Journal of Interdisciplinary Science Topics

Could you hear this whole chorus a mile away?

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24/04/2023

Abstract
Dolores Madrigal from the Disney musical Encanto has super-hearing and can hear her cousin Mirabel singing from a mile away. This paper explores the strength of this ability by calculating her threshold for hearing, -5.05 dB, and comparing it to the normal threshold for human hearing, 0 dB. If an average human were to hear this same song from a mile away, Mirabel would need to sing at a loudness of 125.05 dB, which is much louder than the typical human voice of 60 dB.

Introduction
In the Disney musical 'Encanto', each member of the Madrigal family has been gifted with magical abilities [1]. In the opening song, 'The Family Madrigal', Mirabel Madrigal explains the powers of each member of her family. When describing her cousin Dolores' powers, she states "my cousin Dolores can hear this whole chorus a mile away", suggesting that Dolores possesses enhanced hearing. This is further supported when it is revealed that she is able hear sounds that cannot be heard by the average human, such as an eye twitching. From hearing the rats in the walls to a pin dropping, throughout the movie she proves that her hearing is far superior to that of the average human. This paper aims to quantify this ability, calculating a threshold of Dolores' hearing. It also determines how loud Mirabel would need to sing for an average human to hear her sing this song from a mile away.

Figure 1 – Shows Dolores listening to Mirabel's song outside the town, a mile away [2].

Sound
Sound waves are longitudinal waves which travel through air into the ear. The auricle retrieves the waves at the outer ear and the sound is amplified when the auricle pushes them through the ear canal [3]. From here, the waves are transported to the ear drum, causing it to vibrate.

The loudness of a sound can be measured in decibels (dB). Due to the logarithmic nature of decibels, a slight increase in the decibel scale equates to a significant increase in loudness. For example, a sound that is increased by 20 dB is becoming 100 times louder [4].

Threshold of Dolores' hearing
To determine the threshold of Dolores' hearing, it is assumed that when Mirabel sings "my cousin Dolores can hear this whole chorus a mile away", she is referring to the maximum distance at which Dolores can hear her singing. Using the inverse square law, the intensity, or loudness, of a sound from a particular distance can be calculated using Equation 1 [5]:

$$L_2 = L_1 - 20 \log_{10} \left(\frac{R_2}{R_1} \right) \quad (1)$$

where L_2 is the 'loudness' of the sound at the distanced specified (R_2), and L_1 is the 'loudness' at R_1.

On average, human speech is between 55 dB and 65 dB, with the average conversation taking place at approximately 60 dB [6]. As Mirabel is singing this song in a conversation, it is assumed that she is singing at 60 dB, which will be the value used for L_1 in this model.

Normal Voice Level (dB)	Distance (m) between two objects
70	0.3
60	0.9
54	1.8
48	3.7
42	7.3

Table 1 – Shows the normal voice level in dB at different distances [6].

According to table 1 [6], the average human voice is 60 dB at 0.9 m from the source. This seems consistent with a normal conversational distance; hence this value will be used for R_1. R_2 is equal to a mile according to the song, which is equivalent to 1609.34 m [7]. Substituting these values into Equation 1, it is possible to obtain a value for Dolores' hearing threshold:

$$L_2 = 60 - 20 \log_{10}\left(\frac{1609.34}{0.9}\right)$$

$$L_2 = -5.05 \ dB$$

The threshold of human hearing is 0 dB [8] – any level below this cannot be heard by humans. Dolores' calculated threshold of -5.05 dB means that she can hear much quieter sounds than the average human, as her threshold for hearing is around 5 dB lower.

Could an average human hear this chorus a mile away?
For an average human to hear Mirabel singing from a mile away, L_2 must be equal to 0 dB, the human hearing threshold. To calculate how much louder Mirabel would need to sing to be heard at this distance, we can rearrange Equation 1:

$$\Delta L_1 = L_2 + 20 \log_{10}\left(\frac{R_2}{R_1}\right)$$

Substituting 0 dB for L_2, and 0.9 m and 1609.34 m for R_1 and R_2 respectively, it is possible to calculate how much louder Mirabel's voice would need to be:

$$\Delta L_1 = 0 + 20 \log_{10}\left(\frac{1609.34}{0.9}\right)$$

$$\Delta L_1 = 65.05 \ dB$$

$$Loudness = 60 + 65.05 = 125.05 \ dB$$

Adding this to her original loudness of 60 dB would mean that she would have to be singing at 125.05 dB. A human voice has reached this level; classroom assistant Jill Drake holds the world record for the loudest scream at 129 dB [9], so it could be possible for Mirabel to raise her voice to 125.05 dB. However, sounds above 120 dB can cause immediate damage to human ears [10], thus Mirabel would most likely opt to not sing at this level to avoid harming herself and those in the town around her.

Conclusion
The threshold for normal human hearing is 0 dB [8], this is the quietest sound a human can hear. This paper determines that Dolores' threshold for hearing is -5.05 dB, meaning that she can hear much quieter sounds than the average human. For a normal human to hear her song from a mile away, Mirabel would have to be singing at 125.05 dB, which is close to the world record of 129 dB for the loudest human scream [9]. This would be detrimental to Mirabel's health, and to anyone in the vicinity, so whilst it is possible for an average human to hear this song from a mile away, it is probably better to keep this experience unique to Dolores.

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