Digital Drumming: A Study of Co-located, Highly Coordinated, Dyadic Collaboration

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ABSTRACT
Collaborative drumming is a creative human activity that requires a high degree of coordination among the participants. In this study, inexperienced drummer and experienced drummer participants were paired with a computer or experienced human drummer counterpart and given the task of producing musical rhythms on the fly. We found differing patterns of music production across the computer and human conditions. Participants intentionally and unintentionally assumed leadership roles depending on the dyad dynamic. Also noted were differences in the needs of inexperienced and experienced participants for visual and verbal cues for coordination. In our study, participants did not treat computers as other humans, but seemed to engage a more complex evaluation of the situation. This study contributes to the growing body of knowledge on how people respond to and interact with technology to accomplish complex, collaborative tasks.

Author Keywords
Drumming, collaboration, turn taking, computer agent, coordination.

ACM Classification Keywords
H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous. CSCW.

General Terms
Experimentation, Performance.

INTRODUCTION
Music production is one of the oldest forms of human expression and, today, it has many different forms, meanings, and purposes. For example, people produce music for rituals, celebratory events, communication, entertainment, and spiritual necessities. An interesting aspect of music is its creation can be self-fulfilling; that is, the music is its own reward. Thus, the task of music production, as well as the factors that influence it, present a potentially rich task environment for the purposes of this study [17].

Music has been influenced by technological evolution. While electronic music has existed for several decades, an emerging trend is using commonplace electronic devices to create analog-sounding music. The widespread availability and use of new electronic instrumentation has redefined the notion of a novice musician. New instruments are expanding the limits of musicians and their musical creative process.

In collaborative rhythmic music production activities, the idea of leadership is important. While chaotic behavior can be meaningful, so can the stability provided by strong leadership. Leadership in a collaborative environment has been shown to be an important factor [12]. Leadership can be established and asserted with verbal communication, visual cues, or auditory signals. The flow of leadership between members of a group can be intentionally or unintentionally controlled depending on the needs of the group. Yet, the role of leadership when the task is as highly coordinated as digital drumming requires exploration.

In this study, we focus on the experience of working on the collaborative task of producing rhythmic music using a handheld interface to a drum-like synthesizer. Collaborative activities have the capacity to be better than the sum of their parts, yet making music is a classic example of a task that is at times associative; that is, a task in which the performance of the whole is gated by the least competent performer. We investigate the subjective processes associated with the task of rhythmic music production by inexperienced and experienced participants working collaboratively either with a human or computer partner to produce complex polyrhythm sounds. Specifically, we assess the subjective experience of music production and the performance-related auditory and visual cues involved.

RELATED WORK

Collaborative music has engendered its own literature on cooperation, synchronization, collaboration, and performance that is separate from the computer-supported cooperative work (CSCW) literature. However, key ideas, not surprisingly, do overlap across these research areas.

Cooperation and Synchronization

In *Modes and Mechanisms of Cooperative Work,* Schmidt states, "The articulation of the distributed activities in a cooperative setting normally requires the continuous formation among the members of the cooperating ensemble of a reciprocal awareness of the activities, concerns, and intentions of the other members of the ensemble" ([15] p. 60). This is a good summary of one of the main tasks in musical performance.

People bring different kinds of skills to this task. Crick [5] notes that humans are particularly good at anticipating and harmonizing with rapidly changing environments in real time. Drake [6] emphasizes the importance of these skills in relation to rhythm attention.

Crick [5] identifies a partial set of cues that participants use to direct cooperation. Participants may use *embedded* or *symbolic* representations to draw attention to a specific piece of information. *Ephemeral cues,* such as pointing at something, or *persistent cues,* such as monitoring other's actions may be used as well. *Obtrusive cues,* such as interrupting an activity to redirect action, or *unobtrusive cues* such as hinting at something are common cues.

Nijholt, Reidsma, Van Welbergen, Op Den Akker, Ruttkay [12] focuses on human and virtual human interaction. In their work, they discuss the implementation requirements of a virtual conductor. The virtual conductor assumes the leader role over a human orchestra. In order for the virtual conductor to effectively lead the humans, it must have prior knowledge and reciprocal awareness, as discussed by Schmidt [15]. It is not enough for the virtual conductor to recognize an erroneous tempo from one of the human musicians and immediately start playing the correct tempo, because the human musician will be lost. Instead, the virtual conductor must make small incremental adjustments, based off of reciprocal awareness as well as anticipated action.

Human-Computer Social Responses

In *The Media Equation* [13], Reeves and Nass found that media equals real life. "Individuals' interactions with computers, television, and new media are fundamentally social and natural, just like interactions in real life." ([11] p. 281). Nass and Moon [11] found that humans respond to social cues in the same way, whether the source is human or some piece of technology behaving as a human. Their study was grounded in social psychology, in which previous interaction studies of human-human pairs were replicated with human-computer pairing.

Shechtman and Horowitz [16] found contradictory results to the work of Nass and Moon [11]. Their study [16] was grounded in the principles of Interpersonal Theory. The main variable was whether participants were informed that they were communicating with a computer or human partner. Contrary to *The Media Equation* [13], Shechtman and Horowitz found that when participants believed they were communicating with a human, their behavior was more indicative of attempting to establish an interpersonal relationship.

Digital Music Skills

Collaborative digital music production is a dynamic, skilled task. It draws on general music skills and experience, but differs in some respects. Previous experience is thought to be helpful, but its relevance depends on a number of factors. One factor is the relevance of the physical skill developed on other instruments to the digital musical creation task. Blaine points out that physical mastery and musicality are partially separate attributes of the musician [3]. Just as a classically trained pianist, however musical, may have difficulty performing on the French horn, so too will she have difficulty performing on a digital French horn. Blaine found that limiting the number of notes/sounds an action triggers is related directly to the ease with which a new interface can be learned.

In the realm of spontaneous flow-through collaborative musical environments, musical complexity is not limited to the use of highly skilled instruments. Projects such as Machover's Toy Symphony [10] demonstrate the sophistication that can occur with even simple instruments.

However, differences in the previous experience of players can have a profound impact on the performance and the subjective experience. Blaine notes that mixed abilities among the musicians can cause group dynamic difficulties that lead to the exclusion of less proficient players [3].

Perhaps because they anticipate exclusion, inexperienced musicians often have fears about performing with other musicians or in front of others. Gurevich([7], p. 822) refers to this anxiety as the Amateur Musician's Paradox. "I want to play with other people, but I don't want to be embarrassed."

Tools such as Jamspace [7] address this anxiety by allowing inexperienced drummers to collaborate anonymously over the Internet with other various skilled drummers. This anonimity, at least in the Jamspace situation, helped drummers overcome issues of inhibition and intimidation.

Drumming itself is thought to alleviate some of these concerns, "By attributing less relevance to the importance of traditional music metrics based on melody, more emphasis can be placed on metrics that involve the player's experience" ([3] p. 3).

On cues

The present experiment explores coordination in paired drumming sessions. We focus on examining the experience of drumming *with* a partner, as opposed to evaluating the quality or quantity of resulting music. We attempt to mitigate the Amateur Musician Paradox by emphasizing the experience, promoting communication, employing a simple user-interface, and reducing the number of participants that the inexperienced drummer has to encounter.

The concept of a drum circles

The drum circle is an example of a collaborative music creation task that facilitates both inexperienced and experienced drummers. The drum circle is like brainstorming, in that it attempts to create an ethos in which everyone is invited to participate without criticism. Weinberg praises drumming circles for their, "…rhythmic, improvisatory and collaborative nature" ([18], p.1). Drum circles offer participants the ability to freely switch from a follower to a leader role [2]. This characteristic of drum circles was influential in our present data collection design involving a dyad of music production participants.

The meaning of expertise

Sophisticated use of cues is one marker of expertise. One of the interesting issues in examining collaborative drumming is the possible difference in the meaning of expertise in the area of such a highly coordinated behavior as compared to expertise in areas that have been more widely explored. One of the seminal findings about expert-novice differences is that experts tend to have "compiled" knowledge; that is, knowledge that is hard to break up into small pieces [8]. On the other hand, in studies of expert-novice behavior in resolving spatial location references, experts were able to adjust to the limited knowledge of novices in describing places in New York City within two utterances [9]. Because the skills involved in describing places in New York City from pictures are relatively simple (e.g., if your partner does not recognize the picture of "Rockefeller Center", it is easy to look at the picture and describe it as "the building with the flags") they are not precisely parallel to the skills associated with "compiled" expertise, such as chess playing. Questions remain about how experts adjust to novices in skilled, "compiled" activities. Furthermore, questions remain about how experts adjust to novices when the nature of the expertise is itself about coordination.

EXPERIMENTAL DESIGN

Our study was designed to investigate creative task collaboration with respect to coordination and the associated subjective processes of experienced and inexperienced drummer participants when they were paired with either experienced drummer participants or computers partners.

Participants

A total of 30 participants were recruited from the Research in Gaming list server, an undergraduate CyberArts class, and through word of mouth via a local drum circle. Twenty-one males and nine females participated in the experiment. The average age of participants was 24.3 years, with a standard deviation of 2.49 years.

Participants were divided equally into one of four types of pairings: *inexperienced human paired with experienced human, experienced human paired with experienced human, inexperienced human paired with computer,* or *experienced human paired with computer*. Each participant's experience level was assessed during recruitment and scheduling. Participants were asked if they had any prior experience with drumming activities. As a separate question participants were asked if they had any prior experience participating in electronic rhythm activities, such as rhythm driven adventure video games like Sony Computer Entertainment's Patapon [http://patapon-game.com] or multiplayer performance games such as Activision's Guitar Hero [http://hub.guitarhero.com]. Participants also were asked if they had any prior experience interacting in physical drum circles. Participants were allowed to elaborate on any question to which they answered as "yes."

As discussed earlier, expertise can be described as a person's compiled knowledge [8]. Three questions were chosen to evaluate participant rhythm abilities across analog and digital technologies. Participants were categorized as experienced drummers if they had professional experience in response to any of the three questions, or if they were had experience with any of activities in question for over 3 years. The computer was classified as experienced status, because of its structured playback.

It should be noted that the group *inexperienced human paired with inexperienced human* was intentionally avoided. The rationale was that in collaborative drumming events, such as drumming circles, a drummer's individual playing style would be influenced by the sounds around them [18]. To provide structure to the experiment activities, as experienced entity was present in every group.

Implementing an electronic drumming circle

Weinberg points out that electronic drumming circles are limited by the electronic reproduction and amplification of sound through speakers [18]. These cannot fully capture the richness of acoustic sound. This suggests a choice between accepting or fighting this limitation in the current study. Instead of competing with the real world implementation, we synthesized all sounds. Drummers were given a device that triggered sound playback through a set of stereo speakers. The computer also was set to play through a set of stereo speakers. Each partner's drum sounds were played through an individual set of stereo speakers as an attempt to simulate real world sound production, and to maintain a sense of individuality.

For the present work, we chose to use the program Digidrummer on commodity touch screen devices to enhance the capacity of collaborative flow. The final interface chosen for this experiment consisted of eight large touch sensitive button icons with a specific sound assigned to each.

Hardware environment

To maximize participant flexibility to move their input device to different positions during the drumming sessions, and to simplify the learning curve, Apple iPod Touch and iPhone devices were used. The basic hardware setup consisted of one Apple MacBook Pro 17" Core 2 Duo 2.33GHz laptop connected to one Apple iPod Touch device and one Apple iPhone device. Each iPhone or iPod Touch was connected to a Mackie 12-channel stereo mixer using 6-foot stereo 1/8" mini plug to ¼" plug cable.

The Mackie stereo mixer had two purposes. Because the Apple devices provided low audio output levels, the Mackie mixer provided the needed additional amplification. It also acted as an A-B-Y line splitter. That is, to maintain a sense of individual contribution and realism during the improvisation sessions, each participant heard their own device's sound, isolated, through a set of speakers sitting at their feet. This simulated the sensation of playing a set of bongo-style drums.

For the analysis portion of the sessions, each audio track had to be played back simultaneously. The mixer was used to package one participant's signal to the left channel and the other participant's signal to the right channel.

Four outputs emerged from the mixer; two were speaker outputs for monitor playback during each session, and two were used to relay audio signal to a M-Audio Firewire 410 mobile recording interface. The Firewire 410 converted analog audio to 24bit 96khz quality. Slight signal padding was used to adjust the signal from the mixer. The digital audio signal was transferred through an IEEE 1394 interface to the dedicated laptop.

Software environment

Participants interacted with Magnic Digidrummer [http://www.magnicksoftware.com]. Digidrummer provided an interface to a drum-like synthesizer that was developed specifically for handheld devices. Digidrummer is compatible across Apple's iPod Touch and iPhone platforms, making the two devices interchangeable for the purposes of this study. Digidrummer presented the participant with eight touch sensitive areas on the screen arranged in a two-by-four configuration. During the drumming sessions, participants were limited to the "Bongo King" preset of drums. This preset featured five bongo drums of varying pitch, two timbales, and a tambourine. The touch sensitive pads were pre-assigned specifics sounds and could not be reassigned. Participants could touch any combination of pads simultaneously to trigger multiple high quality sounds, simulating real-world use of multiple drums. During a pilot study where we compared several handheld drum-like synthesizers for the iPhone platform, latency was unreported by participants when using Digidrummer. Latency was not dependent on the number of simultaneous sounds triggered. Aside from single pad and simultaneous multi-pad triggers, participants had the ability to slide across any number of pads quickly to play back several sounds repeatedly. This technique also could be used between two pads to simulate a drum roll or similar trill effect.

Figure 1. Magnick's Digidrummer User Interface

The laptop was configured with Apple Garageband '09 version 5.0.1 [http://www.apple.com/ilife/garageband] for the study. Garageband is an audio recording suite that can record "real instruments", traditional instruments, or vocal parts that are captured using microphones or direct input. Garageband also records "software instruments", non-traditional input where USB, MIDI devices, or onscreen keyboard are used to create sounds using MIDI files and pre-defined loops. For the purposes of this study, each iPhone or iPod Touch device was assigned to an individual real instrument track. This allowed for simultaneous and individualized playback. Using individual tracks also allowed volume adjustment of each device, which was useful when listening to a human-computer paired session.

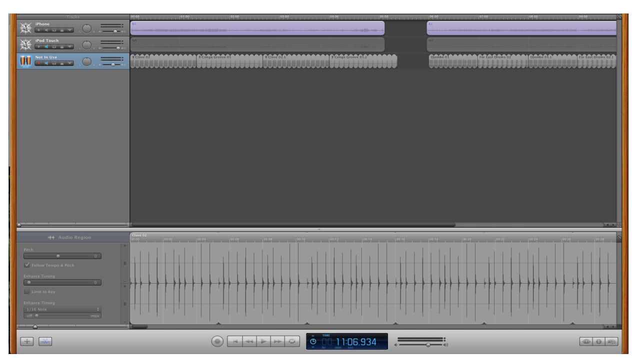

Figure 2. Apple Garageband Recording Interface

Another feature utilized in Garageband '09 in this study was the ability to handle loop creation. Loops are segments of music that are played back to back repeatedly to generate a longer piece of music. Traditionally drum tracks are a popular loop medium because of their rhythmic nature. For this study, two separate sessions were run per participant pairing. The first session consisted of two metronome click beats that looped for 75 seconds before alternating to the other beat. The second session consisted of two different beats. These beats were representational of real world drum sounds; one was an example of syncopation and the other emphasized varying tempo to create space. The second session alternated between loops every 60 seconds.

Garageband '09 also features global tempo control of a project. This feature was used to normalize the loops for each session to 90 beats per minute. The tempo rate was chosen from an informal study and proved to be a comfortable rate for participants.

Physical Setup and Instructions

For the drumming activity, participants paired with human partners were positioned in chairs initially facing each other 3 feet apart. Participants paired with a computer partner were initially positioned facing the computer 3 feet away at the opposite side of a desk. Initially in front of each participant on the desk was an Apple iPhone or iPod Touch and a set of computer speakers at their feet.

After a quick tutorial of Digidrummer, participants were given 2 minutes on their own to become familiar with the possible sounds and button configuration. Participants were allowed to talk to each other at any time. Participants were then told that their task for the day was to produce rhythmic music with their partner using the Digidrummer interface in 2 5-minute sessions. They were told that there were no restrictions on how they held their interface device, they were not restricted to only using their personal interface device, and they could choose to sit or stand at any time.

In order to normalize the human-human and human-computer pairings, each pair was presented with an example drum loop prior to the beginning of each session. Instructions were given that the example drum loop was meant only as possible inspiration, and not an instructional piece.

Last, participants who drummed with the computer partner were seated slightly angled toward the computer screen to facilitate possible visual cues from watching the display of the computer's progression through the loop on Garageband. This was not stated to the participants.

After the sessions were completed, the pairs reviewed their sessions by listening to audio-only copies of their sessions. They were asked to use a think-aloud technique to identify any points of the session that they felt they had strong coordination with their partner, or points where they felt they had poor coordination with their partner. These times and notes were logged for later review.

RESULTS

This section examines the survey response data, observations made during the drumming and analysis sessions, and several phenomena relating to rhythm creation and leadership roles, visual cues, and verbal communication.

Pre-Session Survey

Each participant was asked to complete a pre-study survey prior to beginning the drumming activity. The pre-session survey was used for demographic analysis purposes. In the pre-study survey, participants were asked about previous musical instrument training--83.34% of participants noted they had experience of one year or more playing an instrument. Separately, participants were asked about their drumming experience--53.34% of participants noted that they had actual drumming experience. Participants were asked if they were aware of what a drum circle was, and if so had they ever participated in one--53.34% of the participants noted they were aware of what a drum circle was, and 43.34% of the participants had some experience in a drum circle.

Participants were asked to identify the type of music they like to listen to, as well as several examples of each genre. This was used to gauge the diversity of the drumming groups. Of the 30 participants, 66.67% identified themselves as fans of rock or some derivation of rock (alt-rock, post-rock, classic-rock, punk-rock) music, 36.67% identified themselves as fans of classical music, 40.00% identified themselves as fans of hip-hop music, and 26.67% identified themselves as fans of country music.

In order to assess technological familiarity, participants also were asked if they had any experience using touch screen devices, such as the Apple iPhone or iPod Touch--86.67% reported having previous experience with touch screen devices.

Post-Session Survey

At the end of the session, each participant was asked to complete a post-session survey consisting of 15 questions. Four of these questions asked participants to rate the quality of their collaborative experience using a 1 to 5 subjective rating scale (a value of 1 indicated the least favorable rating, whereas a value of 5 indicated the most favorable rating). The collaborative experience qualities assessed by these four questions were: *enjoyment of activity, satisfaction/frustration of activity, importance of partner to activity,* and *recommendation of drumming experience to a friend. The remaining 11 questions on the post-session survey solicited open-ended comments about the collaborative drumming experience. Information from these latter 11 questions was not evaluated statistically; however, it was used to establish context for the experiment observations and the interpretation of the data trends.*

Data from each of the four subjective rating questions were organized into 2x2 factorial design matrices for statistical analysis purposes. For each 2x2 data matrix, there were two independent variables: *partner type* and *participant experience.* Partner type consisted of *human* or *machine*. Participant experience consisted of *inexperienced* or *experienced*.

Self-reported Enjoyment Level of Activity

		Partner Type	
		Human	Machine
Participant Experience	Inexperienced	Mean: 3.40 SD: 0.89 N: 5	Mean: 4.20 SD: 0.44 N: 5
	Experienced	Mean: 3.80 SD: 0.44 N: 5	Mean: 4.00 SD: 0.00 N: 5

Table 1. Self-reported Enjoyment Level of the Activity by Participant Experience and Partner Type

Both inexperienced and experienced participants reported enjoying the experience more when paired with the computer with an average rating of 4.1 (SD=0.31). When paired with a human partner, the average rating reported was 3.6 (SD=0.69) (Table 1), [$F(1,16) = 4.167$, $p = 0.058$].

Self-reported Frustration Level of Activity

		Partner Type	
		Human	Machine
Participant Experience	Inexperienced	Mean: 3.00 SD: 1.00 N: 5	Mean: 2.60 SD: 1.34 N: 5
	Experienced	Mean: 3.60 SD: 0.54 N: 5	Mean: 2.20 SD: 0.44 N: 5

Table 2. Self-Reported Frustration Level of the Activity by Participant Experience and Partner Type

Both inexperienced and experienced participants reported finding the computer partner less frustrating than a human partner (Table 2) [$F(1,16) = 4.909$, $p = 0.041$]. The average rating of frustration reported by inexperienced and experienced participants paired with a computer was 3.3 (SD=0.82), while those paired with a human reported an average rating of 2.4 (SD=0.96).

Self-reported Importance of Partner in Activity

		Partner Type	
		Human	Machine
Participant Experience	Inexperienced	Mean: 4.00 SD: 0.70 N: 5	Mean: 5.00 SD: 0.00 N: 5
	Experienced	Mean: 2.80 SD: 1.30 N: 5	Mean: 3.40 SD: 0.54 N: 5

Table 3. Self-Reported Importance of Partner Level of the Activity by Participant Experience and partner Type

Inexperienced participants rated the importance of the partner as 4.5 (SD=0.70), while experienced participants rated the partner as significantly less important, 3.1 (SD=0.99), [$F(1,16) = 15.680$, $p = 0.001$]. This was true whether the partner was a computer or a human.

Overall, both inexperienced and experienced participants rated the importance of a partner higher when paired with a computer with an average reported rating of 4.2 (SD=0.91). When paired with a human, inexperienced and experienced participants found the importance of a partner less important with an average reported rating of 3.4 (SD=1.17) (Table 3) [$F(1,16) = 5.120$, $p = 0.037$].

Self-reported Recommendation of Activity

		Partner Type	
		Human	Machine
Participant Experience	Inexperienced	Mean: 4.60 SD: 0.54 N: 5	Mean: 4.00 SD: 0.70 N: 5
	Experienced	Mean: 4.80 SD: 0.44 N: 5	Mean: 3.60 SD: 1.14 N: 5

Table 4. Self-reported Recommendation Level of the Activity by Participant Experience and Partner Type

Both inexperienced and experienced participants reported a high likelihood of recommending the drumming experience to a friend when their partner was a human with an average of 4.7 (SD=0.48). Inexperienced and experienced participants paired with a computer were closer to neutral in regards to recommending the experience with an average of 3.8 (SD=0.91) (Table 4) [$F(1,16) = 7.043$, $p = 0.017$].

Thus, results from the subjective rating post-session survey ratings were equivocal. On the one hand, by several measures, both inexperienced and experienced participants preferred to collaborate with the computer over collaboration with another person. However, they were more likely to recommend the experience to a friend if they had collaborated with a person.

Behavioral Analysis

The analysis of behaviors and subsequent descriptions by participants of their behavior revealed five themes: (a) an interesting relationship between drumming pattern creation, (b) leadership roles from experienced drummer's point of view, (c) the inexperienced drummer's view of leadership, (d) the use of visual cues, and (e) the use of verbal cues.

Drumming Pattern Creation and Leadership Roles

Each grouping of drummers demonstrated unique ways of creating rhythm and drumming patterns. The nature of leadership impacted how and when drummers created their individual drumming patterns.

The experience level of the participants and their partners was not revealed to any of the drummers during the data collection sessions. There was only one pair of drummers that discussed their prior drumming and musical instrument experience. Drummers evaluated each other's skill level by playing simultaneously. This auditory evaluation allowed drummers to quickly take on informal roles based on short samples of ability.

Inexperienced Drummer-Computer

In the inexperienced drummer-computer pairings, the inexperienced drummers viewed the computer as the group leader. The computer offered a consistency in rhythm and tempo that gave the inexperienced drummers a sense of guidance. The computer also offered examples of timbre that inexperienced drummers used to decide on which drum sound to trigger. In the post-session survey, inexperienced drummers discussed setting their tempo by finding the tempo of the computer's drum pattern. During the drumming session, two inexperienced drummers commented on trying to mimic the computer's drumming pattern with their own. One inexperienced drummer said, "The computer kept me on beat… I based my actions off the computer."

Experienced Drummer-Computer

Drummers in the experienced drummer-computer pairings used the computer in a similar way. Instead of mimicking the computer's tempo and drumming pattern, experienced drummers used it as a starting point. experienced drummers elaborated on the computer's drumming pattern, and would try to, as one experienced drummer stated, "fill in what was missing." Several drummers used a call-and-response method, where the computer would play a drum pattern and the drummer would play back a slightly modified counterpoint rhythm. Instead of trying to match exact timing, experienced drummers would focus on synchronizing one beat. In musical terms, if the computer was playing a rhythm in four-four timing, the experienced drummer would align one of their beats with the "one" beat.

Unlike the inexperienced drummers paired with the computer, experienced drummers did not like the computer having the leadership role. One experienced drummer commented, "This was one sided collaboration. My drumming had no effect on the computer." Another experienced drummer commented, "It's important to find something that goes with the computer's rhythm, it will naturally sound good."

Inexperienced Drummer-Experienced Drummer

In the inexperienced drummer-experienced drummer pairing, the importance of the partner played a different role. At the beginning of the sessions the inexperienced drummer would start by creating a simple rhythm. The experienced drummer would then try to supplement the rhythm by adding in more complexity. Each pairing used an informal call and response method in this way. After a steady rhythm had been established, one of the drummers would improvise a new rhythm on top of the current one. There was a significant use of visual cues during these sessions as well. During the drumming session, verbal communication was very sparse. Only one of the five pairs discussed a general approach before beginning to drum.

In the sessions where the experienced drummer assumed the leadership role, the experiences were different. In one session, the experienced drummer established a leadership role early on and directed the inexperienced drummer on what to do in terms of tempo and drum sounds to use. The inexperienced drummer stated during the analysis phase that she felt flustered during the session, "sometimes my partner would switch rhythms without saying anything."

Experienced Drummer-Experienced Drummer

In the experienced drummer- experienced drummer pairing, the use of random improvisation was more common. Three of the experienced drummers reported randomly tapping buttons for extended period of time, while the others reported intent to "make my partner sound good." Two drummers reported focusing on playing a steady beat for their partner to improvise from, and only taking a turn at improvisation once their partner had established a steady rhythm. Three drummers also noted a lack of a single leader during the sessions. Experienced drummers used visual cues such as head nods and eye contact to designate leadership flow. During the analysis phase, every group talked about the importance of "turn taking."

Visual Cues

Visual cues were used to establish grounding between partners, as well as elicit change of direction during drumming. Ephemeral eye contact was used as a confirmation communication method between partners. Partners also used visual cues, such as finger and foot tapping, to synchronize with the other's rhythm pattern.

Inexperienced drummer-Computer

In the inexperienced drummer-computer pairings, visual cues were surprisingly not important. Drummers focused their attention on the drumming interface and the drumming rhythm the computer created. In the post-session survey, one drummer commented on having trouble "connecting with the computer" because there was no movement to focus on.

Experienced Drummer-Computer

In the experienced drummer-computer pairings, the lack of visual cues was more problematic. Experienced drummers commented on relying on visual cues as signal for changing rhythms. In the post-session survey, four of the five experienced drummers in this group commented on having difficulty anticipating the computer's rhythm changes. One experienced drummer commented on having trouble finding a comfortable rhythm with the computer because there was no sign externalized rhythm.

Inexperienced Drummer-Experienced Drummer

In the inexperienced drummer-experienced drummer pairings, visual cues were used heavily. Inexperienced drummers reported using visual cues to synchronize rhythm and tempo with their partner. Inexperienced and experienced drummers would observe their partner's hands to help grasp the rhythm patterns, and their feet to find the tempo of the rhythm. There were several times when drummers were trying to decide on a drum to use, and one of the partners would say "that one" while pointing to a specific touch pad on the device. Inexperienced and experienced drummers appeared to differ on the amount of times they looked for visual cues. Once inexperienced drummers found a comfortable steady rhythm, they would focus their attention on the physical device. The experienced drummers would shift their attention between the drumming device and their partner throughout the improvisation session. When asked about this during the analysis phase of the study, inexperienced drummers were unaware of this. One inexperienced drummer responded, "Once I found a good beat I was afraid of losing it so I focused on my fingers." The experienced drummer of the pair responded, "I could have done this alone, but it was fun to have a partner for inspiration."

Experienced Drummer- Experienced Drummer

Experienced drummer-experienced drummer pairings also relied on visual cues. Similar to the inexperienced drummer-experienced pairings, experienced drummer-experienced drummer pairings used visual cues to synchronize their drumming patterns and tempos. Experienced drummers also used a combination of head bobs and eye contact to convey messages. For example, in one session the lead drummer would pass the leadership role to their partner by changing their drumming style to a steady rhythm, then make eye contact with the other drummer while nodding their head. When asked about this in the analysis phase of the study, both drummers acknowledged that it was an explicit sign of passing control. There was no need to verbalize the intended change of hands.

Verbal Cues

Verbal cues were sparse across all drumming groups, although there were noticeable verbal exchanges in some of the collaborative pairings.

Inexperienced Drummer-Computer

In the inexperienced drummer-computer pairing, two drummers exhibited verbal cues with the computer. Both drummers used groans and loud breathing indicative of frustration. This was confirmed by the post-session survey where they rated high frustration levels with the experience. One of the drummers also talked at the computer, saying things like, "Come on" and "That's it." In the post-session survey, the same two drummers said that the inability to communicate with their partners made it harder to anticipate upcoming rhythm changes.

Experienced Drummer-Computer

The experienced drummer-computer pairing also had drummers that used verbal cues. No drummer talked directly at the computer during these sessions. Three of the five experienced drummers groaned or made loud breathing exhale sounds. These sounds were indicative of frustration, which was also shown by their post-session survey responses. One experienced drummer stated in the post-session survey that the lack of verbal communication made the experience feel like practicing with a metronome and lacked the dynamic nature of a human partner.

Inexperienced Drummer-Experienced Drummer

Inexperienced drummer-experienced drumming pairs used more verbal cues. Four of the five pairings used verbal cues during their improvisation sessions. The verbal cues observed were command-like and sparse. "You go", "now", "not like that" and "okay gotcha" were the types of commands given. One pair of drummers discussed a drumming approach at the beginning of their session. Their discussion focused on who should hold a steady rhythm and who should "add flavor" or improvise. When the group started drumming the verbal cue usage was the same as the other groups.

Experienced Drummer-Experienced Drummer

The experienced drummer-experienced drummer pairs used very few verbal cues. Only one pairing talked while improvising. One of the experienced drummers told their experienced drummer partner, "not like that, slower." The other drummer quickly adjusted and the original experienced drummer made eye contact and nodded approval of the change. Two groups discussed a general plan at the beginning of their sessions, but did not verbally communicate once they began drumming. The plans discussed were focused more on types of rhythm and syncopation. In contrast to the inexperienced drummer-experienced drummer pairings, there was no assignment of roles discussed. The experienced drummers relied more on visual cues such as hand and foot movements, and changes in drumming patterns for direction.

DISCUSSION

This study examined subjective processes associated with collaborative work involving a creative music-creation task. Prior research has been extensive in this area and has pointed to the role of leadership in facilitating collaborative activities. However, past work has not examined the effects of leadership as a function of the participant's experience level with the creative task. Therefore, this study specifically examined the type of leadership available to the participants, which varied in their experience with the task.

It was found that participants experienced more enjoyment when paired with a computer than when paired with a human. It was also found that participants experienced less frustration when paired with the computer. Blaine [3] found that groups consisting of participants with mixed skill levels often have situations where the less skilled participant is excluded. This was the case in one of our experienced drummer-inexperienced drummer pairings, resulting in the inexperienced drummers wanting to be paired with a computer instead. From the post-session survey, inexperienced drummers paired with the computer found the lack of improvisation from the computer to be extremely helpful. The inexperienced drummers used the computer for guidance as to which drumming rhythms to make and which drum sounds to use. By performing with a computer partner, drummers were not exposed to Gurevich's Amateur Musician's Paradox [7], avoiding the possibility of performance anxiety when performing with another human.

An interesting phenomenon occurs when examining the role of leadership. From the post-session survey data, the role of a partner was more important to inexperienced drummers than to experienced drummers. This was an expected measurement. While inexperienced drummers found the importance of a partner important, it was expected to be for leadership. However, when examining the inexperienced drummer-experienced drummer sessions, the inexperienced drummers actually assumed the leadership roles. During all but one of the inexperienced drummer-experienced drummer sessions, the experienced drummers assumed a supplemental role allowing the inexperienced drummer to establish a comfortable rhythm. This trend leads to a distinct pedagogical style that contrasts the pedagogical style found in the inexperienced drummer-computer role. In the inexperienced drummer-computer pairings, the inexperienced drummer reported using auditory and visual cues from the computer to synchronize timbre and drumming tempo. This suggests that the nature of leadership in the case of drumming does not necessarily relate to having the most experience.

The call-and-response technique was used across drumming groups. This technique offered a method of grounding for inexperienced and experienced drummers. According to the post-session survey, inexperienced and experienced drummers would play shortened segments of the computer's rhythm pattern as a way to gain understanding to what the computer was playing. During the second improvisation session, drummers were presented with two rhythms, one with no space between loop cycles and one with an emphasis on space. Inexperienced drummers demonstrated the most difficulty playing along to the rhythm without space. In one case, the inexperienced drummer could not play any more than ten notes during the section. Experienced drummers emphasized techniques such as playing on the one beat, or keeping a steady simple count.

The post-session survey showed that participants were more likely to recommend the drumming when paired with a human partner than when paired with a computer. This is surprising considering that they also reported more comfort with the computer partner. The existence of a computer partner does alleviate issues such as the Amateur Musician's Paradox. It is also helpful in inexperienced pairings where guidance is needed. For an experienced drummer, the lack of improvisation and dynamic adjustment becomes apparent very quickly. The lack of verbal and visual cues limit the level of coordination the pair is able to achieve. As discussed by Schmidt [15], collaborative activities require a constant repeated reciprocal awareness of the activities of other members of the paired activity.

The actions and reactions of leadership differed between partner type and partner experience. When human drummers were paired with a computer, it was apparent to them that the computer was the leader. In the case of experienced drummer-inexperienced drummer pairings, experienced drummers allowed the inexperienced drummers to lead. This was not verbalized during the drumming session. In review of the post-session survey data, inexperienced drummers noted following the rhythm patterns of the experienced drummers. This unique pedagogy of indirect leadership was not found in any other pairings. In the experienced drummer-experienced drummer pairings, a flow of leadership was apparent. Drummers were able to use a combination of auditory and visual cues to control the direction of the drum circle rhythms. Interestingly, according to the post-session survey, the experienced drummer-experienced drummer pairings scored importance of partner lowest among pairings.

CONCLUSION AND FUTURE WORK

The findings of the present experiment provide insight into the experience of coordinated collaboration in a creative activity. In examining the production of music for its own sake, several issues were identified. The collaboration of a human working with a computer offers stability and safe experience for inexperienced drummers, but this type of collaborative pairing can be limiting and unsatisfying for experienced drummers. Also, the Amateur Musician's Paradox is minimized through computer pairing, as suggested by this experiment's observations.

The type of partner that participants were paired with was a consistent effect in the post-session survey questions. This effect confirms the notion that there are differences to working collaboratively with human or computer partners. Our findings align with the previous work of Chiasson and Gutwin [4] and Shechtman and Horowitz [16], which called into question a claim of *The Media Equation* [13] that people respond socially to computers, and more specifically, people respond similarly to social cues regardless of whether they come from a computer or human agent.

In this study, drumming pairs were located in the same physical proximity or space. For future work, a study of remotely located pairs would provide additional insight into the processes and experience of collaborative coordination. Furthermore, the audio produced in the present experiment required speakers in a common space. This audio configuration allowed third parties to overhear the musical composition and collaborative activities. Isolation of sound production to headphones or soundproof rooms may negate a potential source for anxiety among inexperienced drummers by decoupling the music performance aspect from the music creation aspect.

Another logical step for future work in this project would be to incorporate group dynamics while performing in drum circles. For example, it would be interesting to study how 5-10 participants experience collaboration while performing with computer partners simultaneously.

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