A Simpler Explanation for Vestibular Influence on Beat Perception: No Specialized Unit Needed

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ABSTRACT: Some researchers have hypothesized the existence of a specialized brain unit for beat perception in music which is directly influenced by vestibular stimulation arising from motion. They also suggest that the unit is involved in the entrainment of movement to music. However, the data used to support this hypothesis may be explained by a simpler phenomenon: the audiogravic and audiogyral effect. This effect is not related to beat perception at all but deals with perceived sound changes under accelerations. If the perception of a sound changes as a consequence of acceleration of the vestibular system, and those accelerations are timed to coincide with particular beats in a stream of unaccented beats, then those beats will actually sound different. The detection of a given meter in that unaccented stream will therefore arise from this change in sound processing, with no need for a specialized brain mechanism for beat perception. There is no direct evidence supporting the existence of an innate brain unit.

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INTRODUCTION

Perceiving the beat of music is a skill humans find easy to do. A beat pattern is extracted from a repeating auditory pattern on the basis of accented beats. In addition, humans find moving in time with that beat pattern (entrainment) easy. This lead to a hypothesis that beat perception may originate from body movement, and in particular, that it originates from the vestibular signal generated by that movement. If this hypothesis is correct, then it implies the existence of a specialized function in the brain that tracks musical beats and is directly influenced by vestibular system input rhythms. Furthermore, this specialized brain function is suggested to be likely responsible for our ability to entrain to music (Trainor, 2007; Phillips-Silver & Trainor, 2007). If this specialized brain unit actually exists, then it has important consequences on the possible paths evolution took to give us musical minds. Some possible paths will be made very unlikely and others more likely if this unit exists. In so far as the evolutionary path for music is largely an open question, the hypothesis must be examined carefully.

Trainor (2007), Trainor et al (2009), and Phillips-Silver & Trainor (2005, 2007, 2008) used a metrically ambiguous drum rhythm pattern and found that an oscillating movement influences how people hear it. The movement causes vestibular stimulation. The subjects hear accents in the drum pattern that are timed to the vestibular oscillation period. Their experiments strongly show that the perception of beats is influenced by vestibular system input rhythms, but this is unlikely to be a direct influence. To provide strong support for their theory, they must show that the influence of the vestibular system is particular to the brain unit that perceives the beat and is not merely explainable as a more general phenomenon. This they do not satisfy. A basic auditory processing effect that is independent of beat perception also explains the results. It is known that vestibular input can change how any particular sound is heard (Clark 1949; Graybiel 1951). The sound waves reaching the ear drums may be identical for two situations; one where there is vestibular input from head movement and another situation where the head is still, but sound perception is different for the two situations. The difference is very small and is detected as a change in location of the sound relative to the head. Thus, if the vestibular stimulation is timed to certain sounds in an ambiguous pattern, those sounds will be heard as different. If they are different, then some will sound accented and a beat pattern will be detected. That is, the brain unit that perceives a beat is getting different auditory signals depending on whether or not vestibular stimulation is occurring. That auditory change is independent of beat perception.

REVIEW OF EVIDENCE

We need to examine the experimental designs and results to fully understand how they interact. Trainor et al (2009, p. 36) summarizes the beat perception studies well: "Phillips-Silver and Trainor created an ambiguous auditory stimulus. It consisted of a repeating six-beat drum pattern with no accented notes. If every second beat was heard as strong, the rhythm took on a march-like quality (duple meter) whereas if every third beat was heard as strong, the rhythm took on a waltz-like quality (triple meter). (...) A physical bouncing movement [of the subject] on either every second beat or on every third beat of the ambiguous auditory rhythm pattern biased which interpretation was perceived in both infant (Phillips-Silver and Trainor, 2005) and adult subjects (Phillips-Silver and Trainor, 2007)". The experiment in Trainor (2009) then shows the effect is from vestibular stimulation by using a direct electrical stimulation of the vestibular nerve that simulated head motion even though the head was still. After listening to the ambiguous test sample with vestibular stimulation, the subjects chose from duple meter or triple meter sound samples as to which was the same or most similar to the test sample. The subjects' choices corresponded to the vestibular beat rate in around 80% of the trials as compared to 50% that would be expected by chance.

The auditory perception changes that occur with vestibular input are known as the *audiogyral* and *audiogravic* phenomenon. Clark (1949) and Graybiel (1951) contributed the original articles on these effects. These effects deal with how we localize sounds in space. Several acoustic cues are used in localization of a sound source. Inter-aural time difference (ITD) is a strong cue that indicates how far a sound source is from the medial sagittal plane. Other cues are inter-aural intensity difference, frequency spectral changes due to the head shape, and even echoes. We only need to look at the ITD cue. Lewald and Karnath (2001) showed that an ITD is perceived on a sound when there is no ITD if under the influence of passive whole body rotation. This difference is perceived as the sound being off-center. From their abstract: "Pure-tone pulses with various inter-aural time differences were presented via headphones during brief, low-amplitude rotation. Subjects made two-alternative forced-choice (left/right) judgments on the acoustic stimuli. The auditory median plane of the head was shifted opposite to the direction of rotation, indicating a shift of the intracranial auditory percept in the direction of rotation. The mean magnitude of the shift was 10.7 μs". That is, the subjects heard the same sound in headphones differently (a lateral shift) if they were rotated than if they were not rotated. The effect is small, but significant. In fact the right/left choice on zero ITD under rotation to the right was about 75% for right and under no rotation was at the expected 50% for right. These perceptual choice changes are comparable to the beat perception choice selections. We will refer to the ITD change under a rotation (vestibular rotation) effect as the *audiogyral* effect. Linear accelerations and tilts that stimulate the otoliths of the vestibular system also affect the perceived ITD in a similar fashion, and are referred to as the *audiogravic* effect.

A change in sound perception that arises from a vestibular movement is not surprising. The localization of sounds is a critical function and tracking those sounds through head movements is an important cue. Small movements of the head in fact greatly increase the accuracy of sound localization. However, it is a complicated process. For example, it is also known that lateral eye movements affect sound localization the same way (Suzuki 2008) and even neck proprioceptive signals influence sound perception. That eye movements affect sound localization may seem surprising, however it has the effect of re-centering the auditory stage to where the gaze is. This allows better localization relative to eye gaze. All these effects work by adjusting the perceived ITD and IID for increasing accuracy of localization of sounds.

DISCUSSION

The audiogyral and audiogravic effects explain the beat perception of ambiguous meters influenced by vestibular stimulation as an indirect effect of purely acoustic processing. This acoustic processing in the listener causes the meter to be unambiguous because beats that coincide with vestibular acceleration *do* sound different from the other beats because of the audiogyral effect. Those beats will sound as if shifted laterally a slight amount and thus slightly accented. This means that the effects seen in the beat perception experiments are likely independent of beat perception. A beat perception brain unit that is directly influenced by vestibular input may exist, but compelling evidence for such a unit would have to go beyond the more general audiogyral effects outlined here. The data of the vestibular influenced beat perception results are well explained by a known mechanism having nothing to do with beat perception.

There are several experimental changes that could be done to show if the vestibular influence on beat perception is from an innate direct mechanism or from the audiogyral effect. Since the audiogyral effect shows up as a change in perceived ITD and/or IID, then using only a single headphone in one ear with the other ear plugged for no sound detection will eliminate that part of the audiogyral effect. Only one ear should be needed to perceive a beat and to entrain to it, so if the vestibular influenced beat perception effect is not found here, then the prior data was likely due to an audiogyral effect.

CONCLUSION

The existence of beat perception mechanisms in the brain is clear, but the nature of the connection to motion is not clear. The existence or non-existence of an innate beat detecting vestibular processing brain mechanism has a large impact on the understanding of possible evolutionary paths that lead to music and to our ability to entrain to music. If the unit exists, it must have had a selective advantage for evolution to select for it and the advantage would likely be for entrainment. However, other brain mechanisms providing the ability to entrain movement to music may fit better with suggested evolutionary selection pressures. For example, if pleasure is generated by entrained motion to music, then the act of entrainment may be a learned skill and our plastic brains may become very skillful at it. Dancing two year old children go in and out of synchronization with music but at four years old, they are skilled at staying synchronized. This suggests a learned skill that does not require an innate mechanism.

The suggestion of the existence of an innate beat perception mechanism that is directly connected to a vestibular signal is unnecessary to explain current data or behavior. In fact, it is unlikely that this mechanism exists since the vestibular influenced beat perception data is so well explained by known structures and effects.

NOTE

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