



Research paper

Cochlear implant users move in time to the beat of drum music



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ABSTRACT

Cochlear implant users show a profile of residual, yet poorly understood, musical abilities. An ability that has received little to no attention in this population is entrainment to a musical beat. We show for the first time that a heterogeneous group of cochlear implant users is able to find the beat and move their bodies in time to Latin Merengue music, especially when the music is presented in unpitched drum tones. These findings not only reveal a hidden capacity for feeling musical rhythm through the body in the deaf and hearing impaired population, but illuminate promising avenues for designing early childhood musical training that can engage implanted children in social musical activities with benefits potentially extending to non-musical domains.

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1. Introduction

Of great renown is the history of musicians with impaired access to sound—percussionist Dame Evelyn Glennie, British opera singer Janine Roebuck, Finnish rap artist Signmark (Marko Vuoriheimo), Jazz vocalist Mandy Harvey, and composers Ludwig van Beethoven, William Boyce and Bedřich Smetana—whose deafness or hearing loss, whether occurring in childhood or in later life, did not prohibit their musical achievement. It is less well known that the deaf and hearing impaired can dance, and yet a few examples have brought public attention to this fact. One of the most important known models is ballerina Nina Falaise, who was deaf from birth, and was rejected from London's Royal Ballet only after the discovery of her total deafness, but who went on to dance with Ballet Rambert. Other examples include Broadway dancer Jason McDole (who hears from one ear), members of the China Disabled People's Performing Art Troupe, and Washington, D.C.'s National Deaf Dance Theater.

These individuals present an apparent paradox: they can dance to music that they have difficulty hearing, or even have not heard at all from birth. Yet, the ability to dance to music despite hearing loss has received limited scientific attention.

Indications of the key potential mechanisms for perception of the musical beat and rhythm in the deaf and hearing impaired can be found in the cues taught by deaf experts in dance, and from some empirical evidence. Among these are visual, motor imagery, respiratory, tactile and vibrotactile cues, as well as residual auditory cues in some individuals, including for example, amplification of bass frequencies (e.g., Benari, 1995). There is evidence that the hearing impaired rely on vibrotactile cues when they are available, and that deaf populations show enhanced vibrotactile sensitivity (Levänen and Hamdorf, 2001) and vibrotactile stimulation of auditory cortex (Auer et al., 2007; Caetano and Jousmäki, 2006; Levänen et al., 1998). Deaf individuals show an advantage over hearing individuals in synchronizing movement with visual timing cues to an isochronous pulse (Iversen et al., 2015). In combination these cues, when utilized, can result in a fine capacity for rhythmic timing and movement. According to expert deaf dancers and choreographers, the hearing impaired develop an internal sense of timing which can be sustained over the course of a piece, as with hearing musicians and dancers. Nevertheless, in the general population with hearing loss, who do not typically receive training in rhythm and movement, it is not known how these cues are utilized

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or even whether the combination of them results in the ability for musical timing and coordinated rhythmic movement—that is, musical entrainment.

Thus the question of how deaf and hearing-impaired individuals dance is open to empirical investigation. The question extends to cochlear implant users, who likewise suffer from impaired hearing in music contexts, and who also tend to receive little training in music or musical movement. From the framework of entrainment, the first step towards understanding how those with hearing loss can dance is documenting with objective measures that they do indeed synchronize body movement in time to music with a regular beat, and comparing their performance to that of hearing individuals.

The propensity to move in time to rhythmic percussive sounds or chants is manifest from an early age, as seen in children's spontaneous clapping games and nursery rhymes like “Pat-A-Cake”, “Miss Mary Mack” and “Ring Around the Rosie”, and in their impulsive body movement in response to music (Eerola et al., 2006; Zentner and Eerola, 2010). Infants and children produce bodily movements spontaneously to music, more so than to other complex auditory stimuli such as speech (Zentner and Eerola, 2010). The propensity to move to music is related to the positive affect observed in response to musical activity (Zentner and Eerola, 2010), which may explain why rhythmic movement and drumming in young children is strengthened in a social context and promotes prosocial behavior (Cirelli et al., 2014; Kirschner and Ilari, 2014; Kirschner and Tomasello, 2009, 2010).

These communal movement activities share a common root ability: the perception of and synchronization with a musical beat. The musical beat refers to the perceived periodic pulse to which one entrains and synchronizes spontaneous movement, as in tapping or bobbing the head and body. The abilities that underlie musical beat detection, as well as perception of metrical structure, begin to develop early in life (Winkler et al., 2009; Hannon and Trehub, 2005; Hannon and Johnson, 2005). Infants' rhythm perception is influenced not only by the sounds they hear, but by the concurrent movement that they feel (Phillips-Silver and Trainor, 2005), which likely relies on multiple sensory inputs from auditory, proprioceptive and vestibular systems (Phillips-Silver and Trainor, 2008; Trainor et al., 2009).

Among the cues that hearing infants use to represent the beat structure of an unaccented (that is, ambiguous) acoustic rhythm stimulus, there is evidence that movement cues, but not visual cues, are necessary for establishing a subjective representation of strong beats (Phillips-Silver and Trainor, 2005). This early bias towards movement cues in rhythm perception points to the question of how movement cues to musical rhythm might be preserved in individuals in which pitch perception is impaired. For example, the congenital amusic population is characterized by impoverished pitch perception and melody discrimination, yet they show an ability to extract the musical beat in order to synchronize dancelike movement to music, as measured by motion capture (Phillips-Silver et al., 2013). While their synchronization ability is not on par with that seen in a control group, they show potential for improvement given an appropriate stimulus, and practice (Phillips-Silver et al., 2013).

Individuals with severe to profound hearing loss also suffer from impoverished pitch resolution, and furthermore the quality and experience of music is diminished when a CI is introduced. CI devices bypass the outer and the middle ear and directly stimulate the fibers of the auditory nerve, restoring some sensation of auditory perception. The primary goal of a cochlear implant is to permit speech perception in quiet every day listening environments, and for the majority of cochlear implant users this goal is achieved (though the ability can be compromised in noisy environments).

Cochlear implants generally yield an improvement in speech perception, the results of which have far exceeded the expectations of early investigators (Holt and Svirsky, 2008; Oh et al., 2003; Peterson et al., 2010). With modern multi-electrode cochlear implants, scores can reach 70–80% for sentence recognition in quiet (Osberger et al., 2000; Garnham et al., 2002).

However, auditory discrimination is challenging for cochlear implant (CI) users, which can lead to difficulty with speech perception in noise (Spahr and Dorman, 2004) as well as for music recognition and appreciation (Gfeller et al., 2007; Kong et al., 2004). In hearing individuals, pitch information is faithfully transmitted to the auditory system, but pitch transmission with a CI, based on an electrical model, is much less precise. In fact, electrical stimulation is quite good at delivering temporal information, but presents impoverished spectral information and temporal fine-structure that would help to define pitch (Drennan and Rubinstein, 2008) and timbre, with the exception of temporal envelope, or log attack time (Kong et al., 2011). Cochlear implant users tend not to be as good as normal hearing listeners at identifying familiar real-world melodies and instruments (Gfeller et al., 2002a,b; Vongpaisal et al., 2006; Kong et al., 2004; Drennan and Rubinstein, 2008). Consequently, one of the more important challenges in this field has been to identify ways to improve music perception, and to make music more accessible and enjoyable, for cochlear implant users.

As noted above, the electrical stimulation of a CI provides more faithful temporal than spectral information, which can fare better for the perception of rhythm than of pitch. Recent studies of rhythm perception in CI users indicate that rhythm perception abilities are relatively good, and sometimes as good as in hearing individuals (Drennan and Rubinstein, 2008; Gfeller et al., 1997; Kong et al., 2004; Looi et al., 2007; McDermott, 2004). Gfeller and colleagues (1997) used a battery called the adapted Primary Measures of Musical Audiation (PMMA), which contains a test of rhythmic pattern discrimination, and a task in which listeners must detect a short inter-pulse interval in a six-pulse auditory pattern. Adult CI users scored similarly to normal hearing participants for the rhythmic pattern discrimination, but were not as good as normal-hearing participants on the six-pulse task.¹ Kong et al. (2004) found that tempo discrimination was near normal in cochlear implant users, and that complex rhythm discrimination was as good as in normal-hearing listeners. Schulz and Kerber (1994) tested CI users and a control group on a task of identification of musical rhythm patterns (such as a waltz or a tango), and a test of production in which listeners repeated by tapping 3- or 5-beat rhythm sequences. In both tasks, scores averaged 80% accuracy, but no statistical comparison was provided between the two groups of subjects.

Despite indications that temporal processing is relatively spared in cochlear implant users, data is scarce on their perception of and synchronization to *the beat* in music—that is, their ability for *musical entrainment*. Yet great promise lies in the potential for rhythmic entrainment to capitalize on preserved abilities to perceive salient auditory beats (i.e., from bass and high frequencies, increased amplitude at metrical strong beats), and perhaps even more importantly, to tap into somatosensory, motor, vestibular and/or proprioceptive mechanisms. Such mechanisms may either serve to circumvent pitch-processing deficits, or even potentially be used to bolster them. To this end we examine beat finding and bodily synchronization in the context of typical dance music with rich orchestration and melodic pitch variation, but also—critical to our hypothesis—in the context of music which evades the

¹ The PMMA was designed for children, though data on young CI users do not seem to be available.

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