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Dubstep, Darwin, and the Prehistoric Invention of Music

Myles Karp
University of Pennsylvania

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Abstract
Where did music come from, and why are we so drawn to it? Though various scholars have offered a diverse set of hypotheses, none of these existing theories can fully encapsulate the complexity of music. They generally treat music holistically, but music is not monolithic. Musical ability encompasses myriad component parts, such as pitch perception and beat synchronization. These various musical elements are processed in different parts of the brain. Thus, it is unlikely that music arose in one place, at one time, in response to one evolutionary pressure. While existing theories can explain pitch-related aspects of music, such as melody and harmony, they fail to encapsulate rhythm. I explore rhythm's connection with motion, social function, and the brain in order to investigate how and why it may have evolved. In order to do so, I use diverse lines of evidence, such as my own ethnomusicological fieldwork, autism studies, and brain scans of monkeys. I hypothesize that the mirror neuron system, a mechanism in the brain that allows cognitive and physical synchronization, may be behind the connection between rhythm, movement, and social cognition. When eventually rhythm was joined with pitch manipulation activities, music as we know it was born.

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DUBSTEP, DARWIN, AND THE PREHISTORIC INVENTION OF MUSIC

By

Myles Karp

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Abstract:

Where did music come from, and why are we so drawn to it? Though various scholars have offered a diverse set of hypotheses, none of these existing theories can fully encapsulate the complexity of music. They generally treat music holistically, but music is not monolithic. Musical ability encompasses myriad component parts, such as pitch perception and beat synchronization. These various musical elements are processed in different parts of the brain. Thus, it is unlikely that music arose in one place, at one time, in response to one evolutionary pressure.

While existing theories can explain pitch-related aspects of music, such as melody and harmony, they fail to encapsulate rhythm. I explore rhythm's connection with motion, social function, and the brain in order to investigate how and why it may have evolved. In order to do so, I use diverse lines of evidence, such as my own ethnomusicological fieldwork, autism studies, and brain scans of monkeys. I hypothesize that the mirror neuron system, a mechanism in the brain that allows cognitive and physical synchronization, may be behind the connection between rhythm, movement, and social cognition. When eventually rhythm was joined with pitch manipulation activities, music as we know it was born.

In a study published in 2006, psychologists Josh McDermott and Marc Hauser set out to determine what kind of music a group of monkeys preferred. After carefully testing marmosets and tamarins, the duo arrived at the conclusion that monkeys don't care for music at all. Though the primates demonstrated some differential preference for slow rather than fast-paced music, they consistently chose silence over either (1). A number of other studies have demonstrated that music is simply lost on our furry cousins. Experiments with cebus monkeys prompted one researcher to conclude: "'Why monkeys can't hum a tune' must be clear: Because they don't hear them" (D'Amato 478). Non-human primates simply lack the neural mechanisms necessary to process musical input as something distinguishable from more general sound. To the primates, there is little difference between music and noise.

It may be useful to consider a popular philosophical query: If a tree falls in a forest and nobody is there to hear it, does it make a sound? This classic conundrum has been pondered and argued by philosophers and laypeople alike for over a hundred years. Though from most perspectives the answer is subjective, dependent on individual opinions of reality and experience, the scientific response should be unequivocal: No. The falling tree will cause vibrations in the air regardless of whatever animal or human is standing nearby, but these vibrations can only manifest as sound once processed by a brain. According to music psychologist Daniel Levitin, "Sound is a mental image created by the brain in response to vibrating molecules" (*This Is Your Brain on Music* 22).

Now, a slight adjustment: If a boombox plays in a forest, and no humans are there to hear it, does it make music? If there are bears, monkeys, and deer in this forest, the boombox does make a sound, since there are ears and brains present to receive and process the air vibrations. However, in the absence of a human brain, there is no music. Just as sound is a mental image created by the brain in response to vibrating molecules, music is a mental image that can be created only in a human brain in response to molecules vibrating in a very particular way. The monkey perceives sound, but not music; that is why monkeys cannot hum a tune and why they choose silence over music.

If non-human primates' aversion – or indifference – to music seems surprising, it should be enlightening to step back and think about how much more remarkable is the human affinity for it. Every known human society, extant or extinct, has partaken in the creation and consumption of music (Nettl). We spend billions of dollars each year to hear it, and it accompanies or underlies every ritual, from prayer to a stroll through the shopping mall ("Recording Industry by Numbers"). A particular organization of pitches can move us to tears, whereas another can make our hairs stand on end in chilling discomfort, and another can galvanize us to the practice of frenzied arm-flailing and leg-stomping that we call dance. As a species, we take our organized sound seriously. To us, music is much more than noise.

Given the great discrepancy between the abilities to perceive musical sound in humans and our closest phylogenetic relatives, it's clear that something important happened in the 5-7 million years since humans split evolutionarily from the rest of the primate pack (Stringer 242). To search for the origins of music, we cannot simply dig for early bone flutes and percussion instruments. This pursuit would be akin to looking at the archaeological record of shoes and roller skates to investigate the origins of bipedalism. Musical instruments are tools to facilitate the creation of music, but long before we felt it necessary to build such tools, our neurology had to evolve to allow music in the first place. How and why our brains underwent this change is not immediately clear. This is not as easy a conundrum to sort out as the evolution of traits like bipedalism and the preference for sugary foods. Those traits have clear adaptive value, and thus Darwinists can easily explain their appearance and proliferation. Music does not have such a clear function. Numerous scholars, however, have presented hypotheses.

EXISTING HYPOTHESES OF MUSICAL EVOLUTION

The sexual selection theory

Darwin himself touches on the subject in his work *The Descent of Man, and Selection in Relation to Sex*, boldly claiming that the faculties of music creation and perception "must be ranked among the most mysterious with which we are endowed" (878). Documenting numerous examples of animal sounds, he points out that many of these sounds are produced only by males, and exclusively during the mating season. Animal vocalizations have no clear survival value; some birds even sing until they die of exhaustion. With this evidence, Darwin posits that animal sounds persist in evolution as mating signals. He argues that human music presents a similar reproductive advantage, suggesting that early humans "endeavored to charm each other with musical notes and rhythm;" the most successful charmers are the evolutionary winners, leaving the most offspring (880).

Evolutionary psychologist Geoffrey Miller has extended this sexual selection hypothesis. According to Miller, music "has costs but no identifiable survival benefits. Therefore, it is most likely to have evolved due to its reproductive benefits" (337). To illustrate this discrepancy, he offers the case study of Jimi Hendrix; the guitar icon's sexual prowess and promiscuity were perhaps as legendary as his musical skill, but his survival skills were less adept, as he overdosed at age 27. Hendrix was able to increase the frequency of his musical genes in the next generation not by any survival advantage but because of his access to mates. Perhaps more convincing evidence is the fact that musical skill and reproductive potential peak around the same time in development, during adolescence (337).

The sexual selection model relies on biologist Amotz Zahavi's handicap theory, which is best demonstrated by the example of peacock tails (205). A large and colorful tail is energetically expensive to grow and maintain, and it makes a peacock more conspicuous to predators as well as less able to outrun them; it presents a clear survival disadvantage. However, peahens prefer such tails, because they signal that the peacock and his ancestors have had access to so much energy and were so fast that they were able to survive and procreate despite the handicap. Thus, sexual selection places pressure on the evolution of the handicap (207). Music, because it demands the adept use of myriad cognitive functions and even physical stamina, signals to potential mates that the performer has plenty of brainpower and energy to spare.

The social bonding theory

Another faction of scholars has posited that music evolved as a social adhesive, allowing groups to flourish by enhancing cooperation and sociability. Neuroscientist Walter Freeman invokes music as a way for humans to transcend the gulf of "epistemological solipsism" (411). Freeman's research has demonstrated that each brain constructs knowledge in unique patterns, and as knowledge increases, this neurological individualism – or more formally, epistemological solipsism – compounds so that brains become more distinct. During human evolution, group size increased as our species developed social and cooperative tendencies; manners of bridging the solipsistic gap between individuals became necessary in order to engender allegiance and trust. The same neurochemicals that bind together sexual partners in trust – and possibly even that elusive phenomenon sometimes referred to as "love" – could be triggered by synchronized, cooperative behaviors such as singing, chanting, and dancing.

> "What is at issue is the extent to which feelings of bonding and formation of a neural basis for social cooperation might be engendered by the same neurochemical mechanisms that evolved to support sexual reproduction in altricial species like ourselves, and that might mediate religious, political, and social conversions, involving commitment of the self to a person as in transference, fraternity, military group, sports team, corporation, nation, or new deity. The common feature is formation of allegiance and trust." (420)

Freeman clearly believes the social and societal implications of the creation of trust, allegiance, and cooperation are enormous, and any behavior that achieves this effect would be evolutionarily advantageous. This, he claims, is the origin of music, although as a neuroscientist rather than an evolutionist, he leaves the exact mechanisms of the trait's nascence unclear.

Scientists have demonstrated a compelling double dissociation relating to sociability and musical ability. Sufferers of Williams syndrome (WS), a rare genetic disorder caused by a missing portion of genes on the seventh chromosome, experience significant cognitive impairment in nearly all domains of intelligence and functioning

("Musical Behavior in a Neurogenetic Developmental Disorder" 326). However, skills relating to language, face recognition, music, and sociability remain intact or enhanced. Musical ability and interest are higher in WS sufferers than in people of normal cognitive development. They develop musical interests earlier, listen to more music, play more music, and experience more music-evoked emotion than control subjects (327). Furthermore, brain scans have shown that individuals with WS have left auditory cortices that are more than twice as large as those of controls; enlarged left auditory cortices are present in professional musicians as well (Wengenroth et al. 2). In parallel, WS sufferers are extremely social and notoriously trusting of others, demonstrating "uninhibited and often inappropriate friendliness," often hugging strangers. They make frequent eye contact, a trait uncommon in non-WS individuals with similar IQs.

On the other hand, sufferers of Autism Spectrum Disorder (ASD) display impairment in both musical and social realms. A team of Scottish scientists have demonstrated that a lack of rhythm and synchrony is an early warning sign for autism (Trevarthen and Daniel S25). In addition, autistic individuals have difficulty understanding the emotional expressivity of music as well as speech (Bhatara et al. 220). Social impairment is the defining feature of ASD. Individuals with ASD demonstrate difficulties understanding normal social interaction, non-verbal communicative clues, and the emotions of others. An inability to socialize is an early flag-raiser for ASD. Thus, the double dissociation is this: Sufferers of WS are highly social and highly musical, where as sufferers of ASD are antisocial and amusic (exhibiting deficiencies in musical faculties). These results suggest that social functioning and musical functioning are related.

The auditory cheesecake theory

A few thinkers have played devil's advocate to the adaptationists, most notably the prominent psychologist Stephen Pinker. In *How the Mind Works*, he proposes that music is simply a by-product of the evolution of language and other traits (a spandrel, in more technical terms), commandeering the neurological structures developed specifically for those traits and using them for an activity that confers no adaptive benefit (534). He used the now-infamous analogy "auditory cheesecake" to describe music in this evolutionary context (534). Just like cheesecake takes advantage of our evolutionary preference for fats and sugars but itself is too concentrated to offer nutritional benefit, music takes advantage of our abilities to hear the pitch and prosody that language uses more subtly. Although language is the main ingredient in Pinker's cheesecake, he also invokes auditory scene analysis, emotional calls, habitat selection, and motor control as precursors to music, as well as "something else… that explains how the whole is more than the sum of the parts" (538).

Though the music and language connection has been explored by a host of scholars, Pinker's attribution of musical elements to the abilities of auditory scene analysis merits further consideration. Though only humans have language, some non-human animals possess certain abilities that we consider musical, such as simple octave generalization (Wright et al. 1) and, to some degree, consonance perception (Izumi 3073). These traits cannot be explained by the evolution language if their possessors do not also have language. However, auditory scene analysis could account for very basic pitch-relation processing. Some animals emit low-frequency sounds in order to appear larger as a defense strategy; this behavior indicates that the ability to process lower and higher pitches must be common in non-human animals (Cross and Woodruff 4). Of course, pitch is much more complex in music, but this evidence indicates that at least some basic aspects did not arise as byproducts of the evolution of language.

Language from music

Some scholars, most notably Robin Dunbar, have posited theories that are somewhat antithetical to that of Pinker. Music didn't spring from language; it was the other way around. Much of Dunbar's primatological research concerns grooming, or the practice of mutual cleaning, usually involving an individual removing nits, dirt, and dead skin from another. Though hygiene is certainly at stake, the practice seems to be most important in the formation and maintenance of social bonds. Grooming facilitates the release of endogenous opioids and endocrines such as oxytocin, which serve to reinforce affiliative social interaction, creating mutual trust and intimacy (Dunbar 257). The amount of time a primate engages in grooming with another is proportional to its willingness to provide "coalitionary support" for that partner (258). Because of the centrality of grooming in the maintenance of social bonds, primates that live in larger groups spend more time each day grooming. During the course of human evolution, human groups grew to exceed the group sizes of any other primate. Such sizes would demand a quantity of grooming time that would leave insufficient time for other necessary activities, such as searching for food. Dunbar proposes that language evolved to replace grooming as a more efficient method for achieving these bonding effects. Whereas grooming demands full attention and monopolizes the hands, humans can chat while engaged in other activities, they can do so at a distance, and they can talk to many people at once. Thus, they could maintain social bonds efficiently and still find time to mate, sleep, and forage for food.

According to his estimates, hominid group sizes must have surpassed the limit for which traditional social grooming is feasible around two million years ago. However, the earliest estimates for the emergence of speech and language are in the realm of half a million years ago (262). There was a long transitional period, during which anatomical evidence suggests no abrupt change in cranial volume (a metric for intelligence); the emergence of language was not a sudden epiphany.

Dunbar offers music as an intermediary step between grooming and language. When group size initially approached the upper limit for grooming, an increase in "contact calling," a secondary social exchange in Old World primates, would have helped mitigate the time pressures. This upsurge in the frequency and importance of contact calling could have developed into musical chorusing. Music could be an effective prelinguistic bonding agent because it activates emotions and its performance in a communal context releases the same endorphins that allow grooming to reinforce social bonds (263). Speech would have eventually developed as a result of the diversification of preexisting vocal communication modes.

The musilanguage theory

Perhaps neither music nor language can claim primacy. The musilanguage theory suggests that music and language share a common ancestor, which Steven Brown calls musilanguage, which eventually split into the two systems as we recognize them. Brown argues that those basic components that are shared by music and language – namely lexical tone, combinatorial formation of small phrases, and expressive phrasing principles

– must have characterized musilanguage (279). Musilanguage itself, he suggests, may have evolved from preexisting primate vocal communications (291). The divergence of the two modes encompasses both analogous features, which would have developed from shared ancestral features, and distinct features, which arose independently. Distinct features include language's propositional syntax (questions) and music's isometric rhythms (292).

Brown remains mum about the reasons for the divergence and increased specialization of the two realms. Archaeologist and evolutionary psychologist Steven Mithen, however, hypothesizes that as language acquired the ability to convey specific meaning, music remained to communicate wordless emotion. Further specialization would have occurred in order to reinforce these distinct roles, evidenced by music's important place in religion and ritual (Mithen 273).

SHORTCOMINGS OF EXISTING THEORIES AND NEW DIRECTIONS

Initial origins: Where is the clay?

Though the aforementioned scholars have offered compelling insights, it seems unlikely that any of these existing hypotheses could fully explain the evolution of music. Although the sexual selection and social bonding theories describe different reasons why music would have been sustained as an adaptation to evolutionary pressures, they fail to offer any perspective on the initial origins of music. Evolution needs something to act on, and so the sexual selection and social bonding models necessitate at least a primitive form of music in order to spur further development. Geoffrey Miller flaunts his refusal to consider music's initial conception:

> Identifying an adaptation and its function does not require telling the phylogenetic story of how it first arose at a particular time and place in prehistory, and how it underwent structural transformation through a series of intermediate stages. Even for morphological adaptations, biologists often have no idea when the adaptations that they study arose or exactly how they reached their current form. For most psychological adaptations that leave no fossil record, it is not even possible to reconstruct phylogeny in this sense. Nor is it necessary. Adaptationist analysis does not worry very much about origins, precursors, or stages of evolutionary development; it worries much more about current design features of a biological trait, its fitness costs and benefits, and its manifest biological function. This is good news for theories of music evolution. It is just not very important whether music evolved 200,000 years ago or 2 million years ago, or whether language evolved as a precursor to music. The adaptationist's job is to look at the adaptation as it is now, to document its features and distribution within and across species, and to test hypotheses concerning its biological function against this evidence. (336-337)

Considering his article was published in a volume called *The Origins of Music*, Miller seems stubborn in this staunch refusal to contemplate music's origins. He is correct that this is no easy mystery to solve, but he is not correct in his assertion that it should not matter. Many if not most analyses of adapted traits do consider the nascence of those traits, even though it is often the most difficult component to sort out.

Because evolution needs something to act on, it does seem likely that certain aspects of musical behavior would have sprung from other behaviors that either already existed or were evolving for more definitive purposes. This is especially true given the unclear adaptive benefits of music. In order for the pressures of social bonding or mate-seeking to artfully sculpt music into the phenomenon we now know and love, they need an initial lump of clay. Where is the clay? The theories that posit the coevolution of music and language (in any order) do address origins, and language is a good jumping-off point, since the evolutionary benefits of language are clear and definite. Such theories, therefore, account for the emergence of proto-musical elements, in that they arose with language, in response to these clear pressures that created language.

Music is not monolithic

A crucial shortcoming of these theories (as well as the social bonding and sexual selection theories), however, is that they generally treat music holistically. They discuss when music evolved, how music evolved, and why music evolved. However, music is not monolithic. The phenomenon of music represents the sum total of myriad component parts, from octave generalization to polyrhythm perception. Many of these components are very different from each other, and they can exist independently. No melody or harmony exists in drum circles; no pulse or meter can be discerned in Hindustani alap.

Furthermore, the processing of these disparate components of music is similarly decentralized in the brain. Musical behavior activates cortical structures as diverse as the amygdala and Broca's area. Isabelle Peretz, Anne Sophie Champod, and Krista Hyde have performed tests on adults who could be considered variously amusic, or lacking in the ability to create and perceive music. However, their findings indicate a complex variety of deficiencies that are independent and dissociable (Peretz, Champod, and Hyde 1). A subject lacking in the ability to discern the difference between pitches might be able to tap in time to a rhythm as well as a control. Essentially, there is no particular music structure in the brain that is either functioning or non-functioning. This complexity makes it highly unlikely that music emerged as a unified element, in one place and at one time, in response to one set of evolutionary pressures. This is another blow to the hypotheses that offer a single adaptive function for music. Scholars who offer imagery of proto-human hominids or early humans singing and dancing around a campfire as support for a sexual selection or social bonding hypothesis fail to capture the cognitive and behavioral complexity of music. If these theories are true – which they may be, at least partly – these functions could have taken hold only after many separate elements of music evolved independently and were eventually joined; pitch perception alone would be an ineffective mating call. Thus, these theories explain not adaptive functions of music but exaptive ones, gaining relevance only after music's primordial clay began to take shape.

In order to sort out the more complex and nuanced evolution of musical elements rather than the holistic evolution of music, it is useful to make certain distinctions. Overall, the elements of musical behavior can be grouped relatively effectively into the pitch-based and the temporal. Pitch-based aspects of music involve the manipulation or perception of different vibration frequencies, which the brain allows us to understand as pitches. Pitch-based aspects of music include melody, harmony, scale structure, octave generalization, and interval perception. Temporal aspects of music, such as rhythm and meter, involve the organization of sounds into patterns of time.

This broad dichotomous categorization is not arbitrary. Scientific studies corroborate the fact that rhythmic and melodic elements are separate not only in music but also in our cognitive perception of music. In their amusia studies, Peretz and Hyde found that subjects' deficiencies in melodic and harmonic aspects of music exist independently of whatever rhythmic ability he or she retains, and vice versa (Hyde and Peretz 1). With practice, subjects who were melody-deficient were able to improve their rhythm but unable to improve their pitch perception. Lesion studies have reinforced this dichotomy of pitch and rhythm. Patients who have impairments in melody perception generally have lesions in the right hemisphere, whereas rhythm-deficient patients often have injuries in the left hemisphere, although other areas are involved (Sacks 106).

As explained above, elements of music can exist independently not only in the brain but also in the music itself. However, broadly speaking, rhythm and pitch-based elements are the most dissociable. It is easy to create melodic non-rhythmic music (such as Hindustani alap) and rhythmic non-melodic music (percussion ensembles). However, it is more difficult to separate from each other those elements that fall under the same broader category. Harmony is inconceivable without scale structure, which in turn is inconceivable without octave generalization. It is difficult to conceive of meter without a regular rhythmic pulse. The analytical division of music into pitch-based/melodic and temporal/rhythmic elements is clearly articulated in music, both perceptually and cognitively.

Rhythm and language

McDermott and Hauser as well as Justus and Hustler have posited that if an element of music can be shown to be innate and cannot be explained as a byproduct of another more clearly adaptable phenomenon such as language or auditory scene analysis, support emerges for an adaptationist theory of musical evolution. If such an element cannot be found, there is no reason to reject the hypothesis that music came to be as a byproduct of other practices like language. The authors could find no such element. However, neuroscientist Aniruddh Patel criticizes these analyses, and rightfully so, for their narrow focus on pitch perception ("Musical Rhythm, Linguistic Rhythm, and Human Evolution" 99). Rhythm was largely ignored.

Keeping in mind the multiplicity of musical elements, a reexamination of the music-language coevolution theories reveals a crucial lapse. The evolution of language simply cannot account for musical rhythm. Language does have some semblance of rhythm, and these overlap somewhat with rhythmic aspects of music. Patel has explored the connections between linguistic rhythm and musical rhythm comprehensively. A prominent overlap is what he calls "perceptual grouping, the mental clustering of events into units (e.g., phrases) at different hierarchical levels" (99). Such grouping exists in both music and language. Both mark boundaries in similar ways and distinguish between levels; the brain seems to process this grouping in the same place for both practices. However, there is a crucial difference between musical and linguistic meters:

> "Turning from grouping to meter, the story is quite different. In every culture there is some form of music with a regular beat, a periodic pulse that affords temporal coordination between performers and elicits a synchronized motor response from listeners (Nettl, 2000). Although early theories of speech rhythm proposed an underlying isochronous pulse based on stresses or syllables (Abercrombie, 1967; Pike, 1945), empirical

> data have not supported this idea (Bertinetto, 1989; Dauer, 1983), and contemporary studies of speech rhythm have largely abandoned the isochrony issue (e.g., Grabe & Low, 2002; Ramus, Nespor, & Mehler, 1999)." (100)

Language has something like meter; it builds hierarchies based on the prominence or stress on certain syllables. However, it does not have this regular pulse – the beat – that defines musical rhythm. A regular pulse is central to rhythmic synchronization. Patel emphasizes that beat perception and synchronization – or BPS, in his terms – is unique to music and cannot be explained as a byproduct of the evolution of language.

Brown, the principal proponent of the musilanguage theory, argues that although he believes that music and language coevolved, a regular rhythmic pulse was incorporated into music after the schism of the two forms:

> "Finally, at the rhythmic level, music acquires the distinct feature of isometric time keeping, so much a hallmark in Western culture. This metric-pulse function is based on a human-specific capacity to both keep time and to entrain oneself rhythmically to an external beat." (293)

Perhaps melody and harmony piggybacked on language and auditory scene analysis, but the beat – that regular rhythmic pulse that serves as music's backbone – came from somewhere else.

Rhythm and movement

Another factor that separates rhythm from language and other such functions – and one that also offers clues to its origins – is its intimate connection with movement. Anecdotally, I know this connection is strong; in the presence of music, I find it simply impossible not to tap or snap along. Others are compelled to clap and dance. This clapping, snapping, stepping, and other similar musical movements may today generally accompany recorded music. However, it also *is* music. Rhythm is produced by movement, and it in turn incites movement.

Rhythm is inherently physical, and this connection between movement and rhythm is apparent in the brain. Numerous studies (Grahn and Brett; Zatorre, Chen, and Penhune) have demonstrated that in the creation, perception, and even imagination of rhythm and beats, motor areas of the brain are activated. These areas include the dorsal premotor cortex, the cerebellum, the basal ganglia, and the supplementary motor area. It is remarkable to consider that merely listening to a beat can saturate those motor areas to such an extent that an often irresistible urge to move is created. Rhythm is the communication of movement at a distance; it is musical mind control.

Language elicits nothing comparable to this physical response; it is unique to music. Legendary ethnomusicologist John Blacking argues for the centrality of embodiment in music, the inseparability of music and movement (241). Music as a concept has involved both movement and sound for all societies across time and space. We have structured and cultivated the motor response to music as dance, and we take it seriously.

Some proponents of the preexisting theories of musical evolution have acknowledged the connection between movement and rhythm. Mithen posits that rhythm stemmed from the evolution of bipedalism:

> Rhythm, sometimes described as the most central feature of music, is essential to efficient walking, running and, indeed, any complex

> coordination of our peculiar bipedal bodies. Without rhythm we couldn't use these effectively: just as important as the evolution of knee joints and narrow hips, bipedalism required the evolution of knee joints and narrow hips. (150)

Pinker's account implicates motor coordination more broadly, not only that which is specific to bipedalism:

> Repetitive actions like walking, running, chopping, scraping, and digging have an optimal rhythm (usually an optimal pattern of rhythms within rhythms), which is determined by the impedances of the body and of the tools or surfaces it is working with. A constant rhythmic pattern is an optimal way to time these motions, and we get moderate pleasure from being able to stick to it, which athletes call getting in a groove or feeling the flow. Music and dance may be a concentrated dose of that stimulus to pleasure. (537)

Some elements of motor coordination and rhythm certainly coevolved, but these hypotheses cannot account for rhythm sufficiently. Humans are not the only animals that walk, run, and exhibit complex motor actions; why do we alone have rhythm? These scholars ignore a crucial aspect of rhythm. Music in general, but especially its rhythmic aspects, is a strongly interpersonal practice. It is typically created and consumed in groups, and synchronization among members of the group is key to the function of rhythm. Musical rhythm involves not only keeping a steady pulse but also the ability to synchronize with an external stimulus; we need our pulses to synchronize with the pulses of other individuals if we are to collectively engage in rhythmic practice.

Synchronization to an external pulse is rare in the animal world. Though crickets, frogs, and fireflies seem to produce synchronous periodic signals, Patel argues that these practices do not meet the criteria for genuine beat processing and synchronization:

> Yet such displays differ from BPS in important ways. Notably, humans can synchronize to complex rhythmic stimuli (not just simple pulse trains), can sync across a wide range of tempi, and show cross-modal synchronization, with an auditory stimulus driving the motor system in periodic behavior that is not (necessarily) aimed at sound production. Synchronous animal displays do not show these features. ("Investigating the Human-Specificity of Synchronization to Music" 1)

Entomological research suggests that the signals of crickets and katydids result not from attempts at synchronization but rather from the efforts of each male insect to call before the others; females are attracted to "leading calls" ("Music, Language, and the Brain" 408). Rather than matching their calls to a common pulse, these male insects adjust their calls each cycle in attempts to emit the leading call, and the overall result resembles synchronization.

A particularly striking example of the inability of non-human animals to synchronize with external beats and with each other comes from the Thai Elephant Orchestra. Studies of this all-pachyderm musical group have showed that although each elephant can keep a remarkably steady beat, they cannot synch up their beats (408). Beat synchronization does not extend to these supposedly musical animals. The "rhythm" that the elephants do have is merely a solitary timekeeping mechanism; it lacks the central interpersonal (or inter-elephantine) element that musical rhythm necessitates.

The ability to collectively synchronize to a regular pulse, coupled with the strong physical reaction to rhythm, leads to the unique human behavior of dancing, which is as universal as music itself. Blacking's writings emphasize the inseparability of music and movement. According to Blacking, some cultures do not even distinguish between sonic music and dance (241). This connection could offer clues about the social aspect of music as well, since dance is a strongly communal and social phenomenon. I undertook extensive ethnomusicological into the nature of music, rhythm, dance, musical embodiment, and social function. After a detour to describe this research, I will return to evolutionary implications.

RHYTHM IN THE REAL WORLD: ETHNOMUSICOLOGICAL FIELDWORK

A Survey of the Ethnomusicology

With generous financial support provided by an Andrew W. Mellon Undergraduate Research Fellowship and an Anthropology Undergraduate Summer Research Fellowship, in the late spring and summer of 2011 I embarked upon a national tour of music festivals and concerts. In order to investigate how social, biological, and musical factors influence listeners, I attempted to maximize the variety of events I attended. These ranged from formal classical music performances with a seated audience to outdoor punk rock concerts with violent mosh pits (from which one friend emerged with a fat lip and another emerged without his camera). I observed performances of diverse genres including Brazilian forró, orchestral interpretations of the Beatles, Syrian electronic music, dubstep, hip-hop, salsa, jazz, informal drum circles, reggae, ambiguously musical spoken word poetry, folk, and New Orleans second-line. Performance times spanned from shortly after dawn to well after four in the morning. I attended a concert in Manhattan's iconic Carnegie Hall as well as a music festival in the woods of rural West Virginia, a considerable distance from urban civilization. I attempted to account for variables like genre, audience size, time of day, musical particulars, and setting in order to figure out what really mediates audience engagement – what factors most strongly activate those cognitive mechanisms that allow the perception of music and their connections with observable phenomena like movement and social interaction.

Cultural context certainly mediates audience engagement. At certain venues and in performances of certain genres, social rules are codified about what behavior is appropriate and what behavior is inappropriate. For example, classical music concertgoers are expected to sit politely, silent and still, throughout the duration of the performance, clapping only between pieces. At venues associated with classical music, such as Carnegie Hall, architecture recapitulates this code of etiquette; a floor covered with seats, with no space for dancing, emphasizes that sitting is the only option during the performances there. One particular anecdote captivates the rigidity of this etiquette code. I saw the Beninoise singer Angélique Kidjo perform danceable pop and soul music at Carnegie Hall; when she implored the audience to dance, the tension between the rhythmic, high-energy musical style and the perceived etiquette of the venue was clearly visible. Only a few concertgoers rose out of their seats and danced, while most of the audience nervously looked around, one by one sheepishly standing up and dancing hesitantly. The vast majority of the audience remained seated throughout.

Another factor mediating audience engagement was the engagement of others. Put simply, dancing begets dancing. The All Good Music Festival in West Virginia afforded me a unique opportunity to view this phenomenon from a vantage point that was raised above the audience. Two stages were located at the front of the outdoor space, with a large field in front of the stages. Framing the field was a tall hill; sitting on this hill gave me a bird's-eye view of the field, where the crowd congregated in front of the stages. First and foremost, large audiences were conducive to a strongly engaged audience. In the presence of dancing, others dance. Just as a large, densely packed crowd would facilitate the spread of an infectious disease, so it facilitated the spread of dancing. The infectious disease metaphor was indeed apt for describing the geography of audience engagement. From my hill, I could see that dancing spread from particular epicenters, around which concertgoers danced with intensity that gradually decreased with an increase in distance from the epicenter.

By far the most important factor determining the degree of physical engagement with music was rhythm, and especially a regular beat. The stronger and clearer the beat, the more the audience responded physically. Even though classical music has only a limited and un-emphasized percussive element, its failure to incite dance in listeners could be explained away by the aforementioned code of etiquette. However, even at the Bonnaroo Festival in Tennessee, where some of the approximately 80,000 attendees often chose to forego social conventions such as clothing, audiences sat, stood still, or only gently swayed during performances by Iron and Wine, and Explosions in the Sky (Kavner 1). The former is a folk musician who emphasizes lyrics and delicate harmonies, whereas the latter is an instrumental post-rock band with a focus on lush textures rather than rhythm. If rhythms became too complex to discern a clear beat, people simply stopped dancing, as was the case during many occasions at the West Oak Lane Jazz

Festival in Philadelphia, where performers sometimes aimed to display their virtuosic command of their instruments by modulating time signatures and playing jumbled, complicated rhythms. When the beat was simple and clear, people resumed dancing.

I found that physical response is not mediated at all by pitch-related aspects of music. Change in harmony and melody did not influence the bodies of concertgoers whatsoever. The melodic aspects of music could simply stop, and as long as the beat continued, listeners would simply keep dancing, with no indication of a change. If there was a strong, simple, discernable beat, the music on top could feature any instrument or lyrics in any language, and the dancing impulse would be the same. On the contrary, any change in the beat of the music generated a direct physical response. If a beat slowed down or sped up, people would adjust their dancing accordingly. On some occasions, especially during electronic music performances, a beat would temporarily stop while the harmony and melody continued. During these instances, concertgoers would cease dancing, anticipating the resumption of the beat. Upon the return of the beat, dancing would resume as it was before. Even a deaf observer could watch the audience and get a good sense of the music's beat and emphasis on rhythm. However, this hypothetical observer would have no clues about the pitch-related aspects of the music.

I have witnessed this same phenomenon in experiences with my own musical groups. I am a member of two samba groups, a Middle Eastern percussion group, and a rock band. From the stage, I can see that people dance the most enthusiastically when there is a clearly elaborated rhythmic pulse. In samba music, higher-pitched drums called repiniques, tamborims, and caixas often play fast, complex, and syncopated rhythms while large bass drums called surdos keep a regular pulse. When the surdos cut out temporarily, people generally stop dancing; as soon as they come back in, reinforcing the pulse, dancing resumes.

These findings corroborate and enhance the connection between rhythm and movement. The fact that rhythm is processed in motor areas of the brain is no mere trifle; it has real, observable effects, as manifested by patterns of dance.

Dubstepping in Time

Of all the performances I observed during my ethnomusicological tour, none produced audience responses comparable to those of a genre called dubstep. In fact, the physical engagement, overall energy level, and dancing of the audience at this summer's dubstep concerts far surpassed anything that I had ever witnessed in my 21 years of life. In colloquial terms, the kids go wild for dubstep.

Developed in the late 1990s, dubstep is characterized by a relatively slow pulse and extremely prominent rhythmic basslines, known somewhat onomatopoetically as "wobble" bass. The basslines often have no discernible melody, foregoing pitch-related elements in favor of a strong emphasis on rhythm. In 2010, dubstep broke through to the mainstream, bootstrapped by extremely popular performers such as Skrillex and Skream. A testament to his meteoric rise to popularity, Skrillex was nominated for five awards and won three at the 54th Annual Grammy Awards in February 2012 ("Nominees and Winners"). The summer of 2011 represented the culmination of a year or so of a rapid and consistent increase in the genre's notoriety, to the degree that Skrillex and other DJs including Bassnectar, Deadmau5, and Pretty Lights performed to the largest and most enthusiastic audiences at music festivals like Lollapalooza and Bonnaroo.

The "wobble bass" and its strong emphasis on rhythm was certainly a central factor in dubstep's galvanization of its audience to dance. Dubstep artists made a point to make the rhythmic basslines as loud as possible; at his set at Bonnaroo, Pretty Lights blew a speaker. In other words, the bass was too powerful even for the gigangtic state-of-the art speaker system, and the equipment broke.

Have you seen Molly?

There is, however, another very important factor mediating the physical response incited by dubstep in its audience: drug use. The genre is strongly associated with the drug MDMA (3,4-methylenedioxymethamphetamine), the active ingredient in the substance commonly known as ecstasy. More recently, MDMA has acquired the street name "Molly," and those under its influence are said to be "rolling."

The exact effects of MDMA on human physiology and cognition are not precisely understood. Because of the drug's restricted legal status, it cannot be studied using the standard scientific double-blind methodology (Parrot and Lasky 261). The available sources of information are anecdotal studies of users, medical case studies following serious complications, and animal studies (261). Anecdotal descriptions can provide insightful accounts of MDMA's effects on mood and behavior, but they have limited potential in an investigation of the neural mechanisms behind those effects. Medical case studies do little to elucidate the normal effects of the substance, since the complications that lead to situations requiring medical interference are rare and often the consequence of a combination of factors beyond the drug itself. Animal studies are useful in studying the neurology of the drug, but since monkey and especially rat brains are very different from human brains, they cannot paint the complete picture.

Scientists do have a general if imprecise understanding of MDMA's neurological effects. The drug increases extracellular levels of serotonin (5HT) and to a lesser extent dopamine (DA), both neurotransmitters associated with positive emotions and reward, in the nucleus accumbens (White et al. 473). Beyond this fact, our understanding of the neurology gets muddled:

> However, the potential ways in which this increased extracellular DA and 5HT might interact with presynaptic and postsynaptic receptors to alter neurotransmission in the nucleus accumbens and in brain regions that project to the nucleus accumbens are exceedingly complex. As a further complexity, the projection neurons from the nucleus accumbens do not seem to act as a functional unit, but rather constitute numerous input/output "neuronal ensembles" that are functionally distinct (Pennartz *et al*., 1994). Almost nothing is known to date about whether MDMA may affect differentially distinct ensembles within the nucleus accumbens… The ability of MDMA to alter neurotransmission in the brain is not restricted to brain regions that are implicated in the rewarding effects of abused drugs. MDMA produces the facilitation of somatic motoneuron excitability that would be expected of a drug that increased extracellular levels of 5HT, DA and NE. It is very likely that MDMA increases extracellular levels of monoamines in every brain region that contains substantial numbers of monoaminergic terminals, and so can mimic most of the neurophysical effects of monoamines. (473)

In layman's terms, we understand that the increased serotonin and dopamine mediate most of the drug's effects, but we are not sure how, and we also have a limited understanding of the effects beyond the increased extracellular levels of these neurotransmitters.

MDMA was initially synthesized by Merck and patented in 1914 as an appetite suppressant, although it never enjoyed popularity as such (Burgess, O'Donohue, and Gill 287). In the 1950s, the United States Army ran a series of tests to investigate its use in espionage and counter-espionage endeavors (Grob and Poland 374). During the late 1960s and early 1970s, when a number of psychotropic drugs experienced upsurges in popularity, it MDMA enjoyed a brief renaissance under the name "love drug" (374).

Later in the 1970s, the drug came to the attention of Alexander Shulgin, a Berkeley biochemist, who recommended it to psychologists and psychiatrists due to its apparent stimulation of heightened empathy (374). Especially on the West Coast of the United States, MDMA became extremely popular as an aid to psychotherapy. Pyschologists called the substance "Adam" for its induction of "the condition of primal innocence and unity with all life" (374). Around this same time, it experienced another uptake in recreational use, especially on college campuses in California and Texas. The story of the arrival at its more popular and enduring street name is particularly interesting:

> Indeed, the transformation of MDMA as "Adam" into MDMA as "ecstasy" appears to have been a marketing decision reached by an enterprising distributor searching for an alternative code name, who concluded that it would not be profitable to take advantage of the drug's

> most salient features. “Ecstasy was chosen for obvious reasons,” this individual later reported, “because it would sell better than calling it ‘Empathy.’ ‘Empathy would be more appropriate, but how many people know what it means?” (375)

The steady increase in the drug’s recreational popularity led to a comprehensive investigation by the United States Drug Enforcement Administration in the mid-1980s. The end result of the relevant hearings was the DEA judge’s 1986 recommendation that MDMA be classified as a Schedule III controlled substance, meaning that it was safe for use under medical supervision (375). The DEA director, however, overruled the recommendation and instead placed MDMA into Schedule I, the most restricted category of drugs under the Controlled Substances Act.

Following these highly publicized legal debates, recreational use among youth skyrocketed. By the late 1980s, MDMA was the drug of choice at large-scale dance parties called “raves” in both North America and Europe (375). These raves generally featured techno music and dancing for audiences of up to 10,000 (375). In a review of MDMA and its association with dance club culture, scientists Richard Schwartz and Norman Miller described the spectacle as “Ravers engaged in marathon, vigorous group dancing with expensive laser light displays illuminating the darkened building (706).” Ecstasy became strongly associated with techno, dance, and rave cultures on both sides of the Atlantic. Most survey respondents indicated that they mostly took ecstasy at “dance clubs;” and it is this rave culture to which ecstasy’s rise in popularity can be attributed (Grob and Poland 375). In this era’s techno music, rhythm reigned:

> "The most important thing about the electronic revolution was the unremitting, ineluctable repetitive drum and bass…. Rhythm has always been an important quality of pop music, but with its precision and monotony, and played at high volume, it became almost hypnotizing in character." (Ter Bogt et al. 160)

When the popularity of raves dwindled in the late 1990s, so did recreational MDMA use, although evidence suggests it remained relatively level in Europe, and particularly the United Kingdom (Grob and Poland 375).

What I witnessed this summer was a dramatic resurgence in the popularity of MDMA, known this time around as Molly, coincident with the ascent of dubstep. At any given dubstep performance, the ubiquity of Molly was clear. Concertgoers passed around small plastic bags filled with white powder, dipping their fingers and rubbing them on their tongues. Some members of the audience hawked the drug, while others sought it, furtively asking questions such as "Have you seen my friend Molly?" At one point during the Pretty Lights performance at Bonnaroo, a crowdsurfing dubstepper yelled emphatically to the rest of the audience, "Who loves Molly?!" Equally enthusiastic cheers constituted a collective response.

The ubiquity of luminescent accessories at dubstep performances was also astounding. Nearly all concertgoers adorned themselves with glow-in-the-dark necklaces, bracelets, and facepaint. Attendees swung flashing luminescent hula hoops around their hips, wore light-up gloves, and even waved around strobing plastic swords. Some dubsteppers erected glow totems, large sculptures held and swayed above the head that ranged in scope from "glow maces" made of glowsticks stuck in foam pool noodles to a giant multi-person Chinese-style dragon costume fashioned partly out of LED lights. The omnipresent luminescence recalls a similar emphasis on lasers and glow sticks from the earlier rave period; it is likely that these related phenomena stem from MDMA's supposed ability to create light trails – a lingering of light such that a glow stick waved in a circle might be perceived as a full circle of light – in the vision of those under its influence (Greer and Tolbert 376).

As a musical form, dubstep's connection with MDMA almost certainly stems from its strong emphasis on rhythm. As described, dubstep emphasizes a steady percussive pulse with basslines that reinforce the rhythm, such that the bass is more of an auxiliary drum than a melodic instrument. Melody and harmony can be present as well, but some dubstep artists, such as Bassnectar, Excision, and Datsik, barely feature any pitch-related musical elements at all. Anecdotal accounts elucidate that MDMA use strengthens a connection with music but especially with rhythm, and it incites a strong urge to dance.

I conducted a series of informal surveys of MDMA users, and the majority of respondents indicated that they mostly took Molly or "rolled" at electronic music concerts, specifically those of dubstep. The following excerpts elucidate the subjective feelings of the interaction of MDMA, music, and dancing.

"It really makes you *feel* the music, in a more literal way, which in turn makes you feel it in a figurative way as well. Depending on the kind of music, there are different things that stand out, but rhythm is probably the most significant. And since you are typically around a bunch of people dancing together, it makes you feel connected to them through the music... There's something to the idea of really feeling music in your body, and all you want to do is dance." – 22 year old female

"It definitely allows you to feel music, particularly the rhythm of it. I don't think it's necessarily a deeper intellectual connection… It definitely makes me want to dance. It's a special kind of dancing: slower, more grounded, more connected." – 20-year-old female

"MDMA absolutely allows the user to feel a deeper connection with music. The beat, especially in electronic music, feels as though it is pulsing through you, almost as a second heartbeat… Dancing appears to take no effort or thought at all. Very rarely am I conscious of any dance moves that I want to perform; rather, I tend to move my body and arms in ways that feel the most natural in the context of the music. I would describe it as feeling like a highly sophisticated marionette, with specific elements of the music acting as individual strings controlling the body. Many times I have actually caught myself moving without being consciously aware of the movements I was making, but finding them to work well with the music and finding that I was moving in a much more skilled way than I previously thought I could." – 22-year-old male

"It feels really great to dance around, especially if there's good loud music playing. Your body just sort of does its own thing, which can be really cool if you're typically not a good dancer." – 20-year-old male

“I feel like [the music] is almost connected to my body in some way… I feel like the whole electro scene is dedicated to making rhythms that sound good when you’re on MDMA. I love the rhythm of electronic music. When I hear the music, like I said, it feels almost like it’s taking me over. I’m so in with the song that it just kind of moves my body. It’s just like, it becomes a part of me. It just comes almost connected with the elation I have of being on the drug. It moves you like a puppet.” – 20-year-old male

The anecdotal evidence suggests that MDMA’s connection with dance music is not merely circumstantial; the drug itself seems to create an active engagement with the music. The metaphors of feeling the music and especially acting as a puppet to the music suggest that the reaction is strongly physical, representing the embodiment of the rhythms, which act to control the movements of the listener on a subconscious level. MDMA allows music to exert somatosensory control over its subjects.

As attested by the psychologists of the mid-20th century and the recreational users of its “love drug” phase, MDMA certainly has the non-musical effect of increasing feelings of empathy and sensations of connectedness with others:

“I felt the need to talk to everyone I met and find out who they were.” – 22-year-old male

“It really makes you feel connected to people as well – much more compassionate and even sometimes in awe of the people around you… It's not going to make you suddenly trust the creepy dude in the unmarked van or anything dangerous like that, but there is definitely a sense of deeper empathy and acceptance of the people around you." – 22-year-old female

"One of the strongest emotions that MDMA brings out in people is a feeling of closeness and empathy with those around you." – 22-year-old male

This dual effect of MDMA to increase both connection to rhythm and social connections to others strengthens the idea that rhythm and social function have mutual underlying mechanisms. This neural bundling suggests an intimate evolutionary connection between the two realms, social and rhythmic. But what is the nature of these mechanisms? Recent scholarship from the disciplines of neuroscience and psychology may offer some telling clues.

MIRROR NEURONS: MINDS READING MINDS

In 1992, a team of Italian scientists led by Giacomo Rizzolati published a paper called "Understanding Motor Events: A Neurophysiological Study" in the journal *Experimental Brain Research*, after it had been rejected by *Nature* for "lack of general interest" (Rizzolati and Fabri-Destro 223). They reported that they had observed certain neurons in the ventral premotor cortex of a monkey which fired both when the monkey performed an action and when the monkey observed the performance of that same action, either by another monkey or a human (223). Though the initial findings were met with relative apathy, since then, the scientific community has taken the idea and run with it. These neurons have acquired the name "mirror neurons" for the ability of their possessor to mimic the brain activity of an observed actor. In 1996, reports were published of indirect evidence of an analogous mirror system in humans (Rizzolati et al.; Grafton et al.). Direct evidence of mirror neurons in humans was not offered until 2010 ("Social Neuroscience: Mirror Neurons recorded in Humans" 1). Although initially recorded in one particular cortical area of monkeys, the present literature suggests that mirror properties are distributed widely throughout the cortex (Rizzolati and Craighero).

What do these mirror neurons do? As mentioned, they activate upon both the performance and the observation of an action. The brain essentially creates a micro-representation of the cognitive activity of the individual it is observing. This allows for easier imitation of such an observed action, since the brain prepares for the performance of this action through the micro-representation of the mirror neurons. Arguably more importantly, however, mirror neurons allow an understanding of the intentionality of an action. Rizzolati and Fabri-Destro offer the following illustration of this phenomenon:

> Social life is based on our capacity to understand the behavior of others. Let us imagine this situation. John and Mary are in a pub and John's hand comes into contact with a mug of beer; Mary immediately understands whether he is grasping it or not. Moreover, according to how he grasped it, she can also understand *why* he is doing it (e.g., for drinking or for giving the mug to a friend). How does Mary understand the goal of the John's motor act and the intention behind it?
>
> One possibility is that she is using an inferential reasoning elaborating the acquired visual information through some cognitive mechanism (see Frith and Frith 1999; Csibra and Gergely 2007). Another possibility is that this is not necessary in this simple situation, and the

> understanding of what John is doing and why he is doing it, is acquired through a mechanism that directly transforms visual information into a motor format. The proprieties of mirror neurons support the existence of such a mechanism. (229)

The roles and implications of mirror neurons extend far beyond the realm of motor activity. Studies have shown that in addition to offering a co-representation of motor experience, mirror neurons provide a similar co-representation of emotions and sensations ("Towards a Unifying Neural Theory of Social Cognition"). When we see another individual experiencing pain, we flinch. Borrowing neuroscientist Christian Keysers's example, "If we see a spider crawling on James Bond's chest in the movie Dr. No, we literally shiver, as if the spider crawled on our own skin" (385). If we see a peer experiencing disgust, fear, or sadness, our mirror neurons take cues from facial expressions to create a neural representation of those emotions so that we understand the experiences of the observed individual. This is the neuroscience of putting oneself in another's shoes, although it happens automatically. Mirror neurons, thus, play a central role in empathy and social cognition.

The implications for imitation, understanding of intentionality, and co-representation of emotion and sensation are enormous. V.S. Ramachandran, a neuroscientist who has championed the importance of the mirror neuron system and contributed significantly to the mirror neuron literature, argues that this neural mechanism could underlie the "great leap forward" in human evolution. Though other primates – and even birds – have mirror neuron systems, humans likely have the most developed mirror mechanism (Prather et al.). Around 250,000 years ago, hominid brains reached their current sizes, but it was not until about 40,000 years ago that the archaeological record shows a relatively sudden explosion of productivity after hundreds of thousands of years of cultural stagnation. Around this time and shortly after, we see archaeological evidence of cave art, clothing, a marked increase in the diversity and complexity of tools, and other hallmarks of human culture (1). Ramachandran implicates the abilities of imitation and understanding of intentionality as afforded by mirror neurons in the rapid spread of such ideas, and since technology compounds, this constituted a "great leap."

Although the connection between mirror neurons and music has been little explored in formal studies, the emerging scholarship is compelling. Neuroscientist Istvan Molnar-Szakacs and musician/neuroscientist Katie Overy published a paper exploring the role of the mirror neuron system in the processing of music:

> Until the recent advance of recorded music and synthesized sounds (relative to human evolution), music has always been associated with motor activity. From drumming to singing to virtuosic sitar playing, the production of music involves well- coordinated motor actions that produce the physical vibrations of sound. The experience of music thus involves the perception of purposeful, intentional and organized sequences of motor acts as the cause of temporally synchronous auditory information. Thus, according to the simulation mechanism implemented by the human mirror neuron system, a similar or equivalent motor network is engaged by someone listening to singing/drumming as the motor network engaged by the actual singer/drummer; from the large-scale movements of different

> notes to the tiny, subtle movements of different timbres. This allows for co-representation of the musical experience, emerging out of the shared and temporally synchronous recruitment of similar neural mechanisms in the sender and the perceiver of the musical message. (236)

Molnar-Szakacs and Overy posit that mirror neurons underlie the human ability to understand individual actions as component parts of larger hierarchically organized sequences of actions, which is central to music production and processing (236).

But what of recorded music, where there are no visual cues as to the motor actions behind the music? Studies show that the activation of mirror neurons does not require a visual stimulus; mere sound can serve to activate the mechanism. FMRI analyses performed by Valeria Gazzola, Lisa Aziz-Zadeh, and Christian Keysers demonstrate that a "left hemispheric temporo-parieto-premotor circuit" responds both to the execution of an action and to the sound of the execution of that action (1824). The team compared the degrees of the subjects' mirror neuron activity with their scores on an empathy scale and recorded a correlation between the two properties (1824). This correlation indicates that those mirror neurons that correspond to different functions – in this case, social empathy and the auditory system – are not independent. The mirror neuron system is at least somewhat unified.

Electronic music is generally created with software rather than tangible instruments; there is little motor action behind it, besides the typing of computer keys. Likely, however, this has little bearing on the brain's ability to extrapolate a motor signal behind a sound; mirror neurons respond to both human and robotic actions. Gazzola and her team have demonstrated through fMRI scans that the mirror neuron system activates as strongly to a robotic arm and claw performing simple motor tasks as it does to a real human arm and hand performing those same actions (1674). Thus, it is likely that in the case of electronic music, a listener's mirror neuron system infers the kind of motor activity that might underlie a similar auditory signal, as if the synthetic drums were their tangible three-dimensional analogs, struck by human hands.

I propose that the mirror neuron system is more important for rhythmic processing than for the processing of pitch-related aspects of music. No formal studies have parsed the different components of music and analyzed the mirror neuron activity related to each, but I can offer significant indirect evidence. I have thoroughly expounded upon the connection between motor systems and rhythm, both in the brain and in responsive behavior. Additionally, with the percussive and rhythmic behaviors of drumming, clapping, and dancing, the brain has a clearly elaborated motor signal on which to base a mirror neuron response. Activities like singing, likely the first pitch-related musical activity, do provide motor cues and certainly a basis for mirror neuron activity, but not as strongly as rhythmic behavior. The vigorous bowing of a violin or slide action of a trombone would offer a strong motor stimulus, but complex harmonic instruments would not have been constructed until musical structures (and tool-making abilities) in human cognition were established enough to spur these innovations. Once again, we would not have invented roller skates before evolving bipedalism. Clapping, stomping, and percussive beating on solid objects would have always provided the mirror neuron-activating motor stimulus, but they do not require such a degree of technological innovation. Furthermore, the auditory mirror neurons found by Gazzola, Aziz-Zadeh, and Keysers are concentrated in the left hemisphere, where rhythm processing is more prevalent than pitch processing (Sacks 106).

The concept of synchronization, so central to musical rhythm (and importantly absent from elephant "rhythm"), absolutely necessitates a co-representation of a musical experience, and understanding of intentionality, and the ability to place an action in a larger hierarchical sequence. It involves an intimate cognitive and physical connection between the sender of a signal and the receiver of a signal, and it in turn creates this connection mutually among multiple senders and receivers. Mirror neurons must be behind beat synchronization, the central concept of musical rhythm. Mirror neurons, then, are also undoubtedly behind the related concepts of dance and differential engagement with rhythmic versus non-rhythmic music. Rhythm conveys an auditory (and, if performed live, visual) signal that includes information about the motor actions behind the sound, even if, in the case of electronic music, there is no actual motor action. A strong, clear beat engages the mirror neuron system strongly, as the signal is clear and easily decipherable. When a beat gets exceedingly complex and a pulse is difficult to discern, this engagement likely wanes, as the signal becomes more difficult to encode, and listeners stop dancing. Dancing begets dancing, and physical engagement spreads interpersonally, because in the presence of others being similarly engaged, a concertgoer's mirror neuron system is stimulated not only by the music but also by surrounding individuals.

A wealth of recent scholarship associates autism spectrum disorders with a deficiency in the functioning of the mirror neuron system. Autism is characterized by a lack of empathy, the inability to understand the emotional states of others, and a diminished ability to socialize ("The Simulating Social Mind" 311), which are the exact functions mediated by the mirror neuron system. This connection is more than speculation; neuroscience has offered much hard evidence to back up these claims (Oberman, Ramachandran, and Pineda; Oberman et al.). Recall the autism-Williams syndrome double-dissociation that has been offered as evidence of a common neural substrate of music and social function. Sufferers of Williams syndrome are highly social and highly musical despite overall cognitive impairment, whereas sufferers of autism are generally anti-social and amusical. Mirror neurons could underlie this discrepancy, since autism has been associated with a dysfunctional mirror neuron system, and the mirror neuron system underlies both music and social cognition. Unfortunately, no studies have been performed to test mirror neuron function in sufferers of Williams syndrome, but it is likely that they would have highly sensitive mirror neuron systems.

As is consistent with my ideas, I can connect the aforementioned phenomena more specifically to rhythm, rather than music in general. It is often said that autistic people are highly amusic, but a more thorough investigation of these claims reveals that the musical dysfunctions of ASD suffers generally lie within the realm of rhythm rather than music's pitch-related aspects. It is established that autistic people exhibit a lack of rhythm and synchrony (Trevarthen and Daniel S25). However, autistic amusia does not extend to the realm of pitch; in fact, people with autism and ASD have a significantly higher incidence of absolute pitch, the exceedingly rare ability to identify a pitch without any referential pitches for context (Brown et al. 163). The proportion of musical savants with autism is also strikingly high, which would seem to attest to overall musical ability (Heaton et al. 291). However, although strong senses of pitch-related musical elements would be required for, say, virtuosic solo piano performances, these solo performances would not require synchronization with any external beat; such savants rarely perform in ensembles. Therefore, while sufferers of ASD have dysfunctional rhythm and synchronization, their pitch-related abilities seem to be intact or even enhanced. Suffers of Williams syndrome are highly social and seem to have a particular propensity for rhythm (Levitin and Bellugi 357), although the comparison of their rhythmic and melodic abilities is somewhat contentious. This evidence is further support for a strong link between rhythm and social function, mediated by the functioning of the mirror neuron system. In a discussion of hypothetical autism treatments, Oberman and Ramachandran offer one final striking piece of evidence to tie together some of the seemingly disjointed accounts I have offered:

> Another novel therapeutic approach might rely on correcting chemical imbalances that disable the mirror neurons in individuals with autism. Our group (including students Mikhi Horvath and Mary Vertinski) has suggested that specialized neuromodulators may enhance the activity of the mirror neurons involved in emotional responses. According to this hypothesis, the partial depletion of such chemicals could explain the lack of emotional empathy seen in autism, and therefore researchers should look for compounds that stimulate the release of the neuromodulators or mimic their effects on mirror neurons. One candidate for investigation is MDMA, better known as ecstasy, which has been shown to foster emotional closeness and communication. It is possible that researchers may be able to modify the compound to develop a safe, effective treatment

> that could alleviate at least some of autism's symptoms. ("Broken Mirrors: A Theory of Autism" 68)

Oberman and Ramachandran suggest, based on its reputation for inducing empathetic feelings, that MDMA bolsters mirror neuron activity. My musical line of evidence offers another complementary angle of support for their hypothesis, which in turn strengthens my case. The anecdotes of my MDMA-using interview subjects are exactly consistent with a stimulated mirror neuron system. The drug increases engagement with rhythmic music, the desire to dance to a steady beat, and empathy. The metaphors of feeling the music and being moved like a puppet by the music represent a maximized embodiment of the musical phenomena, afforded by the brain's understanding and synchronization with the rhythmic stimulus.

Many of the inferences I have made are speculative and will remain so until scientists with access to expensive neuroimaging technologies explore these questions in a more concrete manner. However, I believe that through the integration of various sources of evidence, a clear picture begins to emerge: The connection between musical rhythm and social cognition has a real neural basis. This underlying neural basis is the mirror neuron system.

WHO WAS THE SCULPTOR?

A summary of my case thus far is this: Existing hypotheses that posit the coevolution of music with language or the piggybacking of music on structures pre-evolved for activities like language and auditory scene analysis cannot sufficiently account for rhythm. The regular pulse that defines musical rhythm is absent in language, and our ability to process this pulse and synchronize with it is seemingly unique to humans. Rhythm, movement, and social cognition are intimately connected through their mutual neural substrate, the mirror neuron system. The mirror neuron system is the clay from which the rhythmic arms and legs of the musical sculpture were built. But who – or what – was the sculptor? Which evolutionary pressures molded the clay into something we now recognize as musical rhythm?

The mirror neuron system is not unique to humans. It was discovered in monkeys, and subsequent studies have shown it to be common in the primate order. Even birds have demonstrated mirror neuron activity. Therefore, the mirror neuron system was not evolved solely for the purpose of rhythmic behavior. It is an ancient mechanism, and, evidenced by the variety of important functions it serves, there are alternative evolutionary pressures that would have spurred its development. But then why do birds and monkeys not drum and dance? How did rhythm arise to capitalize on the mirror neuron system's unique abilities to connect our bodies and minds? I will offer a few possibilities.

Although we share the mirror neuron system with a host of other animals, the human mirror neuron system is the likely the most developed and complex. No studies have compared the degree of mirror neuron activities in various species. However, we do have an understanding of different species' needs for the functions that mirror neurons allow. Mirror neurons play important roles in social cognition. Humans have by far the most complex social systems of all primates, and it is generally accepted that social intelligence was a principle driving force in human evolution (Byrne and Whiten 1). Mirror neurons also allow the understanding, imitation, and synchronization of complex motor actions that would be indispensible in functions like tool use, building, battle, hunting, and even language. If the mirror neuron system is at least somewhat unified, then evolutionary pressures that selected for social cognition and the abilities to build and use tools would spur the evolution of a more complex and developed mirror neuron system, with rhythm as a byproduct.

Although rhythm and rhythmic behavior are absent from non-human animals in nature, one extraordinary animal has seemingly been able to master dancing in captivity. A male sulfur-crested cockatoo named Snowball attracted attention from a 2007 YouTube video in which he bobbed his head up and down and stomped his foot rhythmically in synch to the song "Everybody" by the Backstreet Boys (Studying Synchronization to a Musical Beat in Nonhuman Animals 459). Aniruddh Patel and his colleagues, previously strong proponents of the idea that beat perception and synchronization are uniquely human abilities, conducted studies on Snowball in order to probe his musical abilities. They determined that Snowball was exhibiting genuine rhythm. The perceived ability of one cockatoo certainly is not enough evidence to revolutionize our ideas of rhythm; however, it offers some interesting possibilities. Although the human mirror neuron system is certainly more complex and developed, birds do have mirror neurons. If Patel's studies are accurate and if Snowball is not special, it seems that humans may share their basic neural underpinnings for rhythm with certain species of birds. Since no other primates have been able to acquire rhythm, this would be an episode of convergent evolution. What do we have in common with birds that we do not share with other primates, who lack the ability to acquire rhythm in captivity? According to Patel, it is vocal learning (827). Only some species, including humans, certain birds, and some marine mammals have vocal communication systems that rely on imitation. These systems require a tight connection between auditory and motor circuits in the brain; it is this connection that allows for both vocal learning and rhythm (though he makes no mention of mirror neurons). This is consistent with the theories that posit the coevolution of music and language. This data provides support for the idea that rather than the evolution of a general unified mirror neuron system, the evolution of auditory mirror neurons in particular and their connection with motor mirror neurons gave rise to rhythm. The mirror neuron systems of monkeys and apes, not vocal learners, would not have evolved such a strong neural connection between auditory and motor mirror neurons, and they thus cannot synchronize to a beat.

It is certainly possible that rhythm itself presented an adaptive advantage for any number of reasons. Beyond its neural connection to social cognition, rhythm has functional connections to social cognition as well. As presented by the proponents of the social bonding theories of musical evolution, music binds us together in action and psychological state, fostering closeness and cooperation among a group. Rhythm can accomplish these feats without melody; imagine a group drumming and dancing around a fire, as is a pervasive image in the literature of the social bonding theorists (*This Is Your Brain on Music* 258). Freeman argues that rhythm is the musical component most capable of engendering trust and cooperation among members of a social group:

> The strongest basis for cooperation lies in rhythmically repeated motions, because they are predictable by others, and others can thereby anticipate and move in accord with their expectations. Music gives the background beat. (420)

If rhythm itself presented this adaptive advantage, then it is possible that in addition to the augmentation of the general mirror neuron system, evolution worked to shape stronger auditory mirror neurons in particular and bolster their connection to those in the motor areas of the brain. In this case, rhythm is an adaptation, not a byproduct.

A modified sexual selection scenario is also possible. Given the connections between rhythm, the mirror neuron system, and the various other functions mediated by the neuron system, rhythm could have evolved to signal the health of an individual's mirror neuron system to potential mates. By drumming and dancing, humans can display the functioning of the mirror neuron system, and in doing so they would also signal that they have the ability to function socially, cooperate, understand intentionality, imitate, coordinate movement, and perform a host of other important activities. Thus, rhythmic behavior works in the same way as the ornate feathers of a male peacock, advertising genetic quality to aid reproductive success.

Another possibility is any combination of the previous scenarios. Evolutionary stories need not be mutually exclusive, although it is a tendency of adaptationsts to argue for one particular narrative at the expense of others. It is certainly conceivable that evolutionary pressures selected for social cognition, motor coordination, imitation, vocal learning, and rhythm, strengthening the general mirror neuron system, while at the same time the specific adaptive advantage of rhythm and/or vocal learning worked to increase auditory mirror neurons in particular and strengthen their communication with motor mirror neurons, and sexual selection further enhanced the neural substrates of rhythm because of its ability to signal fitness. All these pressures could have worked together to shape rhythm and rhythmic behavior.

Once we joined rhythm with the pitch-related aspects of music, we truly invented music as we know it today. The various aspects of music are beautifully compatible, and thus it was unlikely that two very different rhythmic and melodic systems existed separately until one brilliant innovator decided to fuse them. There was likely significant exchange between the systems for millennia. Over time, all the various elements of music were fused and solidified so tightly together that music became a unified practice; today we think much more of comprehensive music than we do of isolated rhythm or pitch. We see the forest rather than the trees, the sculpture rather than a collection of fused stone body parts. Music is no mere trifle; it has real biological and neural bases that extend far back in evolutionary time. Because it capitalizes on the same evolved structures, music is as profoundly integrated into our basic humanity as are social function, tool use, and language. Although some aspects of music – particularly rhythm – may have evolved specifically, most are auditory cheesecake, taking advantage of structures evolved for other purposes. Even if music is cheesecake, it is perhaps humanity's favorite dessert. Given music's profound roots, it seems we won't tire of this cheesecake anytime soon.

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