IS THE SOUND WE HEAR ‘REAL’?

Investigate the effect of the length and the diameter of the ear canal on sound

Group H2

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Summary

Our project investigated the effect of the ear canal on how we perceive sound, mainly focusing on the variables of diameter and length of the canal. By modelling the ear canal as a tube open at one end, we built 12 tubes all with different dimensions, with four different diameters and three different lengths. We obtained them by 3D printing. They were then coupled to the test earphone we constructed, and the frequency responses of different tubes were measured using an artificial ear. We found that the presence of the ear canal brings about three high-frequency resonance peaks, and as the canal's diameter increased, the peaks appeared at higher frequencies with greater intensities. Conversely, an increase in its length leads to a reduction in the high-frequency pressure level, causing the resonance peaks to shift inward.

In order to verify the generality of this conclusion, we introduced the electrical-mechanical-acoustical analogy and converted the ear canal into an LCR low-pass filter circuit, with the sound pressure level being analogue to the voltage output of the capacitor. The three electronic components, acoustic resistance, acoustic inertance and acoustic compliance, can represent acoustic properties in a tube and are related to each other by electrical laws. We then analyzed the influence factors of the gain and the resonant frequencies in the equivalent circuit to verify that our experimental conclusions were reliable.

Our findings also have potential real-world applications; An example is the potential assessment of the actual effects of noise on particular groups of people such as infants, as the dimension of their ear canals is significantly different from that of adults.

Is the sound we hear ‘real’?

----Investigate the effect of the length and the diameter of the ear canal on sound

Kevin Ni, Sid Diamond, Nidhi Doshi, Nikhail Virik, Ziyao Xiong

Abstract—**In this project, we 3D printed 12 tubes with different lengths and inner diameters, for which they can be modelled as ear canals with different sizes. We examined how the frequency response changed as the frequency of the emitted sound wave gradually increased in each tube. We obtained 12 different plots of sound pressure level against frequency. Our experiment had two main findings: the resonant frequencies in the tube decrease as the inner diameter decreases and the length increases; the amplitude of the detected sound at resonant frequencies decreases as the inner diameter decreases and as the length increases. These phenomena were interpreted by us using the analogy between sound and electricity.**

I. INTRODUCTION

AS a way of perceiving the world, we are constantly accessing sound. However, it is not true that everyone hears the same sound when it is emitted from the same source. The size and mass of the head, the shape and position of the ears, and the dimensions of the oral cavities all manipulate the incoming sound waves by boosting some frequencies and attenuating others [1]. These variations in the frequencies and amplitudes of sound contribute to an audience's distinct perspective and experience of listening. Past scholars used the term HRTF (head-related transfer function) to describe the uniqueness of the sound people receive. In this project, we decided to focus on the effect of the length and the diameter of the ear canal on the sound we listen to.

The ear canal is a route from the pinna to the eardrum and is where sound waves initially enter a person's ear, thus it plays an important role in people’s hearing. The ear canal can be modelled as a tube opening at one end. Therefore, passing a specific sound wave at the open end and measuring the resultant frequency and amplitude of the sound at the closed end allow the quantitative analysis of the effect of the ear canal on the sound people receive.

II. METHODS

Shown in Figure 1 is an IEM (in-ear monitor) built by us through 3D printing.

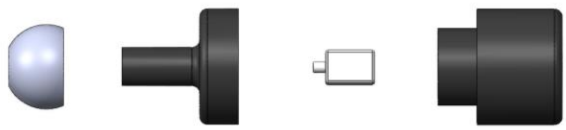

Fig 1. An illustration of an IEM headset. From left to right, it comprised an earplug, a replaceable front cavity, a balanced armature unit Knowles - 29689, and a back cavity.

The tube structure of the front cavity was used to simulate the ear canal. We printed 12 front cavities with different dimensions, specifically with diameters of 2.5mm, 3mm, 3.5mm, and 4mm, and lengths of 10mm, 15mm, and 20mm.

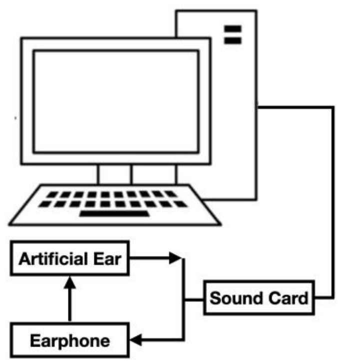

Fig 2. An illustration of our experimental setup. An artificial ear coupler was connected to the headset. The headset and artificial ear were both connected to the computer through a sound card.

As shown in Figure 2, we used an IEC-711 artificial ear coupler to measure the raw data. The artificial ear is a device designed to perform electroacoustic tests on insert IEMs under well-defined acoustical conditions [2]. It was connected to the earplug of the IEM, acting as the receiver of sound. The balanced armature unit inside the IEM acted as the generator of sound. It produced sound signals ranging from 0 to 20kHz, which was approximately the threshold frequency of human listening. We connected the headset and artificial ear to the computer using a sound card, which translated the recorded or produced digital signal data into an analogue format that the computer could recognize [3].

In terms of data analysis, we used Room EQ Wizard (REW), a software that automatically generated the tested product's frequency response curve. Those plots demonstrated the corresponding sound pressure level of each particular frequency.

III. DATA PRESENTATION

Before discussing our experimental results, we must first clarify what exactly was being measured. The frequency response refers to the SPL of sound when its frequency varies. Sound pressure level, or SPL, is a widely acknowledged measure of the strength of an acoustic wave. It is designed so that the output values match a young person's threshold for human hearing at ~1000Hz. Since we experience noise on a logarithmic scale, this is achieved by defining SPL as:

$$SPL = 20\log\left(\frac{P}{P_0}\right) \tag{1}$$

where P is the sound pressure of the noise and P_0 is defined as the reference pressure, 2×10^5 Pa [4]. Consequently, the frequency response was plotted logarithmically on the x-axis, which represented the frequency, and the y-axis represented the strength of SPL. In the following sessions, our analysis will base on these two quantities.

As our topic is about human hearing, we set the test frequency in the range of 20~20kHz. Figures 3, 4, 5, and 6 show the outputted graphs from REW for front cavities with the same diameters but different lengths. Figures 7, 8, and 9 show the outputted graphs from the software for front cavities with the same lengths but different diameters. All curves were plotted on a logarithmic scale on the frequency axis.

Under each figure, there are several subtitles showing the inner diameter and length of the tube used, where D refers to the inner diameter and L refers to the length, both measured in mm. These subtitles correspond to the curves in the diagram in the same colour. The word "Psy" after subtitles indicates that we manipulated the curve using psychoacoustic smoothing, which can produce a plot that more closely corresponds to the perceived frequency response.

Fig 3. Outputted curves of front cavities with an inner diameter of 2.5mm.

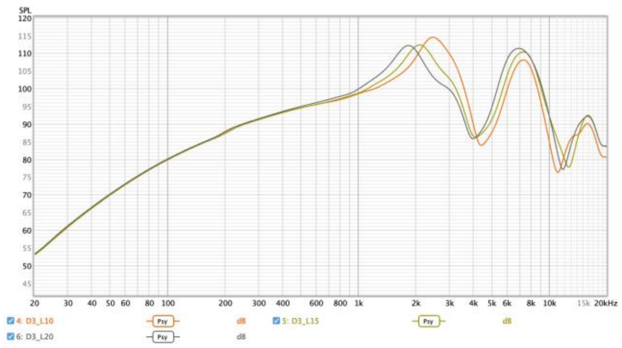

Fig 4. Outputted curves of front cavities with an inner diameter of 3 mm.

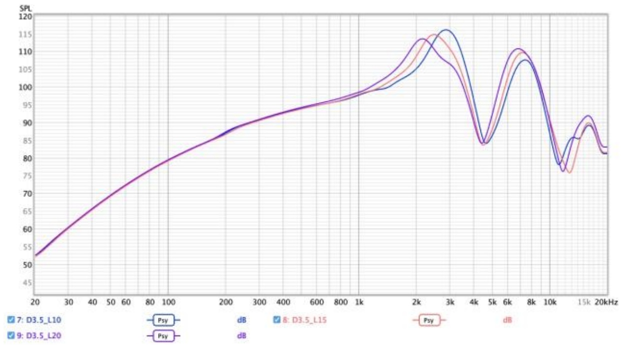

Fig 5. Outputted curves of front cavities with an inner diameter of 3.5 mm.

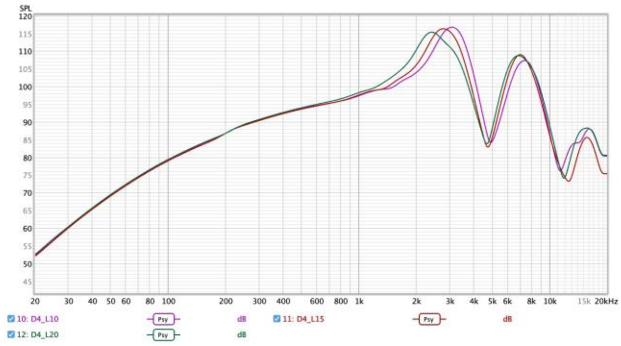

Fig 6. Outputted curves of front cavities with an inner diameter of 4 mm.

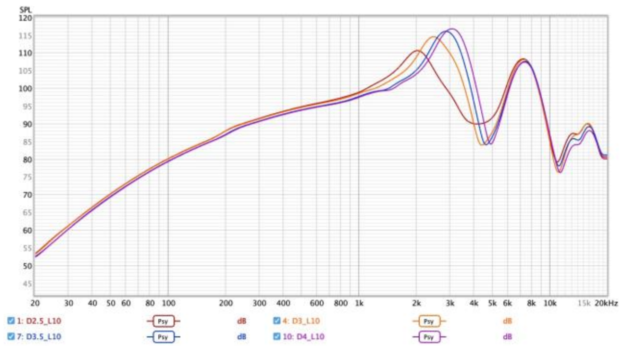

Fig 7. Outputted curves of front cavities with a length of 10mm.

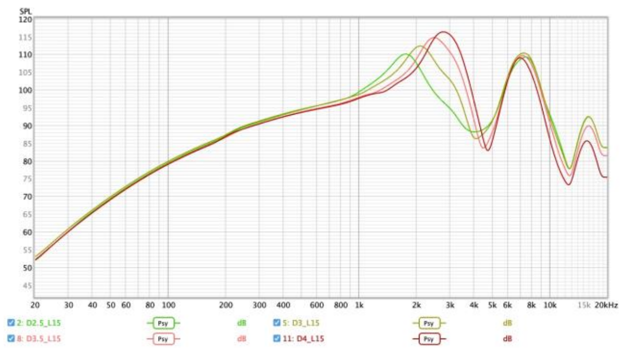

Fig 8. Outputted curves of front cavities with a length of 15mm.

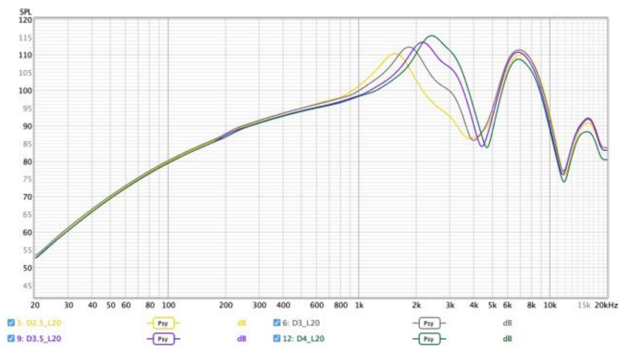

Fig 9. Outputted curves of front cavities with a length of 20mm.

We made several observations from the graphs. Firstly, in the frequency domain from 50hz to 1kHz, the sound pressure level rises approximately linearly from about 53 dB to 100 dB. The curves of different samples in this part are overlapped, indicating almost no difference in their frequency response. The most remarkable feature for the regions with frequencies greater than 1khz is three peaks located at 2 ~ 3kHz, 7kHz and 15kHz. Each curve has these three peaks, and they are located at different frequencies and pressure levels. Regarding the crude equipment and environment we employed, the measurement error of the data on the last two peaks is too large to discuss. Thus, we are going to focus on the first peak mainly.

Table I shows the frequency and pressure level of the first peak of the frequency response of different tubes.

TABLE I

Type	f (kHz)	SPL (dB)
D2.5_L10	2.02	110.7
D2.5_L15	1.76	110.2
D2.5_L20	1.64	110.5
D3.0_L10	2.49	114.6
D3.0_L15	2.10	112.4
D3.0_L20	1.83	112.2
D3.5_L10	2.86	116.1
D3.5_L15	2.48	114.8
D3.5_L20	2.16	113.6
D4.0_L10	3.08	116.8
D4.0_L15	2.77	116.4
D4.0_L20	2.47	115.4

Regarding the frequency and the sound pressure level of the first peak, the data we collected seem to follow a certain tendency: with the increase in length, the frequency decreases and the sound pressure decreases; when the diameter increases, the frequency increases, and the sound pressure increases.

IV. EXPLANATION AND DISCUSSION

A. *Peaks and resonant frequencies*

As shown in Figures 3~9, each curve has three peaks, where the values of SPL are significantly larger than other points. These are where resonance occurs, and their corresponding frequencies of the peaks are resonant frequencies of the tube. Resonance happens when standing waves are formed in the tubes where sound waves with a particular frequency constructively interfere.

This can be explained by the normal mode theory of standing waves. The ear canal can be modelled as a tube opening at one end. Thus, when resonance takes place, there is an antinode located at the opening end and a node located at the diaphragm (in our experiment this is located at the earplug). The patterns of standing waves forming in such tubes are demonstrated in Figure 10.

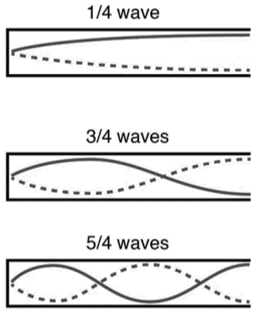

Fig 10. Three possible resonance patterns occur in the tubes. The length of the tube is equal to 1/4, 3/4, and 5/4 of the wavelength of the sound respectively.

This means that the sound wave should show resonance at regular intervals of

$$\lambda = 4L/(2n-1), \tag{2}$$

with n being the n^{th} time a resonance occurs.

The three peaks shown in each curve correspond to the situations where n=1, 2, and 3, therefore, there were three resonances that took place in the tubes. The patterns of these resonances matched Figure 10.

B. *Electrical-mechanical-acoustical analogy*

An acoustic device always consists of acoustical, mechanical, and electrical subsystems [5]. Due to their fundamental transition differential equations having identical forms, the electro-mechano-acoustical analogy has been introduced to model the whole acoustic system by electronic components [6]. The analogy is shown in Table II.

TABLE II

Electricity	Mechanics	Acoustic
Voltage *E (V)*	Force *F (N)*	Sound pressure P (N/m^2)
Current *I (A)*	Velocity *v (m/s)*	Acoustic volume flow U (m^3/s)
Resistance *R (Ω)*	Damper R_m $(N{\cdot}s/m)$	Acoustic resistance R_a $(N{\cdot}s/m^5)$
Capacitance *C (F)*	Compliance C_m (m/N)	Acoustic compliance C_a (m^5/N)
Inductance *L (H)*	Mass *M (kg)*	Acoustic inertance M_a (kg/m^4)

Acoustic resistance arises from energy dissipation due to the viscosity of the transmission medium, or the radiation towards the medium. For sound travels in a tube like an ear canal, its acoustic resistance is given by:

$$R_a = \frac{\rho\sqrt{2\eta\omega}}{\pi r^2}\left(\frac{1}{r}+2\right), \tag{2}$$

where ρ refers to the density of the medium, η is the coefficient of viscosity of the air, r is the radius of the air column in the tube, and ω is the angular frequency of oscillation of the sound wave.

The inertia of air opposes the change of volume flow in a tube, i.e., the acceleration of the flow. Just like the inertia of a mass causes the object to have the tendency of keeping its state of motion. The acoustic inertance can be calculated by:

$$M_a = \frac{\rho l}{S}, \tag{3}$$

where l and S are the length and the cross-sectional area of the air column respectively, and thus the length and the cross-sectional area of the tube.

A small volume's compressibility results in acoustic compliance [6]. The more the air is compressed, the larger the pressure level in the tube. Thus, it is closely associated with the sound pressure level. Acoustic compliance is given by:

$$C_a = \frac{V}{\rho c^2}, \tag{4}$$

where c is the speed of sound and V is the volume of the tube.

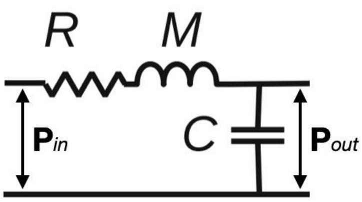

Fig 11. Equivalent circuit of the ear canal. A resistor, an inductor, and a capacitor are connected in series, corresponding to acoustic resistance, acoustic inertance, and acoustic compliance. The output (sound pressure level) can be represented by the voltage across the capacitor.

Employing the theories mentioned, a human ear can be modelled as an LCR circuit, as shown in Figure 11. As sound waves propagate, there is friction between the air and the canal. Some energy of the sound would be lost due to the viscous resistance and thermal conductivity [7], which acts as acoustic resistance. Furthermore, the air in the canal is accelerated by the oscillation of sound waves, bringing in the effect of acoustic inertia. Furthermore, the sound wave compresses the air, which contributes to the acoustic compliance. They can be equivalented to a resistor, a capacitor, and an inductor in a circuit. Since those three effects superpose on the change of frequency response, the components should be connected in series. The compressibility (i.e., sound pressure level) is associated with acoustic compliance, modelled by the capacitor in the circuit. The pressure level matches the analogue voltage in the circuit, hence the output parallel across the capacitor represents SPL.

C. Data analysis

Using the electrical-mechanical-acoustical analogy, we attempted to explain the three key features of the results in our experiment: the frequency response in the low-frequency domain (f <1kHz), the frequency response in the high-frequency domain (f >1kHz), and the change of peaks when tubes have different lengths and inner diameters.

1) The frequency response in the low-frequency domain and high-frequency domain

As shown in Figure 11, the ear canal can be regarded as an LCR circuit, acting as a low-pass filter. Derived from the potential divider equation, its transfer function should satisfy:

$$\frac{V_{out}}{V_{in}} = \frac{\frac{1}{jwC}}{R+jwL+\frac{1}{jwC}} = \frac{1}{1-w^2LC+jwRC}, \tag{5}$$

where V_{out} is the voltage output across the capacitor, V_{in} is the total voltage in the circuit, L refers to the inductance, C refers to the capacitance, R refers to the resistance, and ω is the angular frequency.

At low frequencies, the gain of the capacitor tends to be 1, and nearly all the input can pass through the circuit [8]. Considering that the input sound pressure is controlled constantly by the REW, the output pressure level of different tubes ought to also be very similar at low frequencies. This is the reason why the frequency response curves almost overlap in this section, as shown in all the outputted curves in Figures 3~9.

Joint equations (2), (3) and (4), the circuit's gain could be reformed as:

$$\frac{V_{out}}{V_{in}} = \frac{1}{\sqrt{(1-\frac{w\rho l}{\pi r^2})^2+(\frac{l\sqrt{2\eta w^3}(\frac{1}{r}+2)}{c^2})^2}}, \tag{6}$$

According to equation (6), when the tube radius, r, increases, the gain will decay slower, indicated by the less drop off on high frequencies in Figures 3, 4, 5, and 6. Similarly, when the length of the tube, l, increases, the high-frequency part would be weakened more.

2) Shifts in the positions of peaks of different tubes

The peaks of each curve in Figures 3~9 represent the occurrence of resonance. Their corresponding frequencies are resonant frequencies. Since the ear canal can be modelled as a series LCR circuit, the resonant frequency of the analogue circuit ought to match the resonant frequency in each tube. In an LCR circuit, the value of resonant frequency is given by:

$$f_0 = \frac{1}{2\pi\sqrt{LC}}. \tag{7}$$

Thus, when a tube has acoustic inertance M_a and acoustic compliance C_a, its resonant frequency can also be found by equation (7). Substituting in equations (3) and (4) for the expressions of M_a and C_a, the resonant frequency in a tube is given by:

$$f_0 = \frac{1}{2\pi}\sqrt{c^2\frac{S}{l}}, \tag{8}$$

Therefore, when the diameter of the tube increases, its cross-sectional area increases, thus the resonance peaks occur at a higher frequency. This is shown by the rightward shift in the peaks of tubes with changing diameters and the same length (Figures 3, 4, 5, and 6). On the other hand, as the length of the tube increases, the resonant frequency decreases, as shown in Figures 7, 8, and 9, where tubes have the same diameter but different lengths.

Our analysis focused mainly on the first instance of resonance. In ideal theoretical conditions, the later peaks would follow the same trends.

V. Conclusion

In conclusion, the ear canal will generate three resonance peaks on the sound people hear. If the diameter of the canal increases, the resonance frequency will occur at a higher frequency with greater intensity. As the length of the canal increases, the resonance frequency will decrease and the sound pressure level in the high-frequency part will also decrease.

However, there were plenty of uncertainties introduced in our experiment. The main uncertainties came from the experimental setup and the apparatus used. In the low frequency (<100Hz), the curves obtained were not smooth as the surrounding ambient noise corrupted the sound input since the measurements were not taken in a strict silencer chamber. The artificial ear used, known as the iec711 coupler, is not verified to simulate the human ear at frequencies above 10kHz, so the readings above this point are inaccurate.

Finally, our project not only sheds light on a phenomenon but also has practical applications. For example, when caring for infants, it should be considered that they are startled by higher-pitched sounds because their ear canals are shorter and resonate at a higher frequency compared to adults [9]. Besides, when assessing the effects of noise on people, the role of ear canal resonance should be taken into account and more protection should be poured in at the relevant enhancement frequencies [10].

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01. INTRODUCTION

As a way of perceiving the world, we are constantly accessing sound. However, for sound emitted by the same source, does everyone hear exactly the same sound? Actually, the size and mass of the head, the shape and position of the ears, and the dimensions of the oral cavities all manipulate the incoming sound waves by boosting some frequencies and attenuating others. These variations in the frequencies and amplitudes of a sound contribute to the audience's distinct perspective and experience. Past scholars used the term HRTF (head-related transfer function) to describe how are the sound people receive different from the source. In this project, we decided to focus on the effect of the length and the diameter of the ear canal on the sound we listen to.

We simulated different ear canals with different lengths and diameters of headphone front cavities, measured the frequency response curves of samples with artificial ears and attempted to explain the phenomena using the theory of electroacoustic analogy.

FIG.1 HUMAN'S EAR

02. Methods

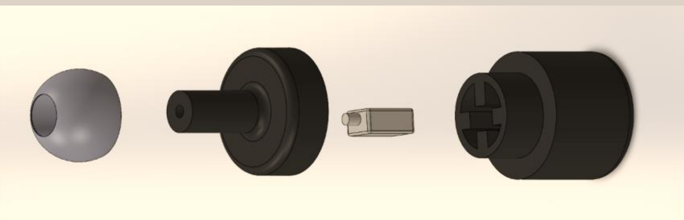

FIG.2 IEM STRUCTURE

IEM stands for in-ear monitor, containing a front cavity that can be modelled as the ear canal.

Shown in Figure 2 is an IEM built by us through 3D printing. It mainly comprises an earplug, a replaceable front cavity, Knowles -29689 balanced armature unit, and a back cavity. We printed 12 different front cavities to simulate different ear canal sizes, specifically with diameters of 2.5mm, 3mm, 3.5mm, 4mm, and lengths of 10mm, 15mm, 20mm.

We used an IEC-711 artificial ear coupler to measure the raw data. We connected the headset and the artificial ear to the computer through a sound card, using the headset as an output to produce sound and the artificial ear as a microphone to receive signals.

About the analysis software, we used the Room EQ Wizard, which would automatically generate the output and analyze the received signal to generate the frequency response curve of the tested product.

FIG.3 SET UP OF EXPERIMENT

03. DATA ANALYSIS

Before discussing our experimental results, we must first discuss what exactly SPL and frequency response are.

Sound pressure response, or SPL, is a widely acknowledged measure of the strength of an acoustic wave. It is designed such that the output values match the threshold for human hearing at ~1000Hz for a young person.

Since we experience noise on a logarithmic scale, this is achieved by defining SPL as

$$SPL=20\log(P/P_0)$$

Where P is the sound pressure of the noise and P0 is defined as the reference pressure, 2×10^(-5) Pa [1].

Figure 4 is about SPL we measured from IEM with tube diameter 3.5mm and lengths 10mm, 15mm, and 20mm. Figure 5 is the SPL of IEM with a tube length of 15mm and diameters of 2.5mm, 3mm, 3.5mm, and 4mm. As the measurement errors of the latter two peaks were so large, there was little point in discussing them. Thus, we mainly focus on the differences between the first peaks. There are two main findings: the resonant frequencies in the tube decrease as the inner diameter decreases and the length increases; the amplitude of the detected sound at resonant frequencies decreases as the inner diameter decreases and as the length increases. Now let's explore the reasons for this phenomenon.

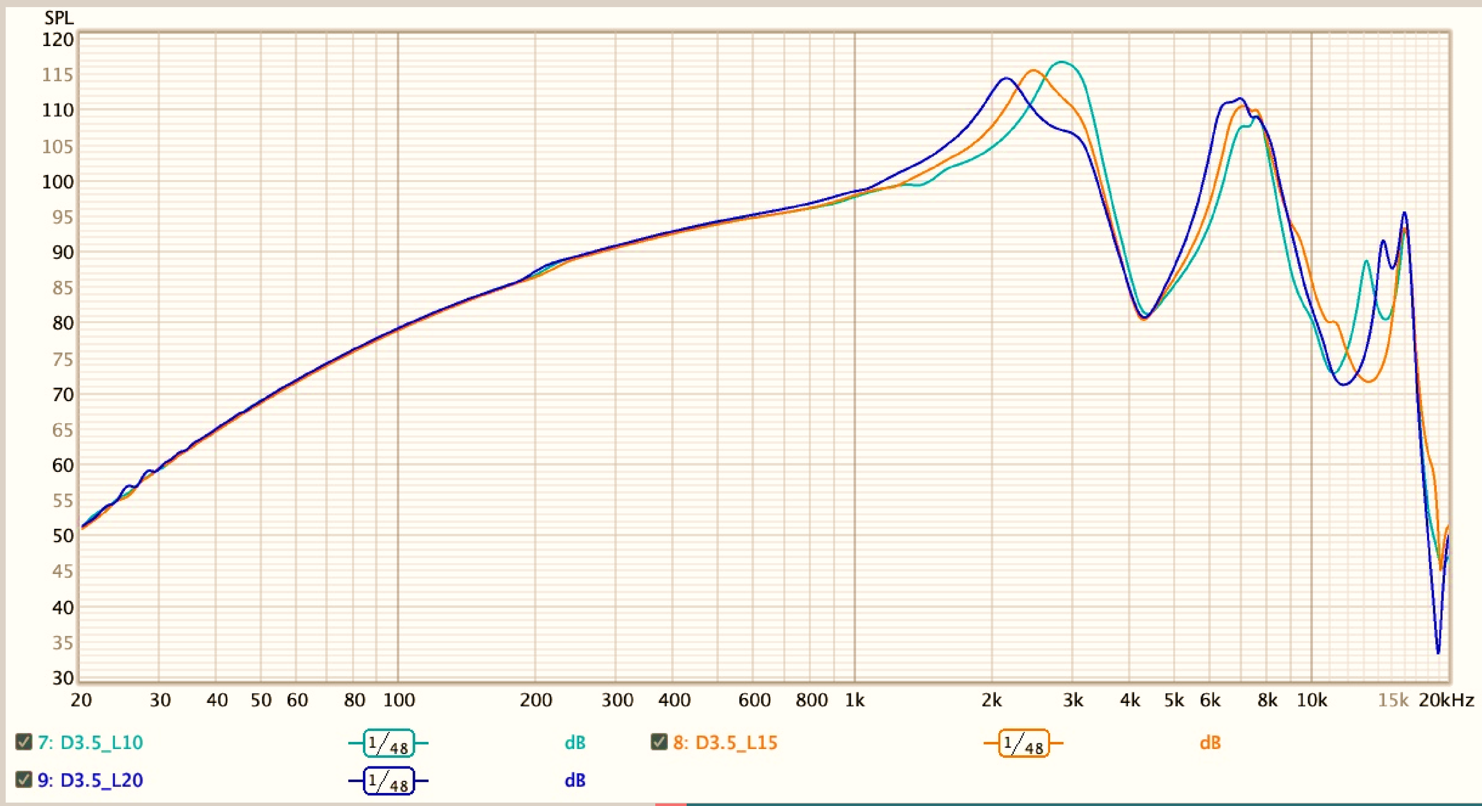

FIG.4 Outputted curves of different lengths of IEM

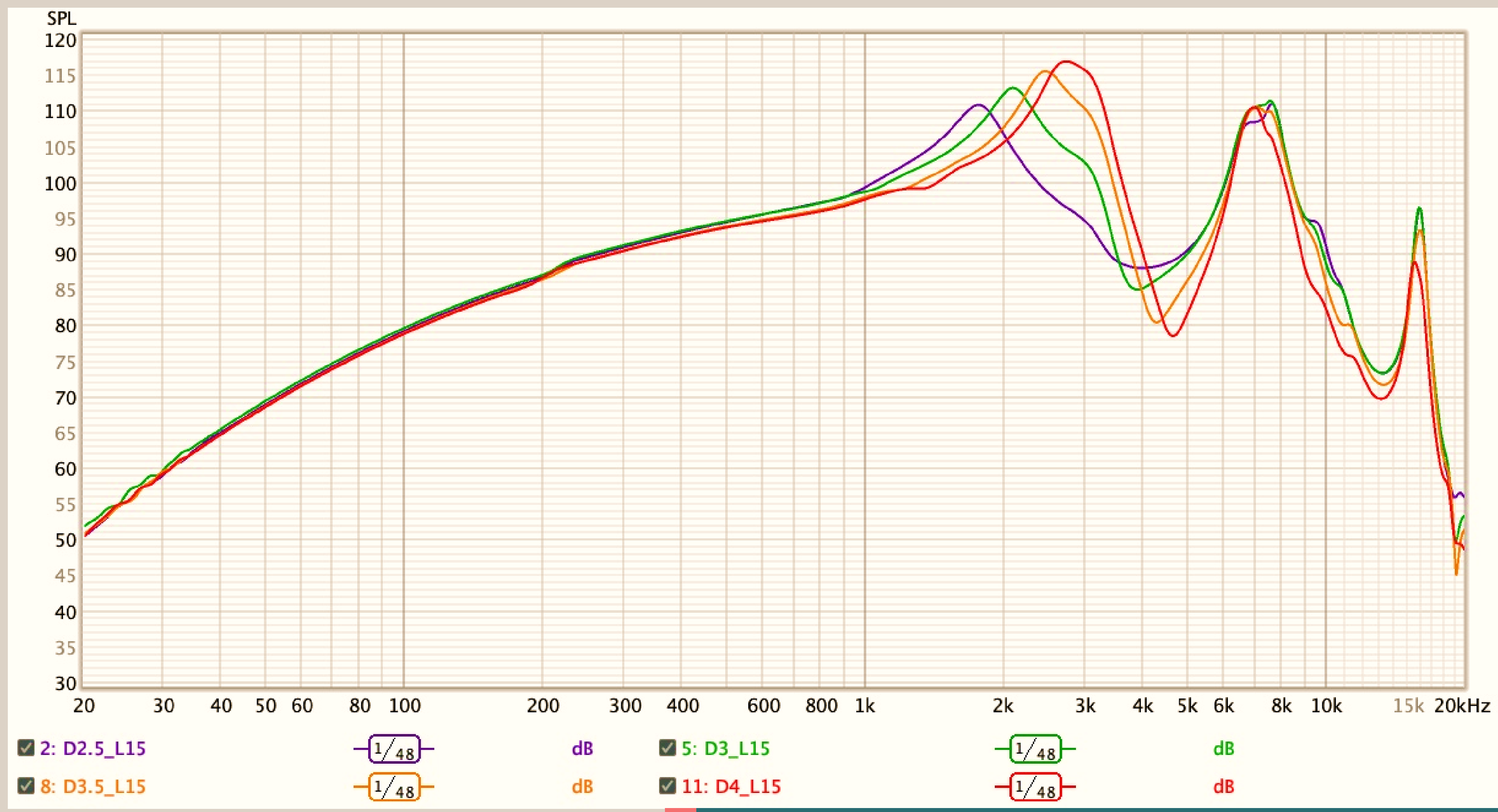

FIG.5 Outputted curves of different inner diameters of IEM

THEORY

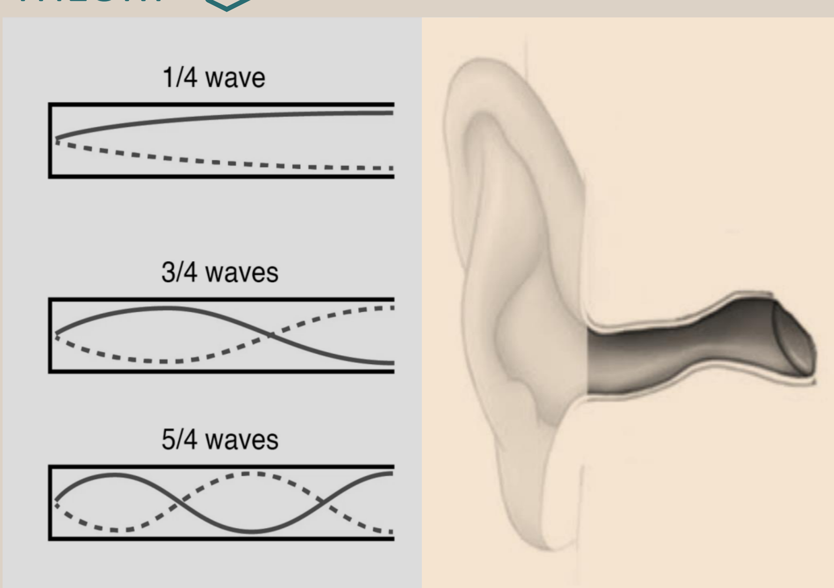

FIG.6 RESONANCE IN EAR CANAL

EFFECT OF LENGTH ON RESONANT FREQUENCY

The first thing that you may notice is that there seem to be three resonance peaks in each diagram. This can be explained by the normal modes theory of standing waves. The sound wave can be thought of as being fixed at two ends, one at the diaphragm of the speaker and the other at the end of the ear canal. This means that the sound wave should show resonance at regular intervals of

$$\lambda = \frac{2L}{n}$$

With n being the n-th mode. With our apparatus, the diaphragm can be seen as being located at the front of the ear canal, thus L is simply the length of the ear canal.

SOUND-ELECTRICITY ANALOGY

Sound has acoustic resistance(Ra), acoustic capacitance(Ca) and acoustic inertiance(Ma). By modelling the ear canal as a Helmholtz resonator, we were able to treat it as either an RC circuit or an LC circuit, where quantified calculations can take place. In this case, Ra, Ma, and Ca can be found as follows:

$$\bullet R_a = \frac{\rho\sqrt{2\eta\omega}}{\pi r^2}\left(\frac{1}{r}+2\right); M_a = \frac{\rho L}{S}; C_a = \frac{V}{\rho c^2}$$

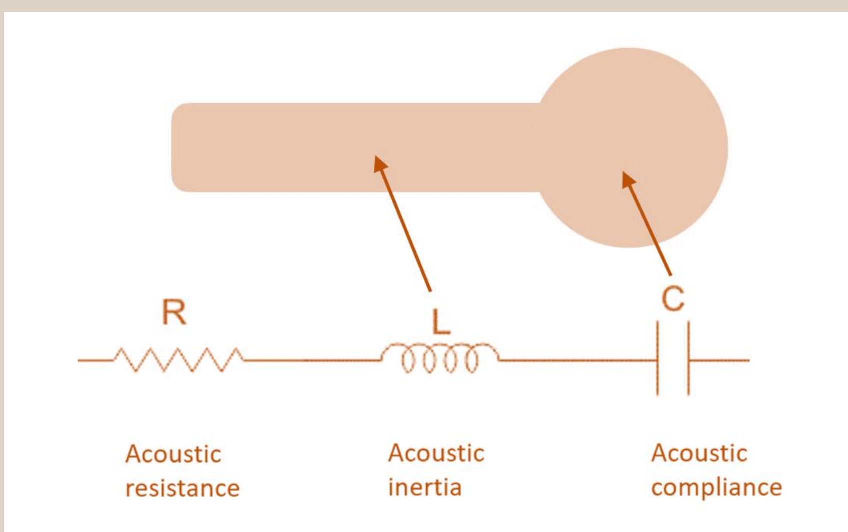

FIG.7 HELMHOLTZ RESONATOR

If we regard an ear canal as the body of the bottle, the circuit turns from an LCR to a CR circuit. In this case, the RC circuit acts as a low-pass filter. The gain of this circuit is described by the equation: $Gain = \frac{1}{\sqrt{1+(\omega RC)^2}}$

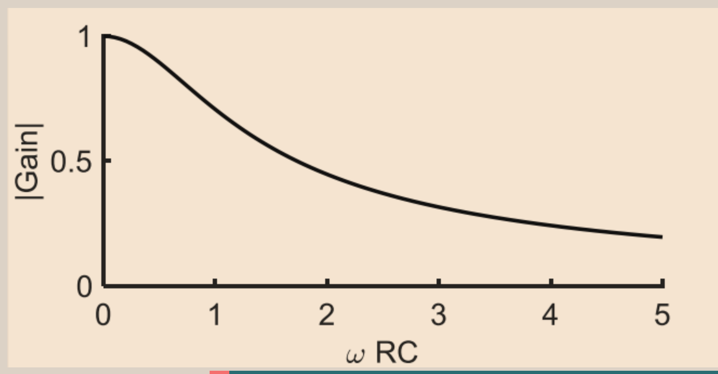

FIG.8 GAIN CURVE

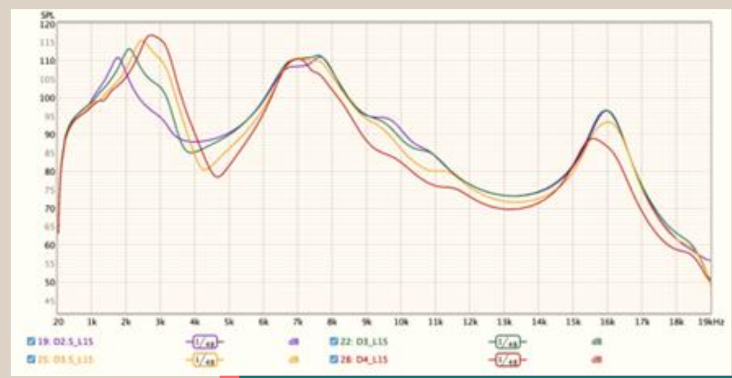

FIG.9 SPL CURVE IN LINEAR SCALE

As you can see from Figure 8, at low frequencies, the gain is close to one. This means that all outputs should be constant. This is reflected in the superimposition of the low-frequency regions of the SPL curve. At the same time, RC is proportional to the length and inversely proportional to the radius. This means that as the length of the headphone increases, the time constant increases, and so after the initial relative constant region, the Gain vs ωRC curve decays faster. As the radius increases, RC falls and so the curve decays slower.

If we assume that acoustical energy is wholly conserved, thus theoretically making acoustical resistance zero. With this condition in place, the LCR circuit becomes an LC circuit.

The resonant frequency of an LC circuit can be found at: $f_0 = \frac{1}{2\pi\sqrt{LC}}$

Plugging in the equation for Ca and Ma gives: $f_o = \frac{1}{2\pi}\sqrt{c^2\frac{s}{Vl}}$

When the diameter of the earphone increases, thus CSA increases, the resonance peaks occur at a higher frequency, which is shown by the rightward shift in the peaks shown in the diagram of changing diameter. On the other hand, as the length of the earphone increases, modelling an increase in the length of the ear canal, the frequency at which resonance occurs decreases. The overall behaviour of the ear canal is the superimposition of both of these effects, which was the trend observed. Our analysis focused mainly on the first instance of resonance. In ideal theoretical conditions, the later peaks would follow the same trends.

04. CONCLUSIONS

In conclusion, as the size of the aperture increases, the resonance peaks occur at a higher frequency and at a higher intensity. On the other hand, an increase in the length of the tube in which the air column passes will cause resonance to occur at a lower frequency. In practical applications, the effect of the ear canal on sound should also be considered. For example, a noise of 2kHz will affect a person more than measured because of the enhanced resonance that occurs in the ear canal. Finally, as Dr. Walter Lewin famously said, any measurement is useless without the knowledge of its uncertainty. The main uncertainties come from the experimental set-up as well as the apparatus used. In the low-frequency range (<100Hz), the curves obtained were not smooth as the sound input was corrupted by the ambient surrounding noise since the measurements were not taken in a strict silencer chamber. The artificial ear used, known as the iec711 coupler, is not verified to simulate the human ear at frequencies above 10kHz, and so the readings above this point are inaccurate and should not be considered.

SOURCES...

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Meeting Diary

Aim: Introduction
Date & Time: 11.7 15:00-16:00
Location: BLKT 113

Content summary: Since Kevin has an artificial ear coupler, which can measure sound pressure level, we decided to choose a topic related to acoustics. After discussion, we decided to study the effect of porous materials on sound. We planned to set different kinds of polyurethane sponges on the front of the headphones to achieve different frequency responses.

Task: Study the basic knowledge of acoustics, search for relevant literature, purchase experimental supplies

Aim: Discuss the results of the study
Date & Time: 11.21 15:00-16:00
Location: BLKT 113

Content summary: After research, we found that it was difficult to purchase polyurethane sponges with clear parameter identification (such as porosity, pore size, film structure, etc.), so it was difficult to control and quantify the variables. Meanwhile, in the relevant literature, material pictures were always procured by CT scan, which we do not have the ability to do. As a result, we decided to change the topic. We then chose to use 3D printing to construct an earphone with a replaceable front cavity, and then use different shapes of front cavities to explore the influence of the shape of sound propagation space on sound.

Task: Modeling, purchasing experimental supplies, reading papers

Aim: 3D print, weld and assemble the earphone, predict experimental results
Date & Time: 12.2 12:00-18:00
Location: Hackspace

Content summary: In Hackspace, we chose an SLA 3D printer to produce the earphone casing for higher accuracy. In the process of printing, we communicated the research results in several days ago. We predicted that the length of the tube would affect the formant's frequency, and the diameter of the tube would affect the overall loudness of the headset. We then connected the balanced armature unit to the MMCX with a soldering iron to complete the assembly of the earphone.

Task: reading relevant papers, bring your own earphones to the next meeting

Aim: Preliminary measurement, try different earphones and feel the impact of different frequency responses on hearing
Date &Time: 12.6 11:00-12:00
Location: BLKT 539

Content summary: We set up the experimental device and found that the frequency response curve of the earphone could be correctly measured, and the experiment was feasible. They we tried different earphones everyone brought, measured their frequency response, and compared their subjective hearing perception.

Task: Study the standard earphone frequency response measurement method

Aim: Measure data
Date & Time: 12.15 12:00-14:00
Location: BLKT 539

Content summary: Twelve samples were measured, and basic data analysis was completed. We found that the experimental results were different from our expectations, and through research and many measurements, we eliminated the causes of experimental operation errors and excessive errors.

Task: Learn acoustics and explain experimental phenomena

Aim: Measure the data
Date & Time: 12.21 19:00-20:00
Location: Online

Content summary: Exchanging learning results, this time we gain more than before. We find some valuable information in duct acoustic, such as end correlation. And we also noticed that our experiment is related to ear canal acoustics. We realized that our project could also be extended to the acoustic aspects of the ear canal, which seemed more interesting and more relevant and specific to our experiments. Therefore, we decided to change the subject to "the influence of ear canal on sound. "

Task: Do relevant research, and construct a full explanation of the experiment's result

Aim: Complete theory and analysis
Date & Time: 12.28 20:00-24:00
Location: Online

Content summary: We have learned the idea of electric-acoustic analogy and explained the experimental results by constructing equivalent circuits. We then drew a mind map about the logical flow of theory, which was used as a reference when we wrote the poster. Finally, we completed the assignment of work and each person was responsible for one part of the poster.
Task: Write our own poster content

Aim: Polish the content
Date & Time: 1.5 15:00-17:00
Location: Online

Content summary: We read others' content drafts and gave suggestions for improvement. Moreover, we chose the poster template and confirmed the general layout.

Task: Finish the final version of the poster write-up

Aim: make a poster
Date & Time: 1.12 13:00-17:00
Location: H-bar

Content summary: Complete the poster production and upload the poster

Task: Practice the presentation

Aim: Start the report write-up
Date & Time: 1.16 12:00-14:00
Location: Senior common room

Content summary: Split the report into 9 parts: abstract, introduction, methods, data presentation, theory explanation, data analysis, conclusion, summary, and reflection. Along with sorting out the meeting diary, each of us picks two tasks to finish by 1st February.

Task: Finish individual parts of the report

Aim: Finalize the report and submit it
Date & Time: 2.03 13:00-15:00
Location: BLKT common room

Content summary: Complete the report writing, put the summary, reflection and report together and upload the report

Task: None

Reflection

- As a group, we worked well as we listened to each other's ideas and communicated our own using mostly messaging and some in person meetings. This increased our group efficiency.
- Our communication could be improved by scheduling more in person meetings as this means we could have more in detail conversations and bounce ideas off on another. Also, keeping an exact weekly schedule (rather than deciding on a weekly basis) is something we would implement next time to increase productivity.
- We completed the practical and write up in the given time, splitting the work in between the group well.
- If we could do it again, we would put in more hours at the start of the term rather than equally distribute it across the weeks as revision/other deadlines meant we had less time in the last few weeks.
- Our record keeping skills were good as we would put all our findings and plans on the group chat so everyone can access it and plan accordingly.
- If we were to do it again, we would keep a record of our meetings and findings on a separate shared document, so it is easy to keep track of and find.
- We worked collaboratively on the poster, each writing a separate section and having one person put it together.
- If we were to do it again, we would be careful to ensure we have sent the poster to be printed.
- However, we worked well as a team to print the poster in a short time frame and present it in time.
- We practiced our presentation a few times, distributing different parts of our research to different people so everyone contributes. Practicing ensured that we could finish in the given time and deliver a professional presentation that people would enjoy listening to.
- We kept a list of our references whilst researching to then write the bibliography at the end.
- Next time we could improve this by the citing our writing as we go (rather than adding them at the end) as this may increase efficiency.

Reward

Kevin Ni	1.0
Sid Diamond	1.0
Nikhail Virik	1.0
Nidhi Doshi	1.0
Ziyao Xiong	1.0