Acoustic Research on Brain Healthy Speech Vibration

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ABSTRACT

The American doctors Karel F. and Heda Jindrak have published apostulate in 1988 concerning brain health: A certain amount of vibrations from vocalization is necessary in order to keep the brain functioning normally. Acoustic Lab of School of Architecture in Tsinghua University has built a box-in-box silence room with 0dB background noise in 2012 and has precisely measured the skull vibration from vocalization in that room. By way of theoretical analysis and experiment we explore the measurement of skull vibration from vocalization. And using that method, we can measure the vibration levels of different words in Chinese. The conclusion of that is that when we speaking normally, the skull vibration from vocalization is random, but if we read a spell made up with the high vibration words, the skull vibration energy can be as high as 10 times of speaking normally and randomly. By comparing the cerebrospinal fluid flow rate from MRI before and after reading the spell for 15 min, we can tell that the vibroacoustic can speed up the cerebrospinal fliud circulation.

1.INTRODUCTION

In 1988,Karel F. and HedaJindrak(JindrakK.F. 1988;Jindrak H. 1988)hypothesizedthat vibrations of human skull caused by vocalization have a massaging effect on brain. On one hand, the more efficient the diffusion of liquid in the brain caused by skull vibration ends up with the higher pace of metabolismin the brain. And the cerebrospinalfluidwillflow faster as they travel from the subarachnoid space to thesuperior sagittal sinus back into the blood circulation system. In this way, the vibration makes a contribution to the cleaning process of brain.On the other hand, the vibration of brain vessels can raise the efficiency of the nutrition of the vessel wall cells and in some way reduce the risk of arteriosclerosis(Olav Skille).

Cerebral arteries can be found in cerebral cortex and brain parenchyma. (Qu Chengyi 2010; Sun Xibin 2010; Zhang Fang et al 2010) Oxygen, glucose, amino acid and some other types of nutrition can travel as close as possible to each individual cell of the body through the blood vessels, but after leaving the blood vessels, they have to move the last hundredths of millimeters to their final destination by way of diffusion.Inorganic ions in the cerebrospinal fluid get into the brain tissue also by way of diffusion.Vibrations from the vocal can cause the vibration of skull. The dura mater and the CSF in the subarachnoid space is incompressible and therefore transmitting the vibrations to the brain.Vibrations facilitate the flow of interstitial fluid in brain, and then facilitate the diffusion in brain.The function of cerebrospinal fluid is not only to float the brain, but also to wash the brain surface andtake some waste products out of the brain. The CSF is generated from the choroid plexus in ventricles:the CSF from the lateral ventricles goes into the third ventricle through the interventricular foramen, and then into the fouth ventricle combined with the CSF generated from the third ventricle through the aqueduct of sylvius, and finally into the subarachnoid space with the CSF generated from the fouth ventricle through the Median aperture and the Lateral apertures.The CSF can mainly leave the subarachnoid space through the arachnoidgranulations. In order to

allow the CSF to enter the blood, the CSF pressure must be higher than the blood pressure in the dural sinuses. The cells in the caps of the arachnoid granulations only allow the CSF flows in one directionfrom thesubarachnoid space into the sinuses.

Atherosclerosis is a common heart and cerebral vessels disease. In arteriosclerosisthere are point-like cushion-like protrusions on the inside of the arterial walls, named plaques. Blood tends to clot over them within the artery and the blood clots may completely obstruct the already narrowed blood vessel. The plaques occur in the places where the pulse is not strong enough to distend the artery. Bad nutrition of the arterial wall cells can end up with the calcareous plaques, and diffusion between the nutrient in the blood and the arterial wall cells is extremely important.The arterial pulse wave makes the cells of the arterial wall squeeze against each other, thus the interstitial fluid are madeto flow to ensure the exchange of nutrients and waste products.For aged people, the elasticity of their vessels is no longer as good as before, and their pulse becomes less strong, so for some certain spot, the arterial wall cannot get enough stretch, leading to worse metabolism, then the calcificationof arterial wall cells happens and later the plaques show their faces.The stretch and contraction of the brain arteries can be assisted by the wave from vibrations caused by vocalization, thus the metabolic exchange of the arterial wall cells can be facilitated. If the arteriosclerotic plaques have already existed, and there are some deposits on it, when we speak, the vibrations are actually “beating” the brain arteries to clean it.

If we do not vocalize enough when we are children or youths, we may be stuck with an inefficient biologicalcomputer for the rest of our lives.Researches showthat, comparing to healthy children in 3~4 years old,learning abilities of deaf-mute childrendrop behind for at least average 2 months. (Qu Chengyi2010; Sun Xibin2010; Zhang Fang et al 2010)The older in age, the difference enlarges. For 7 years old, the difference is 18 months (Gao,Liqun1994; Wu Yanhong1994) and 9, the difference becomes about 2~3years (Zhang Fen2011; Yu Jinming2011;Rong Jing et al 2011),. On the other hand,Hayes, Smits and Mommers had done research comparing the intelligence level between blind children and bright eyes ones in 1950, 1970 and 1972. Their conclusion is that there is almost no difference of intelligence level between the two groups of children, and for some specific questions, the blind children got even higher grade.

Dr. Jindrak did not quantify or measure the vibrations of human skull caused by vocalization after he published his postulate. And there are very few other studies or researches concerned. If we could find a workable way to measure the vibrations and quantify them, then saying a certain words which are picked out by testingwould arousemore vibrations, and this kind of beneficial vibration can be made the best use. Fortunately, the Acoustic Lab in Tsinghua University has worked on this by experiment and measurement.

2.METHODS

2.1 THEORETICAL DERIVATION

The best way to measure vibration level and to get the most accurate data is to fix avibration pickup directly in the vibrating object.But it is impossible to embed avibration accelerometerdirectlyinto a live person’s skull.We designed an accelerometerbolt fixing on the middle of band of a headset, and when people put on the headset on head, the boltprotrudedown to connect his scalp. Since the accelerometerdoesn’tembed inthe skull, the result we get deviates from the exact vibrations by a transfercoefficientsmaller than 1. Whether the vibration measurementdata with this transfer coefficient can be used? In different measurements, could the data be compare each other availably? Simplifya head to a spring—mass system.

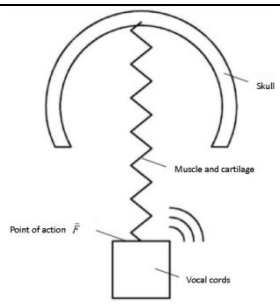


Figure 1：Thesimplified modelof speech vibrating skull

Then：the vibration equation with external force is ：

$\vec{u} = \frac{\vec{F}}{z_m}$ (1)

$\vec{u}$—— velocity vectorof the skull interface

$\vec{F}$——force vector

z_m——impedance of the system

For one speaking person, the skull vibration power at a certain frequency is as follows：

$W_v = \vec{F} \cdot \vec{u} = \vec{F} \cdot \frac{\vec{F}}{z_m} = a_v^2 \cdot \frac{m^2}{z_m}$which means: $a_v^2 = W_v \cdot \frac{z_m}{m^2}$ (2)

a_v——2)h means: ing person, the skull vi

m—2)h means: ing

The total power of this person from vocalization：

$W_{all} = W_s + W_v + W_{other}$ (3)

where, W_s is the air borne sound power emitting from mouth, and W_v is the power of skull vibrating. W_{other} indicates to some other energy consumed by the head muscles or others.

assume：the transfer coefficient of air-borne sound is α,

the transfer coefficient of skull vibration is β,

the transfer coefficient of other sorts of energy is γ.

$W_s = \alpha W_{all}$ (4)

$W_v = \beta W_{all}$ (5)

$W_{other} = \gamma W_{all}$ (6)

$\alpha + \beta + \gamma = 1$(7)

α, β, γ (differsin different person)

then：

$L_{Ws} = 10\lg\frac{W_s}{W_0} = 10\lg\frac{\alpha W_{all}}{W_0} = 10\lg\alpha + 10\lg\frac{W_{all}}{W_0} = C_\alpha + L_{Wall}$ (8)

$L_{Wv} = 10\lg\frac{W_v}{W_0} = 10\lg\frac{\beta W_{all}}{W_0} = 10\lg\beta + 10\lg\frac{W_{all}}{W_0} = C_\beta + L_{Wall}$ (9)

W_0——(9)β+10lgt person)ie

C_α, C_β——(9)β+10lgt person)ient of ot

Measurement provides：Air-borne sound pressure level Lp from a microphone and vibration acceleration level L`a from an accelerometer

air-borne sound pressure level Lp ： in reverberation field ：

$L_p = L_{Ws} + 10\lg(\frac{Q}{4\pi r^2} + \frac{4}{R})$ (10)

Q10)irectivity factor

R10)irm constant

r10)irm constantactordre level Lp from a micr

Q,R and r are all constants at a certain frequency in a certain room

then :

$L_p = L_{Ws} + C_s = C_s + C_\alpha + L_{Wall}$ (11)

C_s——1)and r (differs in test room and the test frequency)

vibration acceleration level L`a from an accelerometer：

$$L'_a = 20\lg\frac{a'_v}{a_0} = 10\lg\frac{{a'_v}^2}{{a_0}^2} = 10\lg\frac{W'_v z_m}{m^2 a_0^2} = 10\lg\frac{W'_v}{W_0}\cdot\frac{W_0 z_m}{m^2 a_0^2} = 10\lg\frac{\delta W_v}{W_0}\cdot\frac{W_0 z_m}{m^2 a_0^2}$$

$$= 10\lg\frac{W_v}{W_0} + 10\lg\frac{\delta W_0 z_m}{m^2 a_0^2} = C_v + L_{Wv} = C_v + C_\beta + L_{Wall} \quad (12)$$

a'_v——12)tion acceleration le

W'_v——12)tion accelera

a_0——12)tion acceleration le

δ——transfercoefficient from the skull to the vibration accelerometer(differs ofthe vibration pickup location onthe skull and the contact condition)

C_v——e skull (differs of the vibration pickup location on the skull and the test frequency)

$\therefore L'_a - L_p = (C_v + C_\beta + L_{Wall}) - (C_s + C_\alpha + L_{Wall}) = C_v + C_\beta - C_s - C_\alpha$ (13)

Theoreticalconclusions:

(1) The determinantfactors response for the difference between the sound pressure level Lp got from a microphone and the vibration acceleration level L`a got from a accelerometer are: person, test room, condition of vibration pickup on the skull, and test frequency.

(2) If a given person in a given room keeps the vibration accelerometeron the same skull conditions, the difference between the sound pressure level Lp got from a microphone and the vibration acceleration level L`a got from a accelerometer is a constant at a certain frequency.

(3) If a given person in a given room keeps the vibration accelerometeron the same skull conditions, the sound pressure level Lp getingfrom a microphone and the vibration acceleration level L`a getingfrom a accelerometer are linearcorrelation at a certain frequency.

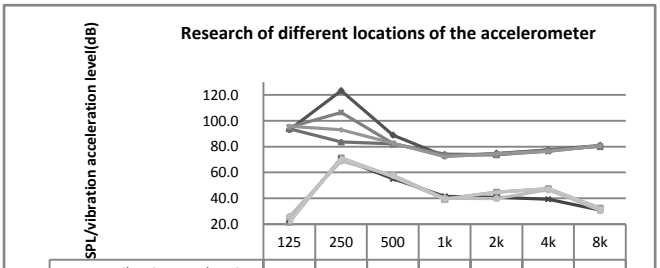
(4)If a given person in a given room keeps the vibration accelerometeron the same skull conditions, the energy distribution of air-borne sound and skull vibration is constant at a certain frequency.

2.2 ACOUSTIC MEASUREMENT

The skull vibration from vocalization is very weak and easily be affected by the ambient vibration. So the acoustic measurement must be done in a box-in-box room with the backgroud noise lower than 0dB(A) to make sure the airborne sound and the vibration we measured are all from the subject.

To explore whether this relative location will affect the transfer coefficient, a preliminary experiment has been done. Subjects put the accelerometer at four differentplaces on the skull and then pronounce the same vowel in Chinese. The air-borne sound pressure level and the vibration acceleration level are both measuresynchronously. In this experiment, the first group of data was measured when the accelerometer was placedjust at the bregma and compressed tightly against the skull, and we called this condition the normal gesture. The second group of data was measured when the accelerometer was placedalsojust at the bregma but not compressed tightly against the skull, and we called this condition theloose gesture. The third group of data was measured when the accelerometer was place several centimetersin front of the bregma (on the frontal bone) and compressed tightly against the skull, and we called this condition the front gesture. And the fourthgroup of data was

measured when the accelerometer was placed at the place severalcentimeters back of the bregma (on the sagittal suture) and compressed tightly against the skull, and we called this condition the back gesture. The result is shown in Figure 2. The air-borne sound pressure levels from four groups are almost the same, while the vibration acceleration levels are distinctively different. For example, thelargest difference of the vibration acceleration levels happenedat 250Hz frequency for nearly 40 dB.In the four groups of data, the normal gesture group has the largest acceleration level, in other words, they are closest to the exact values. So in our experiment, we request the subjects to place the vibration accelerometer right at the bregma and compress it tightly against the skull without any movement of it during the experiment.



	125	250	500	1k	2k	4k	8k
vibration acceleration level La1	93.0	123.2	88.8	72.6	74.7	77.3	80.9
SPL Lp1	21.5	71.1	56.5	39.5	44.7	47.5	32.3
vibration acceleration level La2	93.9	83.7	82.1	74.3	73.8	77.5	80.1
SPL Lp2	23.3	70.4	55.2	41.4	40.6	39.3	30.7
vibration acceleration level La3	95.1	106.5	82.4	73.2	73.6	76.3	80.6
SPL Lp3	25.8	68.8	57.9	39.9	39.8	46.6	30.5
vibration acceleration level La4	95.7	93.0	82.6	72.2	74.4	76.4	80.7
SPL Lp4	21.5	71.1	56.5	39.5	44.7	47.5	32.3

Figure 2： Data for different locations of the accelerometer

Figure 3 shows the sequent data of one subject reading the poem <Nan Ke Zi>.It is clearly to see the wave of each tone in its air-borne sound pressure level curve. So we can mark off the duration of the each tone, and use it to cut out the vibration acceleration level curve in the same time segment. The next step is to calculate the vibration exposure level of each tone.

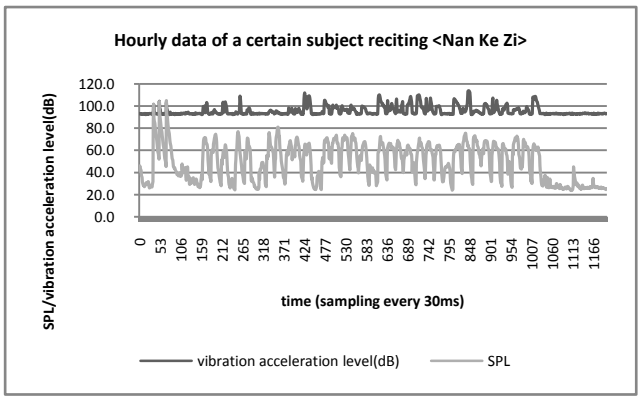


Figure 3： Sequent data of one subject reciting <Nan KeZi>

The subjects read 7 poems in Chinese, then we cut out each word , and calculate the vibration explosure level to make a comparison of the words. The mood of speaking and reciting are different, and then the air-borne sound pressure level of speaking and reciting are different too. Subjects read the 7 poems in speaking mood and then reciting

mood. The RAT 840 records and measures the air-borne sound pressure level and the vibration acceleration level of the whole process.

To make sure that the skull vibration is mainly from vocalization rather than physical movement, we measure the process of walking. It is easily to see the wave of each step from the air-borne sound A-weighted sound pressure level curve. While the vibration acceleration level curve is nearly a straight line in Figure 4. Therefore there is no skull vibration from walking, and vocalization is one of the major reasons causing skull vibration.

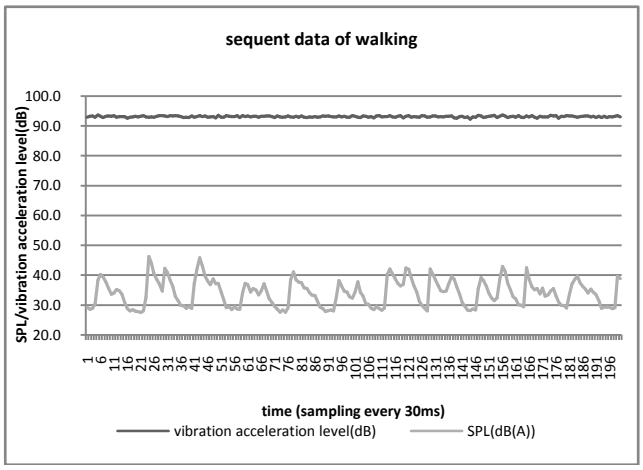


Figure 4: Sequent data of walking

2.3MEDICAL EXAMINATION

There are 18 subjects in the acoustic measurement, and we randomly pick up 6 of them to participate the medical ecamination. These 6 subjects all have their own spell.

The CSF flow rate can be measured by having a MRI scan, so all the subjects have a MRI exam in the Biomedical Imaging Research Center in Tsinghua University Medical School. The whole process can be done in about 30 minutes with 4 steps. Step 1 is to have a 10 to 15 min rest after arriving at the Center. Step 2 is to have the MRI exam for the first time to measure the flow rate of CSF which will last about 6 min. Step 3 is to recite the spell for 15 min. Step 4 is to have the MRI exam for the second time. From step 2 to step 4, the subject will not move but remain lying on his back. We can tell whether the CSF flow rate can speed up or not by comparing the results of the two MRI scan.

3.RESULTS

3.1 RESULTS OF ACOUSTIC MEASUREMENT

After the acoustic measurement, all the 18 subjects have their results. The words with highestvibration exposure level from each subject are different, but in general with the vowel “i” and “ü”. In the meantime, the words with lowest vibration exposure level from each subject are different, but in general with the vowel “a”. If we calculate the mean of the top ten words with highestvibration exposure level, and compare it with the mean of all the words, the latter is about 6~8dB lower than the former. If we compare these two values in energy, the former is about 4~6 times of the latter. In other words, the vibration energy of reciting a poem made up of the top ten words for 10min is equal to the vibration energy of reciting some random poems for 50min.

The L_{eqA} of speaking and reciting the poems are shownthatreciting is about 4~6dB louder than speaking. According to the theoretical derivation, the skull vibration level of reciting is about 4~6dB highestthan speaking too. In our experiment, we ask the

subjects to read the poems in different two moods rather than in different volume, so the phenomenon that reciting is louder than speaking is spontaneous and universal. Combining the conclusion of both Experiment No.4 and Experiment No.5, if we calculate the mean of the top ten words with highestvibration exposure level in reciting configuration, and compare it with the mean of all the words in speaking configuration, the latter is at least 10dB lower than the former. If we compare these two values in energy, the former is about 10 times of the latter. In other words, the vibration energy of reciting a poem made up of the top ten words for 10min is equal to the vibration energy of speaking randomly for 100min.

3.2 RESULTS OF MEDICAL EXAMINATION

The quantity for the CSF flow rate is the the superficial velocity. The data from the MRI exam are the heart rate, the RR interval, the stroke volume, the forward flow volume, the backward flow volume, the regurgitant fraction, the absolute stroke volume, the mean flux, the stroke distance and the mean velocity.It is widely believed that there is a CSF circulation. The CSF from the lateral ventricles goes into the third ventricle through the interventricular foramen, and then into the fouth ventricle combined with the CSF generated from the third ventricle through the aqueduct of sylvius, and finally into the subarachnoid space with the CSF generated from the fouth ventricle through the Median aperture and the Lateral apertures. There are two way of the CSF going out of the brain back into the blood. One is by the arachnoid granulations leading the CSF into the sagittal sinus, and the other is by the olfactory nerve leading the CSF into the nasal mucosa through the ethmoid bone(Johnston M. 2003).The skull vibration can cause the „milking effect“ of the arachnoid granulations, and in the meantime, the vibration of the ethmoid bone reinforce the smooth of CSF-Olfactory nerve pathway. Thus the CSF flow rate can be speed up.

There is a dynamic equilibrium in the CSF circulation system:

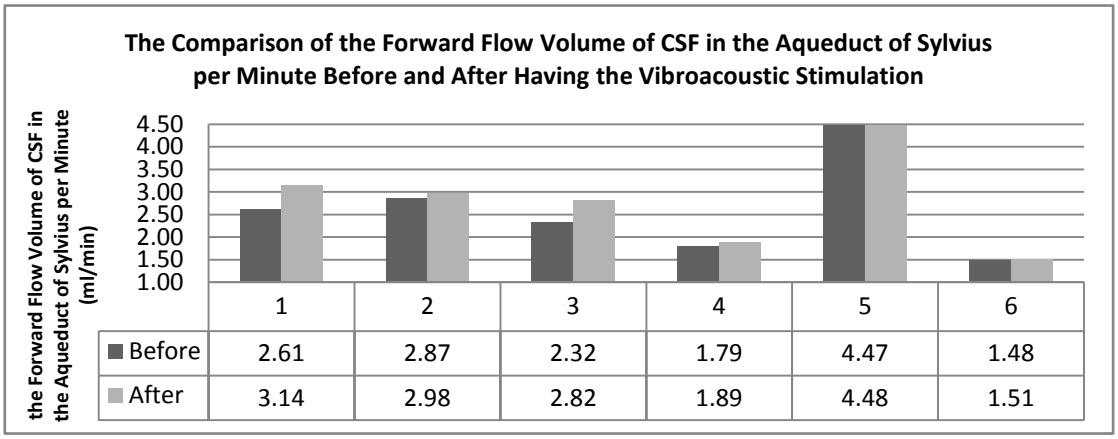
$L_1+L_2+L_3+L_4=L_{AG+ON}$(13)

L_1——the secretion quantity of CSF in the left lateral ventricle;
L_2——the secretion quantity of CSF in the right lateral ventricle;
L_3——the secretion quantity of CSF in the third lateral ventricle;
L_4——the secretion quantity of CSF in the forth lateral ventricle;
L_{AG+ON}——the quantity of CSF back into the blood from both the arachnoid granulations and the olfactory nerve pathway.

There are systole and diastole in a cardiac cycle. At the systole, the CSF travels from the 3rd ventricle to the 4th ventricle, and at the diastole, the CSF travels from the 4th ventricle to the 3rd ventricle. Ifthe choroid plexus do not generate new CSF, the forward flow volume and the backward flow volume should be equal, which means that the volume of CSF in ventricles is macroeconomic equilibrium. But in fact, the choroid plexus does generate new CSF, and the CSF comes from the lateral ventricles and the 3rd ventricle will eventually flow into the 4th ventricle through the aqueduct of sylvius. Seeing the volume of CSF in the aqueduct of sylvius increasing we can tell that the secretion quantity of CSF in the lateral ventricles and the 3rd ventricle increase, and then it means that the quantity of CSF backs into the blood from both the arachnoid granulations and the olfactory nerve pathway increases too. So we can say that the CSF volume in the aqueduct of sylvius is positive related to the flow rate of CSF circulation and the latter can be characterized by the former. The forward flow volume of CSF in the aqueduct of sylvius in a unit interval can be calculated as follow:

$$L_{fpm} = \frac{L_f}{T_{RR}} \times 1000 \times 60 \quad \text{ml/min} \quad (14)$$

L_{fpm}——the forward flow volume of CSF in the aqueduct of sylvius per minute, ml/min;
L_f——the forward flow volume of CSF in the aqueduct of sylvius, ml;
T_{rr}——the RR interval, ms.
The results of calculation are shown in Figure 5.All of the 6 subjects speed up the flow rate of CSF circulation after having the vibroacoustic stimulation for 15 minutes.



	1	2	3	4	5	6
Before	2.61	2.87	2.32	1.79	4.47	1.48
After	3.14	2.98	2.82	1.89	4.48	1.51

Figure 5: The Comparison of the Forward Flow Volume of CSF in the Aqueduct of Sylvius per Minute Before and After Having the Vibroacoustic Stimulation

4.CONCLUSION

The skull vibration from vocalization can be measured in an extremely quiet room. To evaluate that kind of vibration, we use the vibration explosure level. The vibration energy of reciting a poem made up of the words with highest vibration explosure level is about 10 times of speaking randomly. After reading the vibroacoustic spell for 15 minutes, the flow rate of CSF can increase. And according to the Jindrak theory, it fasten the cleaning of the brain.

Our long-time plan is to compare the skull vibration from different language such as English, French and Korean. And we also hope to work with some other institutions to explore the relationship between the skull vibration from vocalization and the heart/cerebral vessels disease or the intelligence of deaf children.

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