and if everyone had a tool that made scratching easy, the DJ world would be inundated with this sound.

Beatmatching Aid: We thought DJs would use the beat markers on D'Groove's turntable as visual aids when beatmatching songs. Instead we saw experienced DJs continue to rely on their ears for this and ignore the visual feedback, but cannot say whether this was because beatmatching is an inherently auditory task, unsuitable for visual offloading, or because a single D'Groove turntable did not offload it in the right way. However, the DJs did agree that the markers might help novices train their ears by helping them overcome the confusion of sorting out the position of beats in one song relative to another.

Appearance and Integration: Aesthetics plays a major role in DJing. DJs want tools that look appropriate and feel sturdy. Scratch1 proclaimed that he liked the Technics 1200 turntable because it is simple, dependable and relatively bare in terms of features. D'Groove lacks the slick appearance of a Technics 1200 – a deficiency that was difficult for the DJs to overcome when testing the system.

Customizablity: Features need to be customizable for each DJ's needs. DJs pride themselves on their unique styles and want different features in their gear. Most of the DJs agreed that they wanted a system where features could be ignored when not required. The ideal will be a basic device that accomplishes the fundamental objectives and has features that can be activated as DJs evolve their craft.

CONCLUSION

DJing began as a technology-centric art form; DJs appropriated the traditional turntable technology and pioneered innovative ways to use it. Because any successful new approach must meet the old standards, we built D'Groove in the form of a turntable. This first prototype allowed us to gather user feedback on a wide range of technical enhancements: its essential form was familiar to our target users, but it was flexible enough that we could implement new features on the fly.

D'Groove was designed using HCI principles, resulting in both anticipated and unexpected results. The response from highly critical DJs was positive overall, confirming that this prototype represents a viable means of manipulating digital audio based on a familiar form of physical control.

To relate what we have learned to digital audio manipulation in general, we can offer these suggestions:

1) To maintain control intimacy and convey a sense of manipulating a material form of digital audio, there should be no perceived delay between the motions of the physical device and the auditory response.
2) Mapping between the physical device and the auditory response should be straightforward and consistent. Here, the simple fact that music only plays when the turntable rotates provides such a mapping. We improved upon the traditional, non-constant relationship between a single record rotation and the consequent duration of musical playback, offering visual feedback and giving the turntable's rotation a more consistent meaning.
3) Uncoupling functionally different controls may not affect their value. The Q-Slider appeared to maintain a function of the needle but was detached from the platter.

4) It may be difficult to substitute another modality for auditory feedback during auditory tasks. In our case, DJs preferred to use their ears for beatmatching and rejected haptic modes such as the resistance mode because it disrupted the auditory channel.
5) For performance, creating sounds in new ways may be as highly valued as creating new sounds. Our haptic spring and textured-record mode gave the DJs a new visual appeal while creating an old sound.

FUTURE WORK

In the next prototype of D'Groove we will concentrate on aesthetics, durability and torque. Our goal is to create a self-contained turntable unit, embedding the computer, that conveys a sense of power and would draw attention in a night club performance.

In hindsight, our decision to replace the visual feedback from a record's grooves with haptic feedback on the Q-Slider was unsuccessful; our users preferred the visual channel for discerning the current musical point and the song's entire structure in a single step. We plan to add a screen to relay this information.

We also need to improve the GUI, moving many of its buttons into a physical form and adding capabilities for song selection and organization.

We plan again to involve DJs throughout the design process, moving from a technology-centric strategy to a user centered design.

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