EXTENDED ESSAY

BIOLOGY

Title: Music and the ear

Research question: Do the right and the left ear have the same capacity to decipher and interpret music and tones?

Name: Solveig Aftret

Exam Session May 2020

This is my extended essay submission to the International Baccalaureate Diploma Programme for the May 2020 Examinations

Table of Contents

Introduction

Music is a huge part of people's everyday life. As a musician myself, it has always been a powerful and important part of my life. Whether it would be simply listening to music on my headphones, singing, or playing my trumpet. Without it I don't know what I would do. Music is my escape, it's amazing, it's magical to me. Music is something that every human on this planet should be able to have. However, not everybody is that lucky. Some people have hearing problems and don't get to enjoy music like we do. The research question for this extended essay examines if our left and right ears hear conflicting tones by vocal reproduction of tones played into both ears separately. Knowing the difference between our ears and what sort of sounds they hear best, can make a huge difference in otology, the study of the ear, and in somebody's life.

The auditory system is a system of our body that is responsible for one of our five senses, hearing. The anatomy of this system is very complex, but it can be divided into two subparts: the peripheral auditory system and the central auditory system.

The peripheral system has three parts:

The outer ear: It consists of the pinna (or auricle), the only visible part of the ear, the ear canal and the ear drum.

The middle ear: It is a small space filled with air that consists of three small bones called the ossicles, or the malleus, incus and stapes.

The inner ear: This part of the ear is not filled with air, but rather with liquid. The cochlea is the main structure of the inner ear and it contains hair cells. The cochlea is connected to the central auditory system by the auditory nerve.

The central auditory system starts at the auditory nerve and continues on with a pathway through the brainstem and to the brain's auditory cortex.[1]

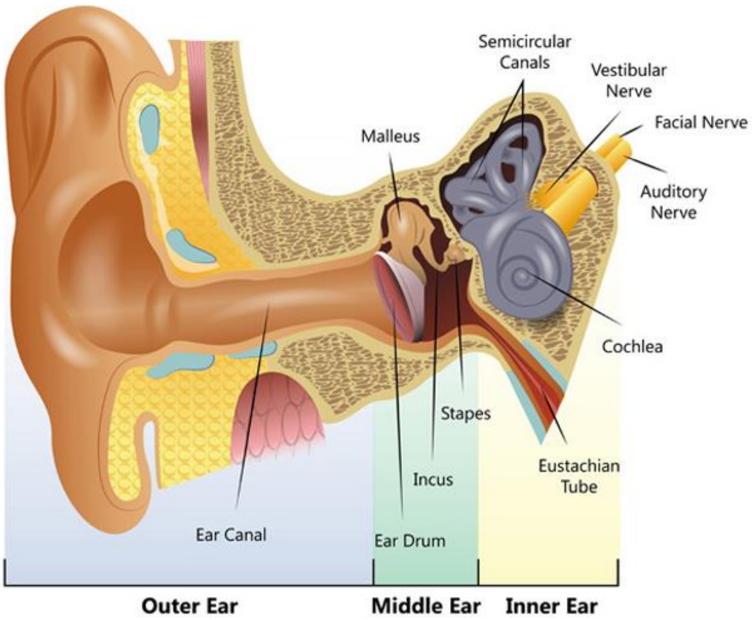


Fig. 1 Labelled diagram showing a cutaway of the different parts of the human ear, from the outer ear through the middle ear to the inner ear[2]

Sounds are vibrations present in the air. Sound waves are almost all unique. Some are low pitched and loud while some are high pitched and quiet. When these sound waves are captured by our ears, they are converted into messages for our brain to understand.[3]

[1] Hearing Link, "How the ear works", https://www.hearinglink.org/your-hearing/about-hearing/how-the-ear-works/, (2018)
[2] Ibid.
[3] Ear Science, "How we hear", https://www.earscience.org.au/sites/www.earscience.org.au/files/field/pdf/how_we_hear.pdf, (n.d.)

The first step in this process is the sound waves entering the ear canal and hitting the eardrum causing it to vibrate. When the ear drum vibrates, it moves the ossicles, a set of three tiny bones (the hammer, the anvil, the stirrup). These bones are what connects the eardrum to the cochlea in the inner ear. The cochlea is filled with a liquid and the vibration from the ossicles creates waves in this liquid. When the fluid in the cochlea moves, it moves the hair cells and creates nerve signals that are sent to the brain. Our brain then understands these signals as sound, and so we hear.[4]

The brain's left hemisphere is better at deciphering speech, while the right hemisphere dominates in interpreting music, and hearing pitch. The brain's neural network is organized in a way that the left ear auditory nerve pathway leads to the right hemisphere's auditory cortex, making it the preferred ear to hear music. On the other hand, the right ear auditory nerve pathway is connected to the left hemisphere's auditory cortex.[5]

It was difficult to find research done on this topic. Nevertheless, related investigations have been done, on for example ear preference for listening to verbal stimuli.

Italian scientists, Luca Tommasi and Daniele Marzoli of the University "Gabriele d'Annunzio" in Chieti, Italy, conducted a series of three studies where they observed ear preference in noisy discotheques during social interactions. Taken together, the results of all three studies confirmed a right ear/left hemisphere dominance for verbal communication.[6]

---

[4] National Institute on Deafness and Other Communication Disorders, "How Do We Hear?", https://www.nidcd.nih.gov/health/how-do-we-hear, (January 3, 2018)
[5] Robin Lloyd, "Most People Prefer Right Ear for Listening", https://www.livescience.com/9679-people-prefer-ear-listening.html, (June 24, 2009)
[6] Ibid.

This was not the first investigation done on ear preference in human communication. Scientists have long understood that the auditory regions of the left and right hemisphere of the brain sort out sounds differently.

These differences were always thought to stem from unique cellular properties of each hemisphere. However, scientists Barbara Cone-Wesson and Yvonne Sininger's study proved that the differences are inherent in the ears themselves. They studied tiny amplifiers in the tiny hair cells in the inner ear. "When we hear a sound, tiny cells in our ear expand and contract to amplify the vibrations," explained Sininger. "The inner hair cells convert the vibrations to neural cells and send them to the brain, which decodes the input."
"These amplified vibrations also leak back out to the ear in a phenomenon called otoacoustic emission (OAE)," added Yvonne Sininger. "We measured the OAE by inserting a microphone in the ear canal."[7] Their findings demonstrated that auditory processing starts in our ears first.

As researchers at the University of California – Los Angeles (UCLA) mentioned in their report concerning the study "Previous research supports the team's new findings. For example, earlier research shows that children with impairment in the right ear encounter more trouble learning in school than children with hearing loss in the left ear."[8] Hence making the right ear the dominated one in terms of speech and learning and the left ear the dominating one in regard to music.

Females and males tend to have very different voices. On average, women have higher pitched voices, while men tend to have lower-pitch voices. This is all due to our vocal

[7] Lori Stiles, "Newborns Have Ear Preferences, Too", https://uanews.arizona.edu/story/newborns-have-ear-preferences-too, (September 2, 2004)
[8] University of California - Los Angeles, "Left And Right Ears Not Created Equal As Newborns Process Sound, Finds UCLA/UA Research", https://www.sciencedaily.com/releases/2004/09/040910082553.htm (September 10, 2004)

cords, muscles located in our larynx. The size of a person's vocal cords affects their pitch. Usually a girl's vocal cords are smaller and thinner than a boy's, which is why their voices sound higher. This difference is not very noticeable on young children. However, after puberty, it is a lot more obvious. During puberty, boys' bodies start producing a hormone, testosterone, that makes the body change. Those changes include their vocal cords growing, making their voices sound even deeper. This also happens for girls. They produce testosterone and in addition, also estrogen. However, they don't produce as much as boys, their vocal cords don't grow as much, and their voice are higher pitched[9].

Hypothesis:

Based on studies done by Italian scientists, Luca Tommasi and Daniele Marzoli, that demonstrated that there is a right ear/left hemisphere dominance for verbal communication and a left ear/right hemisphere dominance for deciphering music[10] and based on the background information I have gathered, the expectation for this experiment is that the participants' vocal reproduction of a tone will be more accurate when the sound will be heard in their left ear rather than in the right ear. This will prove that our left ear is better at picking up musical tones while the right ear dominates in deciphering speech.

[9] Michele Debczak, "Why Are Girls' Voices Usually Higher Than Boys' Voices?", http://mentalfloss.com/article/72393/why-are-girls-voices-usually-higher-boys-voices, (May 1, 2018)
[10] Robin Lloyd, "Most People Prefer Right Ear for Listening", https://www.livescience.com/9679-people-prefer-ear-listening.html, (June 24, 2009)

Method

Materials

1 pair of earphones

Electronic keyboard

Mobile phone

Application "Hearing Test" by e-audiologia[11]

Application "Pitched tuner and pitch patch" by Stonekick[12]

Procedure

Variables

Independent variable:

Frequencies used during the Pitch-Matching Test

Dependent variable:

[11] E-audiologia, "Hearing test", https://www.e-audiologia.pl/HearingTest/?fbclid=IwAR3rihc1pXhbiYhI0AC1kmv2v_lGHRCxYOXRroGvR4DczC-gplD3US7X1KA#home, (n.d.)
[12] Stonekick, "Pitched tuner", http://www.stonekick.com/tuner.html, (2019)

Frequency of the vocal reproductions of the tones of all participants. They were captured by a chromatic tuner and then compared to the original tone.

Controlled variable:

Volume at which the tones were being played.

Room where the participants took the tests

Background noise by choosing a room with minimal noise

The age of the participants only varied by two maximum two years (17 to 19)

In order to test the research question, an experiment was undertaken on eight individuals, four males and four females of about 17 to 19 years old.

I tested my experiment only on teenagers between the age of 17 to 19. This is because the point of the experiment is not to observe how our ability to hear tones differ according to our age but from one ear to another. Experimenting on people of similar ages limits the variables and allows me to analyze my results regardless of an individual's age.

The experiment first consisted of a questionnaire and consent form given to the eight participants in order to find out their age, gender, if they've had some musical training and a self-evaluation of their singing ability (from 1 to 10). The consent form can be found on the next page and the consent forms completed by the participants can be found in appendix 1.

IB HL Biology Informed Consent Form and questionnaire

I give my informed consent to participate in this study.

________I am voluntarily participating in this study.

________I have been informed of the nature of the research and study.

_______ I understand I have the right to withdraw from the study at any time for any reason.

________I understand that any information/data collected about me will remain strictly confidential.

_______ I understand that my anonymity will be protected and that my name will not be identified anywhere in the study or research.

________The research will be conducted so that I will not be demeaned in any way.

________I understand that I will be debriefed at the end of my participation in the study and given an opportunity to find out the results.

Age:________

Gender:________

Musical training:____

Self-evaluation of singing ability (from 1 to 10):______

Participant Signature:__________________________________

Date:____________________

All of the participants underwent two types of test:

1. Hearing test

The hearing test used was one by e-audiologia.[13] They have an application on the phone that will perform a pure-tone audiometry, a basic hearing examination. The test consisting in determining the quietest sound one is able to hear. The test frequencies used were the defaults on the app: 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz, 6000 Hz and 8000 Hz. The test was performed on the left and right ear individually.

2. Pitch-matching test (PMT)

The participants underwent then a pitch-matching test. This test is the one that ultimately will prove whether an individual hears tones differently from ear to ear. The test consists of a vocal imitation of sounds. It is a sequence of five sound tasks that are piano recordings of different tones. From the piano recordings, the participants heard the sound, first only in the left ear and then only in the right ear and tried to reproduce the tone immediately by using the sound /u/ (International Phonetic System)[14]. As was explained in the introduction, females usually have a higher pitch than men so in order for females to be able to reproduce a sound comfortably without any difficulty, I have chosen tones that would be the most easily reproducible for a female's voice. On the other hand, men tend to have lower pitch voices.

[13] E-audiologia, "Hearing test", https://www.e-audiologia.pl/HearingTest/?fbclid=IwAR3rihc1pXhbiYhI0AC1kmv2v_lGHRCxYOXRroGvR4DczC-gplD3US7X1KA#home, (n.d.)

The tones chosen differed from female to male participants as the most comfortable and average tones for each gender were chosen (Table 1).

Table 1 Tones used during the Pitch-matching test[15]

Female		Male	
Tones	Frequencies in Hz	Tones	Frequencies in Hz
C4	261,6	C3	130,8
D4	293,7	D3	146,8
E4	329,6	E3	164,8
F4	349,2	F3	174,6
G4	392,0	G3	196,0

The sounds were made by an electronic keyboard.

The reproductions of the sounds were captured by a chromatic tuner and compared to the original sound presented. The chromatic tuner used was an app called "pitched tuner and pitch pipe" by Stonekick[16]. The chromatic tuner shows the nearest tone being played or sung and the exact frequency of what the participant is singing.

The pitch-matching test was performed on each participant five times.

[15] Donald Byrd, "Musical Pitches", http://people.virginia.edu/~pdr4h/pitch-freq.html, (Nov, 2006)
[16] Stonekick, "Pitched tuner", http://www.stonekick.com/tuner.html, (2019)

Research

Results

<u>Questionnaire</u>

Out of all the participants, two guys and two girls were musically trained, participant 2,3, 7 and 8. The other four had never gotten any musical training other than music lessons at school.

<u>Hearing test</u>

The results from the hearing test are displayed as an audiogram on the application that illustrates an individual's ability to hear by showing your hearing threshold at different frequencies. The test was performed to make sure none of the participants were suffering from hearing loss and could hear the frequencies played during the PMT perfectly. An example of how the results were presented can be seen in figure 2. The hearing test performed on the rest of the participants can be seen in appendix 2.

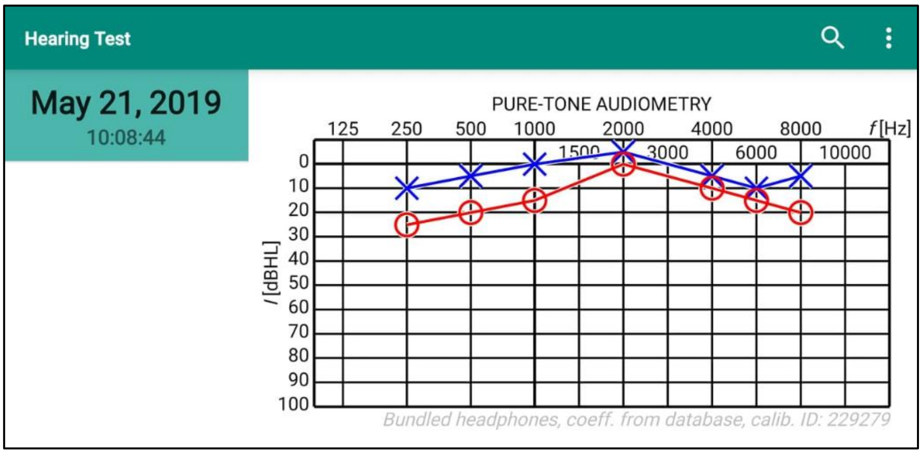


Fig. 2 Results from hearing graph performed on participant 1

The results of the hearing tests appear in an audiogram where two hearing curves are drawn for each ear. The blue color represents the hearing curve for the left ear while the red represents the hearing curve for the right ear. The frequency is measured in hertz (Hz) and is shown form the lowest (left) to the highest (right) across the horizontal axis on the top. “The intensity in decibels (dB) required for an individual to perceive a tone at a given frequency is plotted from soft to loud down the vertical axis and gives an indication of the individual’s degree of hearing loss.”[17]

In terms of the results, there was nothing critical recorded, every participant had a normal hearing.

[17] German Hearing Center, “How to Interpret an Audiogram”, https://www.hoerzentrum-hannover.de/en/diagnosis/how-to-interpret-an-audiogram/, (n.d.)

Pitch-matching test

Results from the female participants

Table 2 Table showing raw and processed data from the female participants

		Participant 1		Participant 2		Participant 3		Participant 4	
Actual frequency	Trial	Left ear	Right ear	Left ear	Right ear	Left ear	Right ear	Left ear	Right ear
261,6 (C4)	1	272,8	274,5	269,5	270,1	265,6	267,1	275,4	279,1
	2	273,4	270,9	267,9	269,8	265,9	267,3	273,7	278,4
	3	272,1	275,8	266,7	268,0	266,3	268,1	272,5	275,0
	4	271,5	273,9	266,3	269,6	268,9	270,0	271,0	275,4
	5	271,0	274,7	265,4	267,2	264,7	265,4	270,9	274,2
	Mean	272,2	274,0	267,2	268,9	266,3	267,6	272,7	276,4
	STDAV	0,9	1,6	1,4	1,1	1,4	1,5	1,7	2,0
293,7 (D4)	1	302,1	297,2	300,8	302,0	295,1	299,4	304,9	307,5
	2	302,9	300,2	299,5	300,9	295,6	298,5	303,4	305,7
	3	305,4	308,2	298,1	300,2	297,6	300,0	305,6	310,0
	4	303,3	306,8	299,0	302,7	296,7	299,9	303,1	307,2
	5	301,7	304,4	297,0	299,2	295,2	298,8	302,0	304,8
	Mean	303,1	303,4	298,9	301,0	296,0	299,3	303,8	307,0
	STDAV	1,3	4,1	1,3	1,2	1,0	0,6	1,3	1,8
329,6 (E4)	1	320,7	317,4	339,7	341,4	334,4	336,7	340,4	344,3
	2	321,1	319,8	337,2	340,5	334,9	335,6	339,9	342,2
	3	319,9	326,4	337,9	342,2	331,2	333,2	341,0	345,8
	4	322,2	325,6	335,8	337,7	332,5	335,0	336,2	342,8
	5	320,6	317,7	333,1	337,9	332,0	334,1	338,3	343,5
	Mean	320,9	321,4	336,7	339,9	333,0	334,9	339,2	343,7
	STDAV	0,8	3,9	2,2	1,8	1,4	1,2	1,7	1,3
349,2 (F4)	1	360,5	362,7	354,2	357,8	353,9	355,4	356,2	360,7
	2	361,3	357,6	353,6	355,1	354,1	356,1	358,4	363,0
	3	358,4	362,4	353,0	355,5	352,5	354,8	360,1	366,2
	4	360,9	358,0	355,7	358,0	353,0	355,6	359,3	364,9
	5	359,5	355,1	354,1	358,3	351,4	354,3	356,9	355,0
	Mean	360,1	359,2	354,1	356,9	353,0	355,2	358,2	362,0
	STDAV	1,0	2,9	0,9	1,4	1,0	0,6	1,5	3,9
392,0 (G4)	1	385,3	388,2	388,2	385,4	391,4	385,4	379,1	374,6
	2	386,3	380,1	389,0	387,3	390,3	389,3	380,2	380,5
	3	385,7	382,0	387,5	385,3	391,1	387,2	380,9	378,0
	4	387,6	384,6	388,6	385,7	388,6	388,0	382,3	379,8
	5	396,4	381,9	389,9	386,1	389,9	386,4	385,3	381,4
	Mean	388,3	383,4	388,6	386,0	390,3	387,3	381,6	378,9
	STDAV	4,1	2,8	0,8	0,7	1,0	1,3	2,1	2,4

STDAV stands for Standard Deviation

Actual frequency represents the frequency of the tone the participants had to reproduce

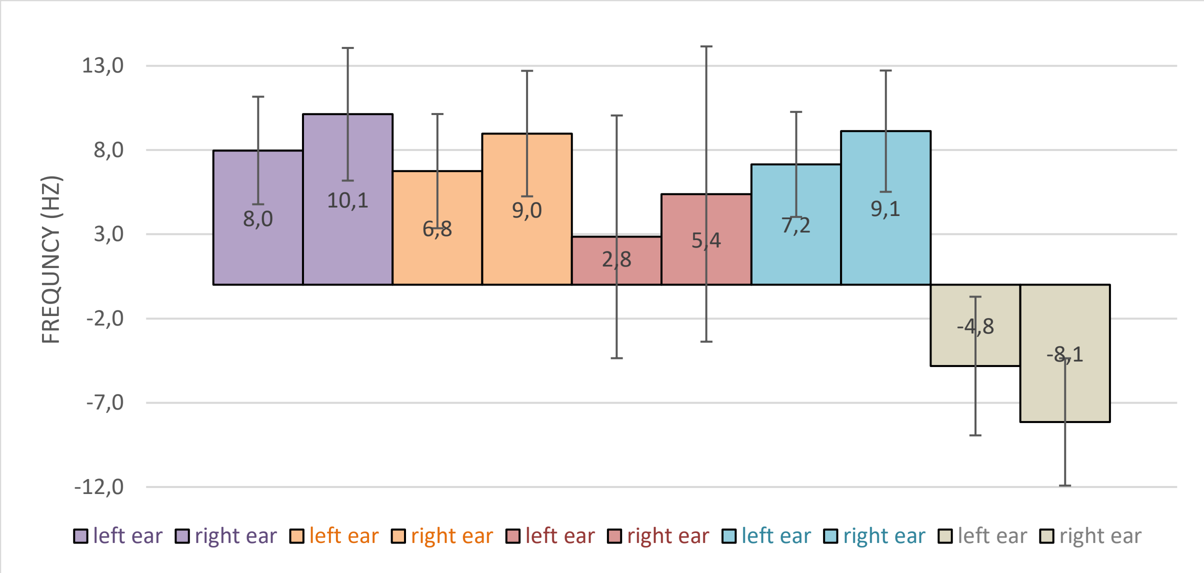
Table 3 Table showing difference between the vocal reproduction of the female participants and the frequency of the tone they were attempting to reproduce

		C4		D4		E4		F4		G4	
		left ear	right ear	left ear	right ear	left ear	right ear	left ear	right ear	left ear	right ear
Vocal reproduction - actual frequency	Participant 1	11,2	12,9	8,4	3,5	-8,9	-12,2	11,3	13,5	-6,7	-3,8
		11,8	9,3	9,2	6,5	-8,5	-9,8	12,1	8,4	-5,7	-11,9
		10,5	14,2	11,7	14,5	-9,7	-3,2	9,2	13,2	-6,3	-10,0
		9,9	12,3	9,6	13,1	-7,4	-4,0	11,7	8,8	-4,4	-7,4
		9,4	13,1	8,0	10,7	-9,0	-11,9	10,3	5,9	4,4	-10,1
	Participant 2	7,9	8,5	7,1	8,3	10,1	11,8	5,0	8,6	-3,8	-6,6
		6,3	8,2	5,8	7,2	7,6	10,9	4,4	5,9	-3,0	-4,7
		5,1	6,4	4,4	6,5	8,3	12,6	3,8	6,3	-4,5	-6,7
		4,7	8,0	5,3	9,0	6,2	8,1	6,5	8,8	-3,4	-6,3
		3,8	5,6	3,3	5,5	3,5	8,3	4,9	9,1	-2,1	-5,9
	Participant 3	4,0	5,5	1,4	5,7	4,8	7,1	4,7	6,2	-0,6	-6,6
		4,3	5,7	1,9	4,8	5,3	6,0	4,9	6,9	-1,7	-2,7
		4,7	6,5	3,9	6,3	1,6	3,6	3,3	5,6	-0,9	-4,8
		7,3	8,4	3,0	6,2	2,9	5,4	3,8	6,4	-3,4	-4,0
		3,1	3,8	1,5	5,1	2,4	4,5	2,2	5,1	-2,1	-5,6
	Participant 4	13,8	17,5	11,2	13,8	10,8	14,7	7,0	11,5	-12,9	-17,4
		12,1	16,8	9,7	12,0	10,3	12,6	9,2	13,8	-11,8	-11,5
		10,9	13,4	11,9	16,3	11,4	16,2	10,9	17,0	-11,1	-14,0
		9,4	13,8	9,4	13,5	6,6	13,2	10,1	15,7	-9,7	-12,2
		9,3	12,6	8,3	11,1	8,7	13,9	7,7	5,8	-6,7	-10,6
Mean		8,0	10,1	6,8	9,0	2,8	5,4	7,2	9,1	-4,8	-8,1
STDAV		3,2	3,9	3,4	3,7	7,2	8,8	3,1	3,6	4,1	3,8

STDAV stands for Standard Deviation

Actual frequency represents the frequency of the tone the participants had to reproduce

Graph 1 Bar graph showing the mean difference between the vocal reproduction of the female participants and the frequency of the tone they were attempting to reproduce



The bar graph shows the mean difference between the vocal reproduction of the female participants and the frequency of the note they were attempting to reproduce - C4, D4, E4, F4, G4 - when it was played into their left ear and right ear. The bar graph shows that the difference between the two was smaller when the note was played into their left ear rather than into their right ear.

Results from the male participant

Table 4 Table showing raw and processed data from the male participants

		Participant 5		Participant 6		Participant 7		Participant 8	
Actual frequency	Trial	Left ear	Right ear	Left ear	Right ear	Left ear	Right ear	Left ear	Right ear
130,8 (C3)	1	119,5	116,3	142,0	145,1	123,7	120,3	124,9	122,0
	2	118,4	115,1	147,9	149,8	121,9	117,3	123,7	121,8
	3	118,3	102,4	144,7	149,0	123,3	119,1	126,5	125,7
	4	121,5	112,0	145,5	151,6	122,7	117,0	124,7	123,2
	5	118,2	116,7	143,0	147,2	124,9	121,0	125,8	121,9
	Mean	119,2	112,5	144,6	148,5	123,3	118,9	125,1	122,9
	STDAV	1,3	5,3	2,1	2,2	1,0	1,6	1,0	1,5
146,8 (D3)	1	136,1	133,3	157,6	160,5	133,7	131,3	143,5	141,4
	2	137,8	136,4	155,8	157,8	135,3	133,0	142,6	140,5
	3	135,3	133,2	160,4	164,1	132,8	129,4	144,6	141,0
	4	135,4	132,0	158,3	162,3	134,0	132,1	143,7	142,8
	5	136,9	136,9	155,9	158,4	133,4	130,7	142,9	141,8
	Mean	136,3	134,4	157,6	160,6	133,8	131,3	143,5	141,5
	STDAV	0,9	1,9	1,7	2,4	0,8	1,2	0,7	0,8
164,8 (E3)	1	152,3	151,0	174,5	179,9	158,0	156,9	160,7	157,7
	2	153,1	149,8	174,8	179,2	158,2	157,5	161,2	159,3
	3	149,8	145,3	177,0	182,1	157,6	155,3	159,0	156,4
	4	150,5	157,1	155,6	150,4	156,3	155,7	160,4	158,4
	5	150,0	147,2	173,9	152,7	160,9	159,1	162,3	160,6
	Mean	151,1	150,1	171,2	168,9	158,2	156,9	160,7	158,5
	STDAV	1,3	4,0	7,9	14,2	1,5	1,4	1,1	1,4
174,6 (F3)	1	161,7	156,7	186,5	190,4	169,1	167,8	168,3	166,3
	2	163,4	159,5	186,8	188,8	170,4	168,7	169,0	167,4
	3	162,9	157,8	183,8	185,0	171,5	170,7	167,3	164,2
	4	163,8	161,7	185,0	190,3	168,9	166,8	170,3	167,6
	5	164,0	162,1	182,3	187,0	170,5	168,6	169,9	168,8
	Mean	163,2	159,6	184,9	188,3	170,1	168,5	169,0	166,9
	STDAV	0,8	2,1	1,7	2,1	1,0	1,3	1,1	1,5
196,0 (G3)	1	210,3	208,4	206,8	209,7	190,4	188,3	193,4	192,5
	2	205,6	202,6	207,5	210,6	190,1	188,4	192,3	191,9
	3	206,7	202,0	205,4	209,4	193,6	192,5	194,0	190,2
	4	204,9	201,8	206,5	209,4	189,7	189,0	191,9	190,9
	5	207,0	205,2	206,4	209,5	190,8	189,3	193,9	191,7
	Mean	206,9	204,0	206,5	209,7	190,9	189,5	193,1	191,4
	STDAV	1,9	2,5	0,7	0,5	1,4	1,5	0,9	0,8

STDAV stands for Standard Deviation

Actual frequency represents the frequency of the tone the participants had to reproduce

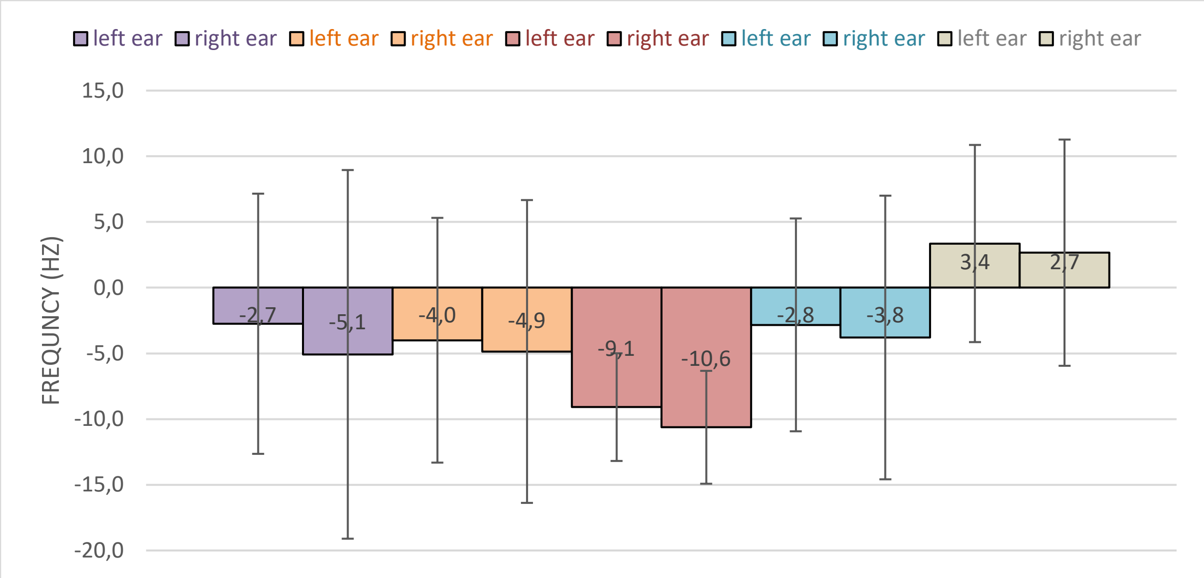
Table 5 Table showing difference between the vocal reproduction of the male participants and the frequency of the tone they were attempting to reproduce

		C3		D3		E3		F3		G3	
		left ear	right ear	left ear	right ear	left ear	right ear	left ear	right ear	left ear	right ear
Vocal reproduction - actual frequency	Participant 5	-11,3	-14,5	-10,7	-13,5	-12,5	-13,8	-12,9	-17,9	14,3	12,4
		-12,4	-15,7	-9,0	-10,4	-11,7	-15,0	-11,2	-15,1	9,6	6,6
		-12,5	-28,4	-11,5	-13,6	-15,0	-19,5	-11,7	-16,8	10,7	6,0
		-9,3	-18,8	-11,4	-14,8	-14,3	-7,7	-10,8	-12,9	8,9	5,8
		-12,6	-14,1	-9,9	-9,9	-14,8	-17,6	-10,6	-12,5	11,0	9,2
	Participant 6	11,2	14,3	10,8	13,7	-13,1	-13,9	11,9	15,8	10,8	13,7
		17,1	19,0	9,0	11,0	-10,5	-15,8	12,2	14,2	11,5	14,6
		13,9	18,2	13,6	17,3	-11,1	-11,6	9,2	10,4	9,4	13,4
		14,7	20,8	11,5	15,5	-12,0	-14,4	10,4	15,7	10,5	13,4
		12,2	16,4	9,1	11,6	-13,4	-12,1	7,7	12,4	10,4	13,5
	Participant 7	-7,1	-10,5	-13,1	-15,5	-6,8	-7,9	-5,5	-6,8	-5,6	-7,7
		-8,9	-13,5	-11,5	-13,8	-6,6	-7,3	-4,2	-5,9	-5,9	-7,6
		-7,5	-11,7	-14,0	-17,4	-7,2	-9,5	-3,1	-3,9	-2,4	-3,5
		-8,1	-13,8	-12,8	-14,7	-8,5	-9,1	-5,7	-7,8	-6,3	-7,0
		-5,9	-9,8	-13,4	-16,1	-3,9	-5,7	-4,1	-6,0	-5,2	-6,7
	Participant 8	-5,9	-8,8	-3,3	-5,4	-4,1	-7,1	-6,3	-8,3	-2,6	-3,5
		-7,1	-9,0	-4,2	-6,3	-3,6	-5,5	-5,6	-7,2	-3,7	-4,1
		-4,3	-5,1	-2,2	-5,8	-5,8	-8,4	-7,3	-10,4	-2,0	-5,8
		-6,1	-7,6	-3,1	-4,0	-4,4	-6,4	-4,3	-7,0	-4,1	-5,1
		-5,0	-8,9	-3,9	-5,0	-2,5	-4,2	-4,7	-5,8	-2,1	-4,3
Mean		-2,7	-5,1	-4,0	-4,9	-9,1	-10,6	-2,8	-3,8	3,4	2,7
STDAV		9,9	14,0	9,3	11,5	4,1	4,3	8,1	10,8	7,5	8,6

STDAV stands for Standard Deviation

Actual frequency represents the frequency of the tone the participants had to reproduce

Graph 2 Bar graph showing the mean difference between the vocal reproduction of the male participants and the frequency of the tone they were attempting to reproduce



The bar graph shows the mean difference between the vocal reproduction of the male participants and the frequency of the note they were attempting to reproduce – C3, D3, E3, F3, G3 - when it was played into their left ear and right ear. Similarly, to the female participants, this graph shows that difference between the vocal reproduction and the actual frequency was smaller when the note was played into their left ear rather than into their right ear. However, there is an exception. When the tone G3 was played for the male participants, it seems that their vocal reproduction was a few frequencies better when the tone was played into their right ear as the difference is smaller.

T-test

A t-test was performed on the raw data from all participants to find out if the difference between the vocal reproduction of a participant when the sound was played into their left ear and when it was played into their right ear is significant or not (p=0.05). These results can be found in the following table.

Table 5 Table showing the results from the t-test performed on the raw data of all participants

	Participant 1	Participant 2	Participant 3	Participant 4
C4	0,04	0,04	0,12	0,01
D4	0,45	0,02	0,00	0,01
E4	0,41	0,03	0,04	0,00
F4	0,28	0,00	0,00	0,05
G4	0,04	0,00	0,00	0,07
	Participant 5	Participant 6	Participant 7	Participant 8
C3	0,02	0,02	0,00	0,02
D3	0,05	0,04	0,00	0,00
E3	0,32	0,39	0,12	0,02
F3	0,01	0,02	0,04	0,03
G3	0,05	0,00	0,10	0,01

If the p-value is ≤ (lower or equal to) 0,05, it means that it is less than 5% likely that the difference is due to chance or coincidence, i.e. the difference is significant. The p-values calculated differed a bit from participant to participant; however, on average there are a significantly larger number of p-values under 0,05: 30 out of 40. This means that the difference between the vocal reproduction when the sound was played into the right and left ear was mostly significant and that the results were not just due to chance.

Analysis

From these results, it can be observed that the right and left ear hear tones differently. The vocal reproduction of all participants was closer to the frequency of the tone they were attempting to reproduce when the sound was played into their left ear, expect for when the participants were attempting to reproduce G3 (see graph 2). This can be seen from the graphs 1 and 2, where the mean difference between the vocal reproduction of the participants and the frequency of the tone they were attempting to reproduce was presented.

In addition, what can be observed from the graphs is that the female participants had a tendency to sing at a higher frequency than the frequency of the tone they were trying to reproduce; however, as the tone got higher they started singing lower and lower. When they had to reproduce G4, the highest tone, they all sang lower than the actual tone. On the other side, the male participants mostly sang at a lower frequency. However, it differed a bit more than the females and during the last tone, G3, in average they sang at a higher frequency.

There was a small difference between the participants that had the most musical training and scored themselves the highest on the self-evaluation of their singing ability (participant 2,3,7,8). Their vocal reproductions were all closer to the frequency of the tone they were attempting to reproduce than the other participants.

The standard deviation on the graphs 1 and 2 varied quite a lot. The participants had different levels of musical training and so some of their pitches were generally a lot closer to the frequency of the tones than others, hence the big gap between the vocal reproductions.

Discussion and evaluation

The results demonstrate that there is a difference between how well the ear interprets a music tone. They support my hypothesis that when the tone was played into the left ear, the vocal reproduction of the tone would be more accurate than when the tone was played into the right ear of the participants. The vocal reproduction of all participants was closer to the frequency of the tone they were attempting to reproduce when the sound was played into their left ear than when it was played into their right ear. The t-test performed on the results showed significant results for 30/40 tests and strengthened my hypothesis that this difference had something to do with the right hemisphere/left ear being the dominating side in interpreting music.

There was however one exception which was when the male participants were attempting to reproduce the tone G3 (196 Hz), the mean frequencies of the vocal reproduction show that on average, their vocal reproductions were more accurate when the tone was played into their right ear. (see table 4).

The experiment was carried out in a way that errors could have occurred, resulting in a slight change in the data.

The first issue with the investigation is the number of trial and participants. In order for a study to have a true impact on the knowledge us humans have about a subject, the number of participants should be around 100, only eight participants were a part of this investigation. In addition, more trials should be performed on each individual.

Another error could have occurred due to the time between when the participants heard the tone in their left ear and in their right ear. There was no real break after the participants attempted to reproduce the sound they heard being played into their left ear. Therefore, the vocal reproduction after they heard the tone in their right ear could have been more accurate as they had just heard it in their left ear. In order to avoid this error, there should be a break between when the tone is played into the left ear and the right ear. In addition, during that break, it could be a good idea to make the participants listen to something else in order for them to completely forget the tone they just listened to. During the experiment the order was always to first play the tone into their left ear and then right ear. This is another weakness from my experiment. It probably would have increased the accuracy of the results to alternate the first ear the tone was played into. For example, for the females, making them listen to the tone C4 first in their left ear and then in their right ear and for the second trial making them listen to the tone into their right ear first and then into their left ear.

Another issue with the experiment could be the setting of the experiment. I was alone with the participants during the experiment, but it was done on school grounds. I attempted to find a room with as little background noise as I could, but there were still some background noises. This could have prevented the participants from focusing fully on the tone that was being played into their ear. In order to improve this, either headphones could have been used, the type that covers the entire ear or even noise cancelling headphones could have been worn over the small earphones in order to cancel out the background noise.

Using an electronic keyboard to produce the tones the participants were asked to reproduce was not the best option. A study was done by the Department of Communication

Sciences & Disorders of James Madison University to “investigate how vocal fundamental frequency control was influenced by the timbre of target auditory stimuli”[18]. The results show that the participants, that consisted of only females, were more accurate at matching the pitch when it came from a female voice due to the similarity to the participant’s voice. Therefore, I believe that the tone the participants were asked to reproduce should have been from a male and female voice.

[18] Christopher Watts, “Timbral influences on vocal pitch-matching accuracy”, https://www.tandfonline.com/doi/full/10.1080/14015430802028434?scroll=top&needAccess=true, (11 July, 2009)

Conclusion

From the experiment, it can be understood that the left ear interprets music better than the right ear. The experiment consisted in making participants reproduce tones played into their left and right ear separately. The results showed a trend of a more accurate vocal reproduction when the tone was played into the participants' left ear rather than the right ear, which is in line with my hypothesis. There was one exception to the male's results. The mean frequencies of their vocal reproduction of the tone G3 seemed to be closer to the actual frequency of the tone when it was played into their right ear.

There were some errors and problems to the experiment such as background noise that could have disturbed the participants when they were trying to listen to the tone they then had to reproduce or a lack of participants and trials.

These findings are not enough to know for sure that the left ear dominates in interpreting tones; however, it could be a start and together with studies done on the right ear's dominance in deciphering verbal communication it could really be a breakthrough in medicine. Cone-Wesson explained how her and Sininger's study as well as other similar studies about the difference in the left and right ear could help: "If a person is completely deaf, our findings may offer guidelines to surgeons for placing a cochlear implant in the individual's left or right ear and influence how cochlear implants or hearing aids are programmed to process sound," "Sound-processing programs for hearing devices could be individualized for each ear to provide the best conditions for hearing speech or music."[19]

[19] Lori Stiles, "Newborns Have Ear Preferences, Too", https://uanews.arizona.edu/story/newborns-have-ear-preferences-too, (September 2, 2004)

References and bibliography

Byrd, Donald. "Musical Pitches." *Indiana University.* November 2006. http://people.virginia.edu/~pdr4h/pitch-freq.html (accessed August 1, 2019).

Debczak, Michele. *Why Are Girls' Voices Usually Higher Than Boys' Voices?* May 1, 2018. http://mentalfloss.com/article/72393/why-are-girls-voices-usually-higher-boys-voices (accessed August 16, 2019).

German Hearing Center. *How to Interpret an Audiogram.* n.d. https://www.hoerzentrum-hannover.de/en/diagnosis/how-to-interpret-an-audiogram/ (accessed September 15, 2019).

Hearing Link. *How the ear works.* 2018. https://www.hearinglink.org/your-hearing/about-hearing/how-the-ear-works/ (accessed August 12, 2019).

Information Technology in Medicine. *e-audiologia - Hearing test.* n.d. https://www.e-audiologia.pl/HearingTest/?fbclid=IwAR3rihc1pXhbiYhI0AC1kmv2v_lGHRCxYOXRroGvR4DczC-gplD3US7X1KA#home (accessed August 10, 2019).

Institute Australia. "How we hear." *Ear Science.* n.d. https://www.earscience.org.au/sites/www.earscience.org.au/files/field/pdf/how_we_hear.pdf (accessed August 19, 2019).

Lloyd, Robin. "Most People Prefer Right Ear for Listening." *Live Science.* June 24, 2009. https://www.livescience.com/9679-people-prefer-ear-listening.html (accessed August 10, 2019).

National Institute on Deafness and Other Communication Disorders. "How Do We Hear?" *U.S. Department Of Health & Human Services.* January 3, 2018. https://www.nidcd.nih.gov/health/how-do-we-hear (accessed August 20, 2019).

Sincero, Sarah Mae. "The Auditory System." *Explorable.* March 18, 2013. https://explorable.com/auditory-system (accessed July 23, 2019).

Stiles, Lori. "Newborns Have Ear Preferences, Too." *The University Of Arizona.* September 2, 2004. https://uanews.arizona.edu/story/newborns-have-ear-preferences-too (accessed August 15, 2019).

Stonekick. *Pitched tuner.* 2019. http://www.stonekick.com/tuner.html (accessed June 29, 2019).

University of California - Los Angeles. "Left And Right Ears Not Created Equal As Newborns Process Sound, Finds UCLA/UA Research." *ScienceDaily*. September 10, 2004. https://www.sciencedaily.com/releases/2004/09/040910082553.htm (accessed June 14, 2019).

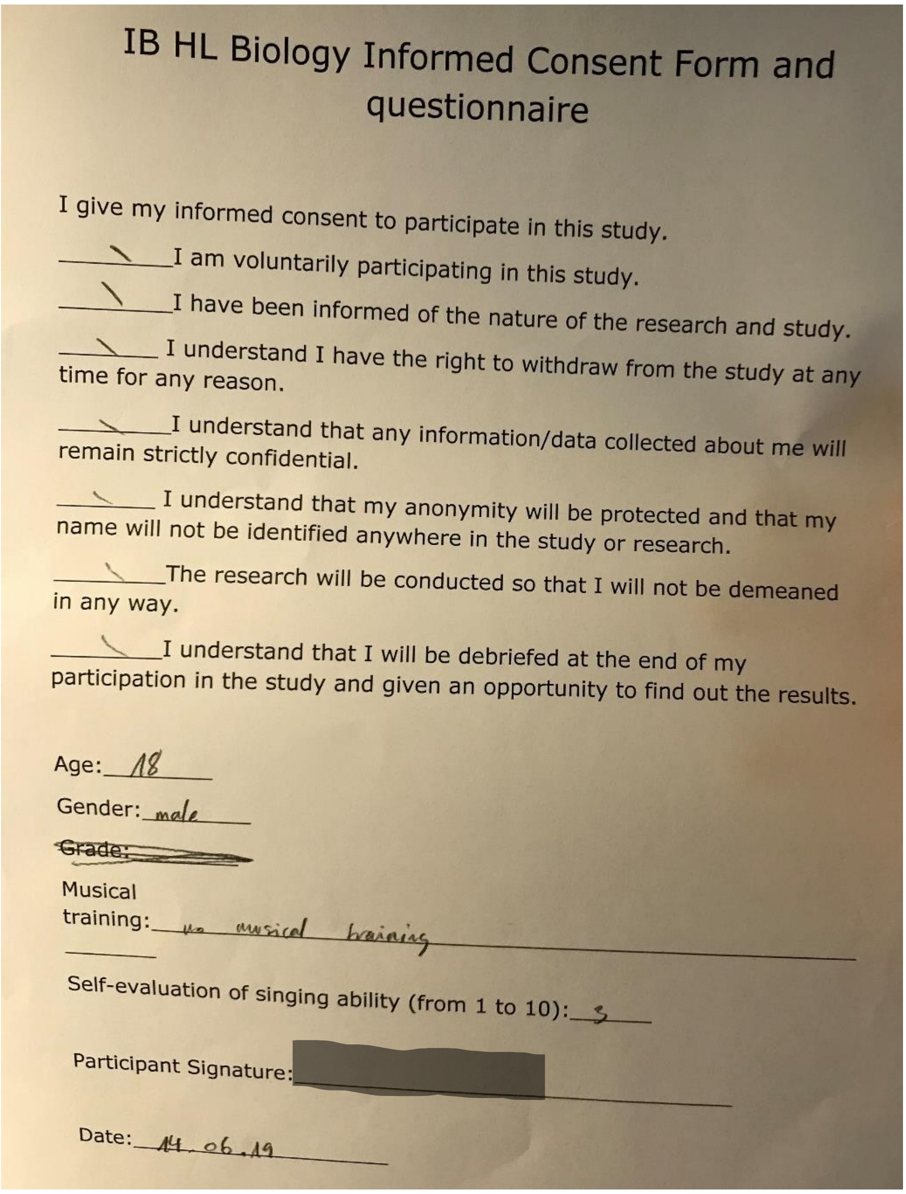
—. "Want to listen better? Lend a right ear." *ScienceDaily*. December 6, 2017. https://www.sciencedaily.com/releases/2017/12/171206090611.htm (accessed October 2, 2019).

Watts, Christopher. "Timbral influences on vocal pitch-matching accuracy." *Taylor & Francis Online*. July 11, 2009. https://www.tandfonline.com/doi/full/10.1080/14015430802028434?scroll=top&needAccess=true (accessed September 28, 2019).

Appendix

Appendix 1 : Questionnaire for the participants

Participant 5



IB HL Biology Informed Consent Form and questionnaire

I give my informed consent to participate in this study.

______ I am voluntarily participating in this study.

______ I have been informed of the nature of the research and study.

______ I understand I have the right to withdraw from the study at any time for any reason.

______ I understand that any information/data collected about me will remain strictly confidential.

______ I understand that my anonymity will be protected and that my name will not be identified anywhere in the study or research.

______ The research will be conducted so that I will not be demeaned in any way.

______ I understand that I will be debriefed at the end of my participation in the study and given an opportunity to find out the results.

Age: 18

Gender: male

~~Grade:~~

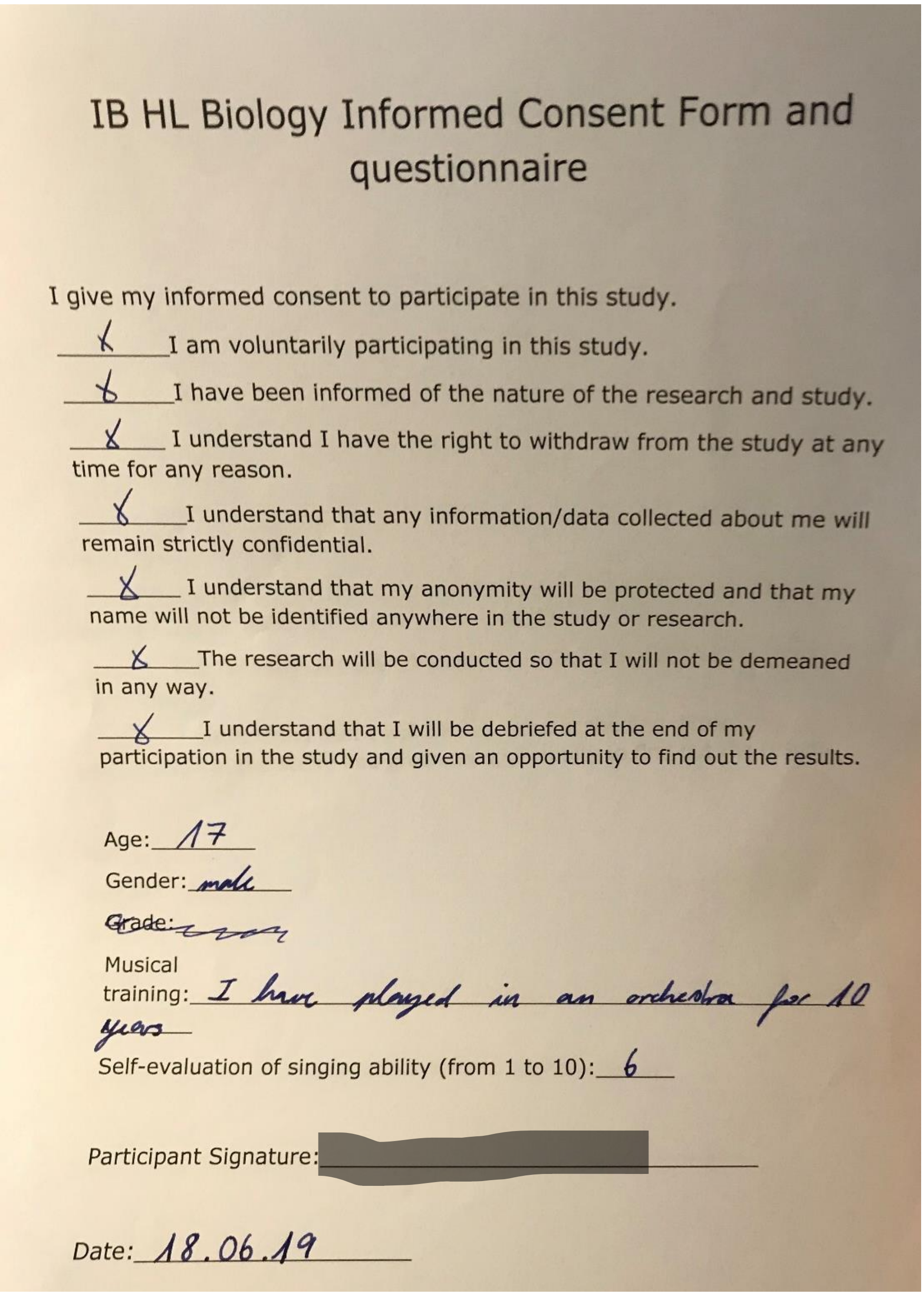
Musical training: no musical training

Self-evaluation of singing ability (from 1 to 10): 3

Participant Signature: [redacted]

Date: 14.06.19

Participant 7



IB HL Biology Informed Consent Form and questionnaire

I give my informed consent to participate in this study.

__X__ I am voluntarily participating in this study.

__X__ I have been informed of the nature of the research and study.

__X__ I understand I have the right to withdraw from the study at any time for any reason.

__X__ I understand that any information/data collected about me will remain strictly confidential.

__X__ I understand that my anonymity will be protected and that my name will not be identified anywhere in the study or research.

__X__ The research will be conducted so that I will not be demeaned in any way.

__X__ I understand that I will be debriefed at the end of my participation in the study and given an opportunity to find out the results.

Age: 17

Gender: male

~~Grade:~~

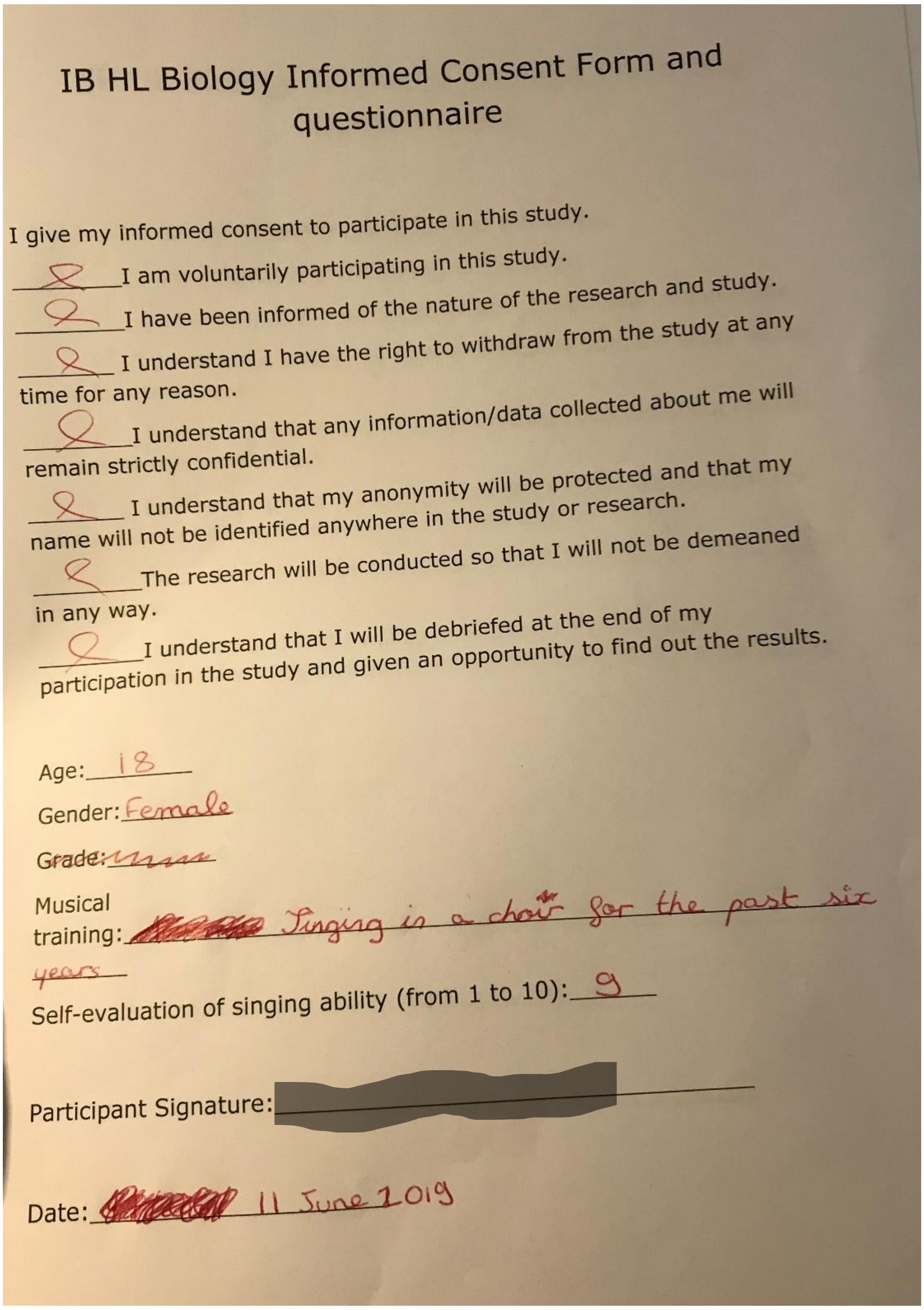
Musical training: I have played in an orchestra for 10 years

Self-evaluation of singing ability (from 1 to 10): 6

Participant Signature: [redacted]

Date: 18.06.19

Participant 2



IB HL Biology Informed Consent Form and questionnaire

I give my informed consent to participate in this study.

_____I am voluntarily participating in this study.

_____I have been informed of the nature of the research and study.

_____I understand I have the right to withdraw from the study at any time for any reason.

_____I understand that any information/data collected about me will remain strictly confidential.

_____I understand that my anonymity will be protected and that my name will not be identified anywhere in the study or research.

_____The research will be conducted so that I will not be demeaned in any way.

_____I understand that I will be debriefed at the end of my participation in the study and given an opportunity to find out the results.

Age: 18

Gender: Female

Grade:

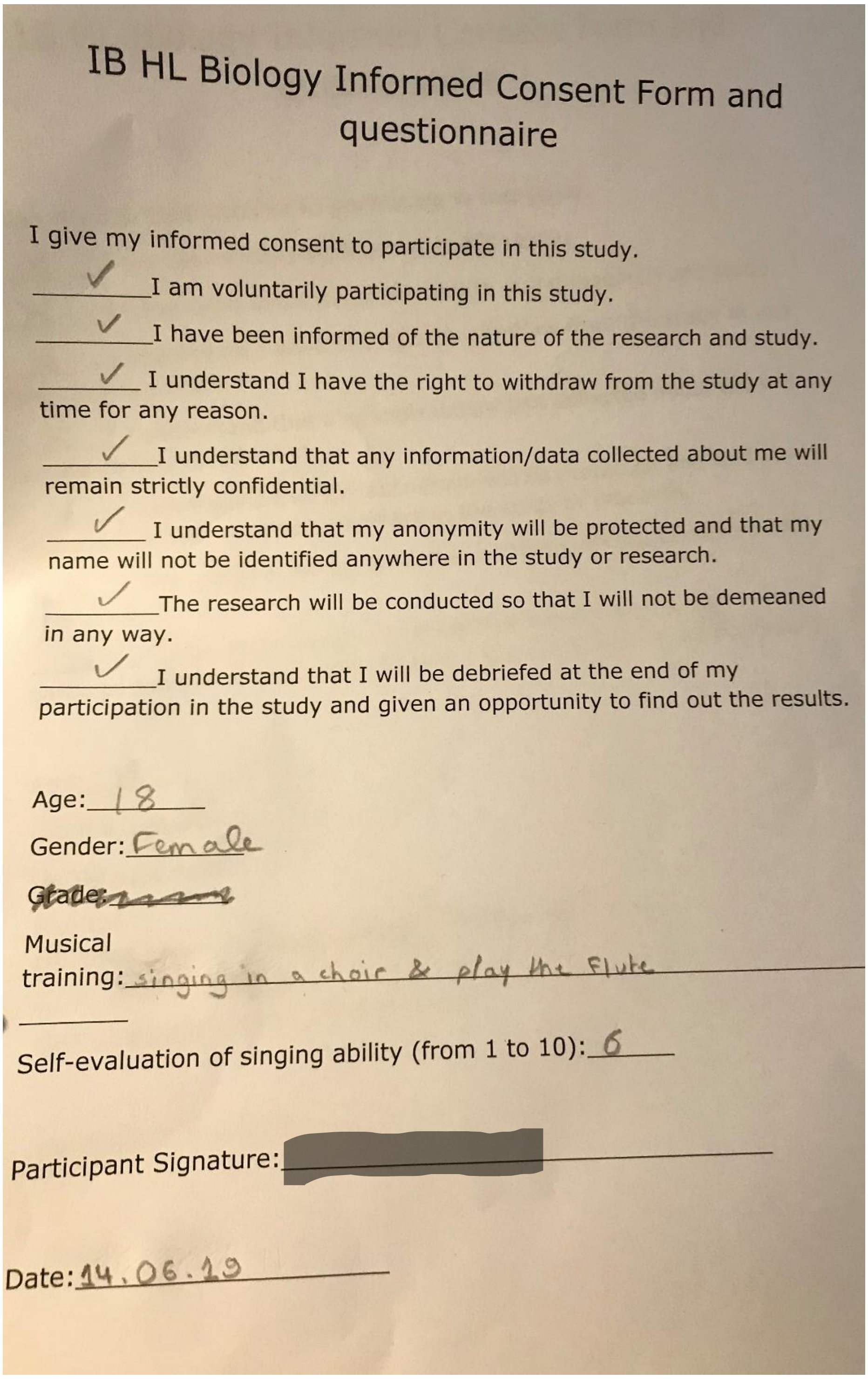
Musical training: ~~[illegible]~~ Singing in a choir for the past six years

Self-evaluation of singing ability (from 1 to 10): 9

Participant Signature: [redacted]

Date: ~~[illegible]~~ 11 June 2019

Participant 3



IB HL Biology Informed Consent Form and questionnaire

I give my informed consent to participate in this study.

✓ I am voluntarily participating in this study.

✓ I have been informed of the nature of the research and study.

✓ I understand I have the right to withdraw from the study at any time for any reason.

✓ I understand that any information/data collected about me will remain strictly confidential.

✓ I understand that my anonymity will be protected and that my name will not be identified anywhere in the study or research.

✓ The research will be conducted so that I will not be demeaned in any way.

✓ I understand that I will be debriefed at the end of my participation in the study and given an opportunity to find out the results.

Age: 18

Gender: Female

~~Grade:~~

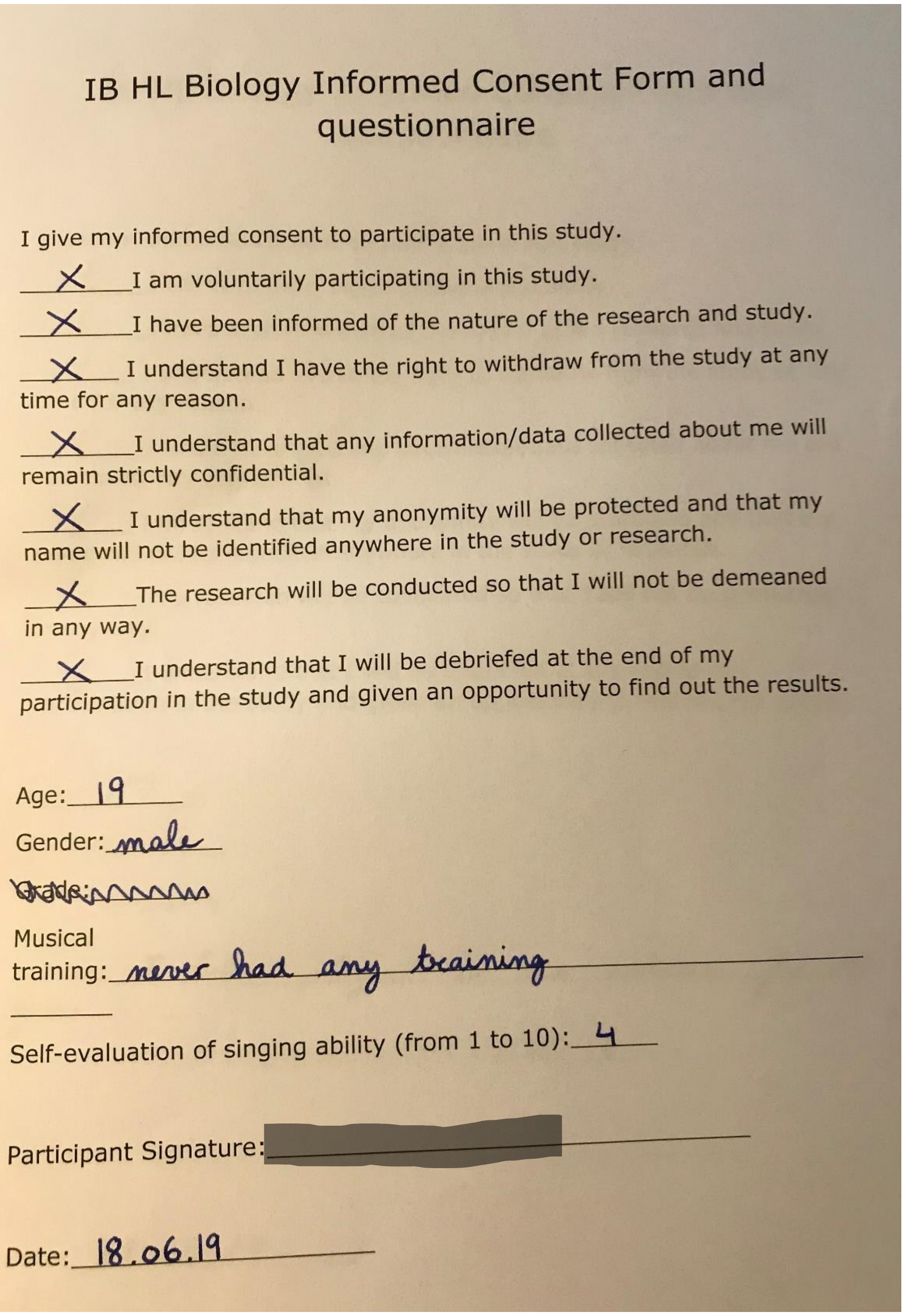
Musical training: singing in a choir & play the Flute

Self-evaluation of singing ability (from 1 to 10): 6

Participant Signature: [redacted]

Date: 14.06.19

Participant 6



IB HL Biology Informed Consent Form and questionnaire

I give my informed consent to participate in this study.

__X__ I am voluntarily participating in this study.

__X__ I have been informed of the nature of the research and study.

__X__ I understand I have the right to withdraw from the study at any time for any reason.

__X__ I understand that any information/data collected about me will remain strictly confidential.

__X__ I understand that my anonymity will be protected and that my name will not be identified anywhere in the study or research.

__X__ The research will be conducted so that I will not be demeaned in any way.

__X__ I understand that I will be debriefed at the end of my participation in the study and given an opportunity to find out the results.

Age: 19

Gender: male

~~Grade:~~

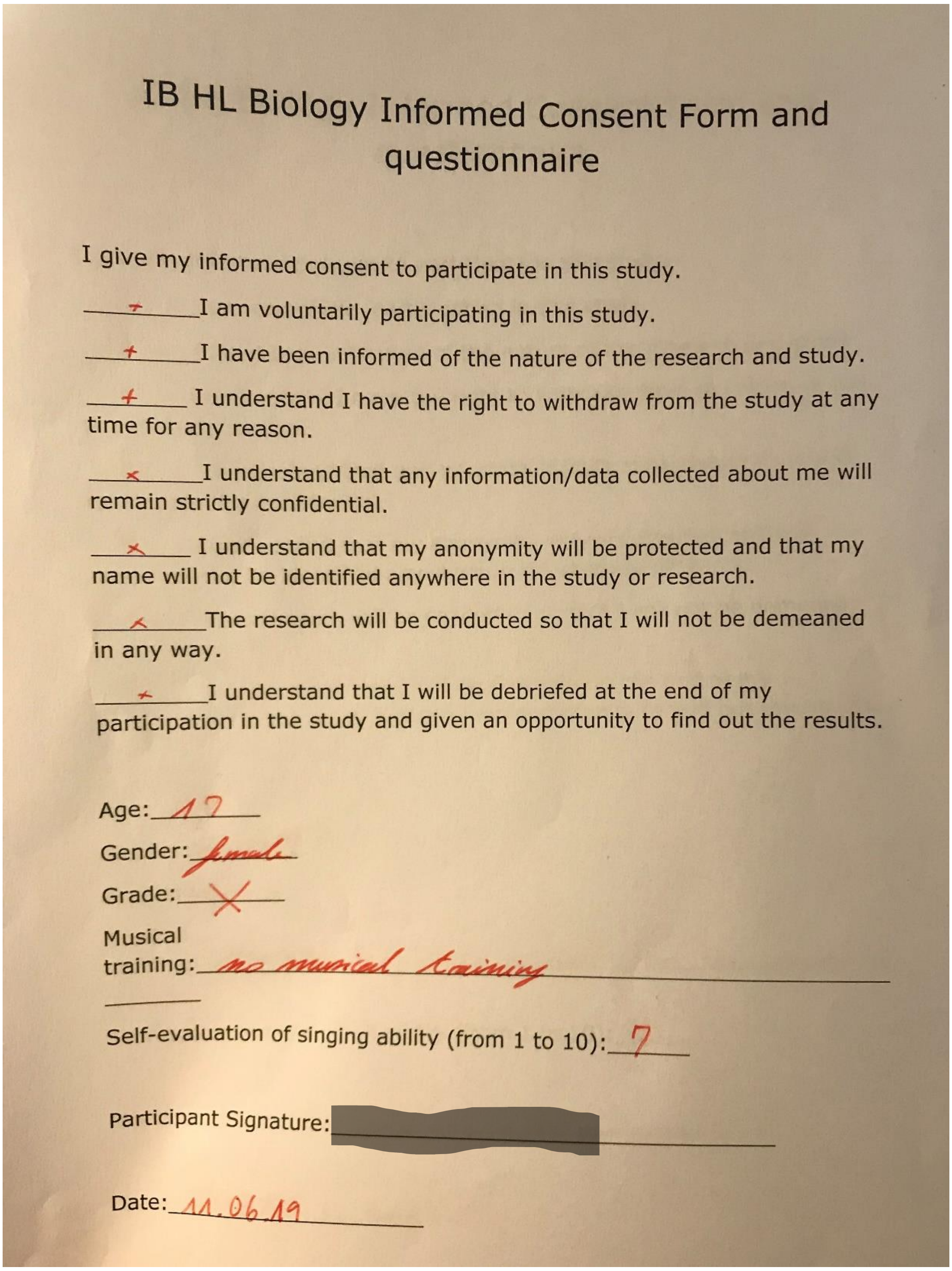
Musical training: never had any training

Self-evaluation of singing ability (from 1 to 10): 4

Participant Signature: [redacted]

Date: 18.06.19

Participant 1



IB HL Biology Informed Consent Form and questionnaire

I give my informed consent to participate in this study.

__+__ I am voluntarily participating in this study.

__+__ I have been informed of the nature of the research and study.

__+__ I understand I have the right to withdraw from the study at any time for any reason.

__x__ I understand that any information/data collected about me will remain strictly confidential.

__x__ I understand that my anonymity will be protected and that my name will not be identified anywhere in the study or research.

__x__ The research will be conducted so that I will not be demeaned in any way.

__+__ I understand that I will be debriefed at the end of my participation in the study and given an opportunity to find out the results.

Age: 17

Gender: female

Grade: X

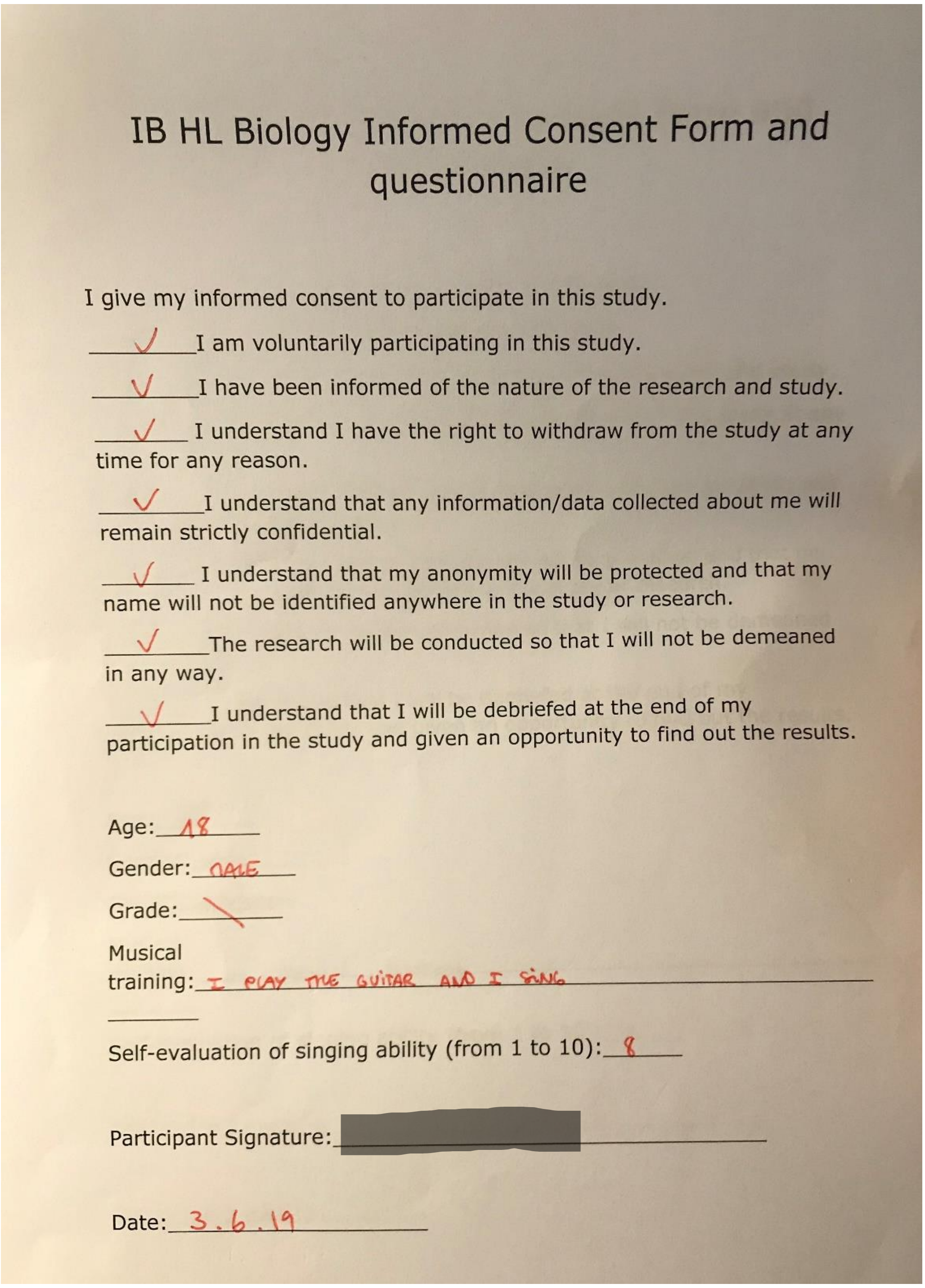
Musical training: no musical training

Self-evaluation of singing ability (from 1 to 10): 7

Participant Signature: [redacted]

Date: 11.06.19

Participant 8



IB HL Biology Informed Consent Form and questionnaire

I give my informed consent to participate in this study.

__✓__I am voluntarily participating in this study.

__✓__I have been informed of the nature of the research and study.

__✓__ I understand I have the right to withdraw from the study at any time for any reason.

__✓__I understand that any information/data collected about me will remain strictly confidential.

__✓__ I understand that my anonymity will be protected and that my name will not be identified anywhere in the study or research.

__✓__The research will be conducted so that I will not be demeaned in any way.

__✓__I understand that I will be debriefed at the end of my participation in the study and given an opportunity to find out the results.

Age: 18

Gender: MALE

Grade: ______

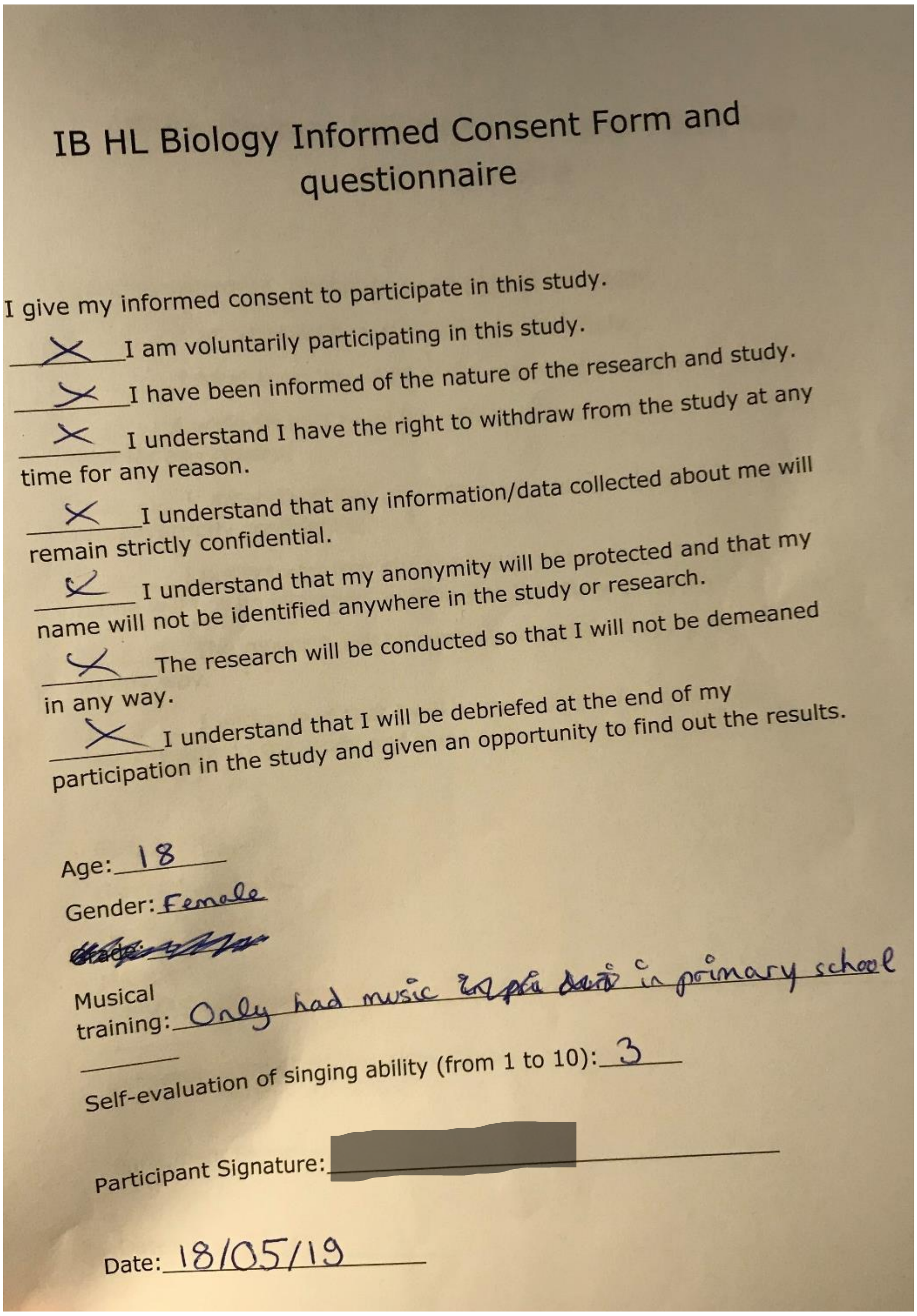
Musical training: I PLAY THE GUITAR AND I SING

Self-evaluation of singing ability (from 1 to 10): 8

Participant Signature: [redacted]

Date: 3.6.19

Participant 4



IB HL Biology Informed Consent Form and questionnaire

I give my informed consent to participate in this study.

__X__ I am voluntarily participating in this study.

__X__ I have been informed of the nature of the research and study.

__X__ I understand I have the right to withdraw from the study at any time for any reason.

__X__ I understand that any information/data collected about me will remain strictly confidential.

__✓__ I understand that my anonymity will be protected and that my name will not be identified anywhere in the study or research.

__X__ The research will be conducted so that I will not be demeaned in any way.

__X__ I understand that I will be debriefed at the end of my participation in the study and given an opportunity to find out the results.

Age: 18

Gender: Female

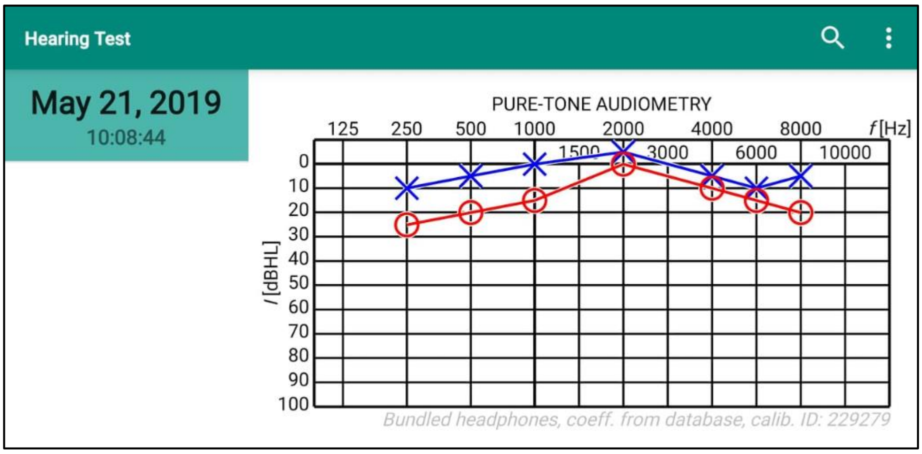
Musical training: Only had music [illegible] in primary school

Self-evaluation of singing ability (from 1 to 10): 3

Participant Signature: [redacted]

Date: 18/05/19

Appendix 2: Example of results from the hearing test



Appendix 3: Chromatic tuner on the phone used to measure the frequency of the vocal reproductions of the participants