

## **A vibroacoustic couch to improve perception of music by deaf people and for general therapeutic use.**

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### **Introduction**

Vibrotactile and vibroacoustic chairs/couches have been used in two areas: for therapeutic use and for helping hearing impaired to perceive music. Pioneers in the therapeutic use have been Olave Skille [1] and Tony Wigram [2]. Our own work was for many years solely in the perception of music area [3], but in the last three years we have moved very much into the therapeutic area.

Systems have been produced commercially; in the UK these include those made by The Sound Beam Project and overseas by the Somatron Corporation in the USA, and a number of systems from Scandinavia.

These have fallen into two classes: (a) those where music is played through headphones and the vibration in the chair or couch is unrelated to the music (e.g. those designed or employed by Skille and Wigram); and (b) where the vibration is driven by the music itself.

Type (b) is of course the only type of interest for the perception of music by hearing impaired people. We believe it is to be preferred for therapeutic use, other than for specific physical treatments designed for example to improve joint angles in people with cerebral palsy. (The latter topic is not covered in this paper.)

Why is it then not more used? We believe this is because of the several technological problems which have to be solved to make this possible in a truly satisfactory way. The solution to these will be described. Incidentally, when this is achieved, there is then no conflict between the requirements of designing a chair/couch for therapeutic use and for music perception; only the way of using it, including the choice of music, is different.

## Features to be considered in obtaining a satisfactory system

### 1. A suitable type of sensation

First, and most important, we seek a means of generating vibrations in the body which gives a sensation which is as analogous as possible to the sensation of hearing music. Thus while it is well known that the finger tips are the part of the body most sensitive to vibration, the sensation of vibration in the finger tips is, we believe, not very analogous to hearing. Our research has shown that the preferred part of the body to which to apply vibration is the back, above the lungs. However it is not a matter of creating a superficial vibration there on the skin; it has to be a deep body sensation if it is to be judged analogous to hearing. Hence we are considering large transducers and powers of 15 watts and above, rather than the small, low powered transducers which are employed to assist in the conveying of speech in a number of commercially available aids for deaf people. For a review of the latter see [4].

Having established that, it is not just a matter of putting a loudspeaker driver (or other transducer) in a box or buried in the upholstery of a chair. Doing that will certainly provide a sensation of the rhythm and a feeling of the bass notes, and indeed that is largely what is felt by using some of the existing commercial systems. But our goal is to go well beyond that and to do so we have to consider all the factors below.

### 2. To produce the desired sensation over the widest possible range of pitches.

Low notes are no problem. In any case it is undesirable to go below about 30 Hz: to do so is to invite feelings of discomfort even nausea. It is extremely dangerous to use frequencies below about 12 Hz because the body's internal organs can be driven into resonance. Fortunately, most if not all, commercial systems are fail safe in that respect because neither the amplifiers nor the transducer have a significant response at frequencies below about 20 Hz.

It is the high notes which are the problem. Merely embedding loudspeakers in the upholstery or mounting them in a plywood box does not give a good acoustic design, and many such systems respond effectively only to bass notes.

Before one can discuss the upper limit of pitch response one has to define the conditions. There are several mechanisms in the body through which mechanical vibrations may be transduced, giving nerve impulses which can be received by the brain. Some of these mechanisms operate best at low frequencies, eg around 30 Hz; the one capable of best transducing the higher vibrational frequencies, is through the Picinian corpuscles [5] and [6]. These are inherently capable of responding up to a maximum frequency of about 950 Hz. However the energy required to obtain a response increases very rapidly with increasing frequency.

To obtain a constant displacement resulting from a vibration in free space, the energy has to be increased as the square of the frequency. Now the body is not free space, nor will the transduction in the body depend linearly on the displacement produced by the vibration at varying frequencies. But if this were to hold even very roughly over the frequency range 100-900 Hz it would illustrate how the energy required could increase so rapidly with frequency: one would need something like 16 times as much energy at 440 Hz than at 110 Hz.

Hence, if extremely high powers are used in an effort to obtain higher frequency response in question, then the result is a volume of sound as a by-product which would be considered unacceptable by most people. Indeed almost any design could be pressed into giving a higher frequency response if the resultant volume of sound were not a problem. Further, as well as excessive volume of sound, it would be a sound which is distorted and unpleasant to the ear irrespective of its volume.

Hence a good design for the purpose is one (which amongst other things) is efficient in giving a strong sensation of vibration without large power inputs and with as little sound as a by-product as possible.

No standard exists for assessing/defining the frequency response of a vibroacoustic chair/couch. The following is what we use and it is proposed that it might be adopted:

We define the upper frequency response of a vibroacoustic chair/couch as that frequency which can be reliably sensed by the body using no more than 10 watts of electrical power in total supplied to all the vibration transducer in the chair at any frequency in the range claimed. The sensing should be under typical music listening conditions rather than "ideal laboratory" conditions. The response should be measured for 8 people, the highest and lowest figures discarded and a geometric mean of the remainder obtained.

Most of the vibroacoustic chair/couches/boxes on the market are then capable of responding up to about the note A3 (in the notation where C4 is middle C). This is the fundamental reason why many give a sensation of little more than the rhythm and the bass, at acceptable levels and quality of sound produced as a by-product of the vibration.

A major part of our work has been the design of a suitable acoustic coupling system. Our most recent design enables us to go up an octave higher, to A4. The details of this design, which is also helpful in obtaining the desirable type of sensation as described in 1., have to remain confidential until patenting is complete.

This means that the tune, rather than just the bass of a small number of original pieces of music can now be perceived. However by using arrangements of music, eg pieces written for say the violin but arranged for the 'Cello or Euphonium the repertoire of pieces can be much enlarged. Further with modest amount of pitch shifting downwards, a reasonable number of original pieces are also brought within range.

It should be remembered that relatively large amounts of pitch shifting, or transposing, corresponding to a change by more than an interval of a fourth, usually gives a result which is musically unacceptable for reasons well understood in musical acoustics. But this of course applies for listening through normal hearing; we deal with hearing through the ears separately as will be described later

### 3. To obtain an even response to different pitches over the useable range.

Electronic equalisation can be applied but for this to be successful the acoustic design should be such that there are no sharp peaks and troughs in the frequency response of the transducers combined with their coupling system to the body. (An exactly similar requirement is found in the design of loudspeaker drivers /loudspeaker enclosures for Hi-fi use.)

Having achieved this, equalisation can be applied to the signals sent to the power amplifiers so that a sensation of vibration at the different frequencies in the range is judged subjectively as equal, or rather of a level corresponding to approximate equality when listening to sounds of the same pitch.

With variations in degrees of equalisation required which change quite rapidly, albeit smoothly, with frequency, it is indispensable to use 1/3 octave equalisation. This can be achieved conveniently using a commercially available 30 band graphic equaliser, such as the *Alesis* model M-EQ230. The table below shows a typical equaliser setting for our system, this being a combination of the relative sensitivity of the body and the particular design of the acoustic coupling and of the transducer.

Frequency (Hz)	25	31	40	50	62	80	100	125	160	200	250	320	400	500	640	800	Onwards
Gain/Atten. (dB)	0	-6	-8	-9	-10	-11	-12	-12	-11	-10	-4	4	10	12	-2	-12	-12

Why not apply even more equalisation – eg by using two such graphic equalisers in series? Because as discussed in 2., the volume of sound as produced as a by-product together with its unpleasantly distorted nature, should prohibit it.

### **To carry out amplitude compression.**

The volume of sound of a symphony orchestra, live at a classical concert, might range from 35 to 115 dB HL. While the ear can cope with such a very large range, the tactile sense certainly can not, and hence very considerable amplitude compression would be necessary – so that the range of amplitude variation is within 10 dB and ideally 6 dB.

In “pop” music the range is very much smaller and sometimes it is in already amplitude compressed in the recording process – reducing further the already small range of the original. Sometimes little or no additional compression is necessary.

There is no technical difficulty in carrying out the compression; a commercial dynamic range compressor such as the *Behringer* model MDX 1200 or the *Alesis* model 3630 is suitable for the purpose. If very great compression is required it may be necessary to use two compressors in series with appropriate settings on each.

A note on 3. & 4.

There is an alternative to the use of a 1/3 octave equaliser and a dynamic range compressor. This may be attractive to save costs since each of these is required on each separate channel – and there may be up to 4 channels, necessitating the use of two compressor or equaliser units. (Two rather than 4 because these are normally intended for stereo sound use, ie containing a pair devices which may be used separately if desired).

This is to produce a special recording on tape with this processing already done. However commercial copyright considerations on commercially available recordings would have to be tackled.

### **4. To have an adequate means of conveying pitch.**

The following applies only to the application for the perception of music by deaf people – and then only to those with no hearing whatsoever.

Pitch perception was formerly the greatest problem, in the use for completely deafened people, because the sense of pitch, conveyed through vibration in the absence of any cochlear action, is very poor. For western art music at least, one needs to be able to discern, as a minimum, a semitone, whereas the discrimination here is about a fourth or a fifth under realistic music listening conditions. Moreover, there is no sensation of musical intervals – not even a sensation of an octave – just a sensation of faster or slower vibration..

Deaf or deafened people who can do much better – eg who say they can discern musical intervals and to be able to discriminate semitones or better, in the authors experience, always have had some cochlear sensory action at the frequencies in question. They might insist that they are “stone deaf” but that does not mean that they are!

Accordingly an attempt was made to represent pitch by using a spatial array of transducers. This is fully described in [3] and will be mentioned here only briefly.

Each transducer responded to one musical note, irrespective of its octave. With the frequency of vibration doubling in each octave the octave can then be discerned readily, at least over a 3 octave range.

In our first attempt the array was on the forearm, inspired by the pioneering work of von Békésy [8]. One forearm was used for the tune and the other for a monophonic (ie single note) accompaniment. Our second attempt was a truly extensive digital system – using the digits – the fingers! – as well as the digital electronics used in the first system.

Although both the systems worked technically in the way we had designed them, neither was practical success for reasons explained in the paper.

Hence we would not have been able to produce a satisfactory system for those people who had no hearing whatsoever, had it not been that multi-channel cochlear implants came along at just this time when it appeared we were unable to provide a satisfactory solution to this pitch perception problem. These give enough hearing sensation for a large proportion of users – results varying very much for different individuals for reasons which no one seemed to understand, at least at the time. For some the results were so good that a certain range of music could be enjoyed with the cochlear implant alone.

## **5. Hearing and feeling music simultaneously.**

It is highly desirable to present music to the ears and to the body separately. The reason for this is that if a compromise is attempted by pitch shifting or transposing the music downwards, and then using the same signals for both, it will generally be too low in pitch for clarity of hearing or to be satisfactory musically. Yet it will often remain too high in pitch for clear and comprehensive vibrational sensations (particularly with other vibroacoustic chairs/couches). Moreover the envelopes of amplitude will not be optimal for each; and the harmonic content of the signal driving the vibration systems will generally not be low with strong fundamentals.

Only very small and low powered loudspeakers are required for the ears, or if desired, headphones may be chosen. The choice is down to the individual. Some do not like the pressure or feeling of headphones on the head; some like them because they help to exclude the sound of the vibration in the rest of the chair/couch.

Which ever of these is used, their function is important: to convey the high pitched information. Remember that since even with our developments the highest note sensed by vibration alone is A4 (concert A) or at most few semitones higher.

The system we employ is different according to whether it is MIDI based music or ordinary audio.

With MIDI we produce a copy of the notes of the music an octave down (occasionally, when appropriate, 2 octaves down) and usually with different instrument sounds – chosen to have a suitable amplitude envelope and a strong fundamental pitch, giving optimum vibratory perception as well as optimal hearing. The system for this is described in [3].

With ordinary audio we cannot do this nearly so well, but by signal processing of the signals to the head speakers and for the vibrational systems separately, we do the best we can in the above direction.

#### **6. Simplification but maintaining the essence of the music – creating and using musical reductions.**

When perception via vibration rather than a pleasing or therapeutic accompanying sensation to hearing is desired, no more than 3 monophonic parts is desirable. To begin with it is suggested just 2 parts. Later as the person builds up some experience of vibratory perception, they can perhaps go on to up to 4 parts, but we think not beyond that number. The use of music with this restriction on the number of parts is strongly recommended for profoundly deaf people.

For therapeutic use this requirement is not necessary, which is fortunate as this would be too restrictive of the repertoire of music employed for this purpose. But some musical reduction is often useful where the music is complex. This may be done by the selection, or creation, of suitable arrangements of music.

#### **7. Separation of parts.**

The ear/brain is able to separate the sound of instruments wonderfully well. Thus the sound of a prominent oboe part in a symphony orchestra can be picked out against a background of perhaps 80 instruments playing at the same time. To illustrate how wonderful such hearing ability is, it might be noted that this is a task which even a room full of computers is unable to accomplish.

However, the body, through the sense of touch, certainly cannot do this! Hence we believe it is very important: to simplify the body's perceptual task, and we do this by splitting up the parts and sending them to different parts of the body. For example suppose we have a trio arranged for baritone saxophone, trombone and bass guitar. We might place the vibration generated by the saxophone on the right side of the back, that from the trombone on the left back and the guitar's on the buttocks and thighs. If in addition there were another bass instrument, playing lower notes, we might place that on the feet. Not everyone would prefer that choice of positioning. In particular, some people like the tune on the left back and the counter-tune on the right back and vice versa for others. The actual choice of which part goes where can be made by the individual if desired, simply by setting 4 rotary switches.

How is this separation of parts achieved?

With a MIDI based system each part is allocated a separate MIDI channel and a MIDI sound generator is used which has a facility to allocate a separate audio output to individual MIDI channels. For example the *Roland D100* is very suitable for driving the vibrational systems and these are now available at very moderate cost second hand. Further details can be found in [3].

Without a MIDI based system it is more difficult, yet having a satisfactory means is important because, with MIDI, the repertoire is limited, (although ever increasing) and, perhaps more importantly, many of the commercially available MIDI based performances are of a mechanical nature with little or no expressive feeling.

One solution is to make special recordings of performances. While acceptable for duets and trios, costs (or difficulties in finding suitable volunteer musicians) would increase rapidly with larger groupings. Another difficulty is that to obtain really good separation (note this is not something which is required, or even desirable, for normal audio listening) the instruments would have to be widely spaced and with microphones very close to the instruments. (The ideal would be in separate sound booths).

A solution which we have employed for larger groupings of performers is to add a part to a commercial recording (eg an ordinary CD of the music). To do this we ask a musician to play along with one of the performers on the recording on a piano type keyboard and we record this (directly or indirectly) as separate track on a four track recorder, the other tracks being used for the signal processed version of the original recording. This requires some special skill (beyond that of being a reasonably good pianist or organist) as well as dedication in practice and preparation for recording the part of the music because the "doubled" musician cannot be seen (or indeed any of the other musicians), nor the conductor where present.

There are advantages in using a MIDI based, rather than just an audio producing keyboard, for the doubling of a part: it allows the performer to hear what is being played by them at the same pitch as the doubled instrument and with a suitable aesthetic choice of timbre for the performance. Simultaneously, a sound in a different octave, amplitude envelope and harmonic content can be generated for recording on the multi-track tape. Some performers are aided in this process by being given a monitoring system which allows them to hear their own playing in one ear, and the original recording in the other,

## 8. Aesthetic, and ergonomic considerations

To be acceptable a chair/couch has to look nice and to appear as a professional product. It also has to be suitable ergonomically; it has to be comfortable, easy to get on in and out of, or on and off in the case of a couch/bed. It has to be constructed so that it is physically safe; without any risk of jerky movements which might jar the user and of course any possibility of collapse.

We do not have the skills or knowledge to achieve the above; accordingly we begin with what we believe to be the best of the existing commercial products, the Somatron range of vibroacoustic chairs/couches/beds, which as well as being good vibroacoustically, meets all the above criteria very well. We then either replace the Somatron vibratory drive units with those of our own design, or modify the drive units to our own design.

## A brief word on results

This paper is about design requirements and results will be mentioned very briefly.

People who prior to becoming very deaf, were music lovers, and who have experienced other vibroacoustic systems, have without exception, said something such as “I have never experienced music anything like so clearly”. No statistic needed here!

We have tried it with 6 children who were “attention demanders” in the classroom; these children were described by their teachers as not giving them a minute’s peace. Of these, 5 of them were calm and relaxed, and showing every sign of enjoying the experience, within 2 minutes. This amazed some of the teachers – who said that they had never seen these children like that - so much so that they went to fetch a succession of colleagues.

Very good results, which could truly be described as “heart-warming” have been achieved in brightening up the lives of very severely brain injured children and young adults.

Further trials are planned or in progress, and we hope to carry out trials with people who have certain mental illnesses, in co-operation with medical colleagues.

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