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Unbalanced lateral mandibular deviation associated with TMJ sound as a sign in TMJ disc dysfunction diagnosis.

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Authors

Sven E Widmalm*, Yan Dong**, Boxiu Li**, Min Lin**, LiJie Fan***, Simin Deng**.

Affiliations

*University of Michigan, School of Dentistry, Department of BMS/Div. Prosthodontics. Ann Arbor, USA.

**Department of Prosthodontics, College of Medicine, Second Affiliated Hospital, Zhejiang University. Hangzhou, China.

***Department of Oral Surgery, Stomatology Hospital, Zhejiang University. Hangzhou, China.

Correspondence

Prof. YanDong. Department of Prosthodontics, College of Medicine, Second Affiliated Hospital, Zhejiang University. No.88, Jiefang Road, Hangzhou, 310009, China. Email: yandong_66@163.com

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Abstract

The aim was to study the characteristics of lateral mandibular horizontal deviations during opening-closing movements and their association with TMJ sounds of the clicking type. Subjects were 28 healthy volunteers and 38 patients diagnosed with MRI imaging as having TMJ disc dysfunction, 22 with disk displacement without (DD) and 16 as having disc displacement with reduction (DDR). TMJ sounds were recorded with miniature microphones placed in the ear canals, and jaw movements were documented with a kinesiograph. A sign, *unbalanced lateral deviation (ubd)* was defined as a rapid, short duration, change of jaw movement direction from, and back to, a smooth deviation path in the horizontal plane and associated with TMJ clicking. The *hypotheses* were that degrees of maximal deviations, proportions of unbalanced deviation (*ubd*), and of such deviation associated with TMJ sounds (*ubdS*), differ between healthy subjects and patients with DD or DDR. Comparisons between groups were made using one-way ANOVA and chi-square analysis, as appropriate. No differences were found between groups regarding degree of lateral deviation per se. The proportions of *ubd* and *ubdS* were significantly higher in patients with DDR than in healthy subjects and than in patients with DD ($p < 0.001$) but no such differences were found between healthy subjects and patients with DD. For prediction of DDR the sensitivity and specificity of the sign *ubdS* were found to be 68.8% and 89.3%. For the sign *ubd* they were 100.0% and 64.3%. This indicates that the sign *ubdS* has diagnostic value in screening for DDR.

Key words

TMJ sounds, TMJ dysfunction, disc displacement, kinesiograph, unbalanced lateral deviation, sensitivity, specificity.

Background

The most common temporomandibular joint (TMJ) sound recorded in patients with temporomandibular disorders (TMD), and also in non-patient populations, is reciprocal clicking indicative of a disc displacement.[1] TMJ sounds associated with deviation ≥ 2 mm. is acknowledged as a sign of TMJ dysfunction, that should be noted in clinical examination, but it has not been used to differ between patients with (DDR), and patients without (DD) disc reduction.[2, 3, 4, 5] There is no general consensus about the diagnostic significance of TMJ sounds (audible vibrations) and how to best record them in TMD clinics.[6, 7, 8] The main purpose of this study was to test if the simultaneous electronic microphone recording of TMJ sounds and another classical dysfunction sign, namely mandibular deviation[2], can be of value in diagnosis of TMJ dysfunction.

A mandibular deviation can be smooth (Fig.1) but it can also have a sharp unbalanced short time deviation within a long lasting smooth deviation (Fig.2). Sudden changes in the velocity and direction of the condylar path have, in autopsy and clinical studies, been found to be associated with TMJ sounds of clicking type.[2, 4] It is logical to assume that smooth vs. uneven or unbalanced deviations associated with TMJ sounds and deviations per se may have different weight as clinical signs in diagnoses of disc dysfunction. It is possible to record the deviation itself by articulator recordings, palpation, and visual observation, and TMJ sounds by auscultation. Adding electronic microphone recording is of value by giving a detailed and objective recording of positions in, and time relations of, jaw movements and TMJ sounds.

Miniature microphones, with a wide and known frequency response, that can be placed in the ear canals have the advantage in TMJ sound recording[9, 10, 11, 12] of being closer to the site where sounds are caused than skin contact transducers. However, no system is presently commercially available for simultaneous recording of TMJ sounds with such microphones and of jaw movements. A new method for synchronizing signal recordings from two systems was therefore tried by using tooth contact sounds, recorded by both systems, as time markers (Fig.3).

The *hypotheses* were that degree of maximal deviations, proportions of unbalanced deviation (*ubd*), and of such deviation associated with TMJ sounds (*ubdS*), differ between healthy subjects and patients with DD or DDR, and between patients with DD vs. DDR.

The **aims** were to measure degrees and shapes of maximal deviations, and their association with TMJ sounds during large, close to maximal, opening-closing movements.

Methods

Subjects All subjects (N=66) gave informed consent. The experimental protocols were approved by the Zhejiang University Ethical Committee.

There were three groups of subjects. Group 1 (N=28) consisted of 14 males, age 26.8±6.94(SD), and 14 females, age 23.5±2.41 years, healthy volunteers without any facial pain and having jaw movement ability in the normal range. Group 2, a patient group (N=38) consisted of 6 males, age 23.2±11.48 (SD) and 16 females, age 32.3 ±13.53 (SD) years having the diagnosis DD in one or both joints. Group 3, also a patient group, consisted of 6 males, age 29.0±13.33 (SD) and 10 females, age 26.1±10.62 (SD) years having the diagnosis DDR in one or both joints.

Diagnoses of disc position were based on bilateral MR imaging of the TMJs. The patients were recruited from those coming for treatment of acute TMJ pain, which ranged from 2 to 6 on the VAS scale, or acute jaw movement dysfunction[6].

Diagnoses of disc position were based on bilateral MR imaging of the TMJs. The subjects underwent bilateral MRI examinations of their TMJs with the jaw in closed and open positions. MRI was performed with a 1.5T magnetic resonance unit (Signa, General Electric Co, Milwaukee, WI). Images were obtained at closed- and open-mouth positions in the sagittal plane and at the closed-mouth position in the coronal plane. Disk position evaluations, both uni-and bilateral, were based on the criteria described by JE Drace, & DR Enzmann (1990)[13]. The method was devised to quantify disk displacement in terms of the number of degrees from a 12 o'clock or vertical position relative to the condyle.

It is the policy of the Clinic to not treat pain free subjects without jaw movement dysfunction even if they had clicking of DDR type observed at auscultation.

Recording of jaw movements and TMJ sounds The BioPAK system Version 7.2 (Bio Research Associates Inc. Milwaukee, WI) used includes hard- and software for simultaneous recording of jaw movements with a jaw tracker (JT-3D), and TMJ vibrations with skin contact accelerometers. This system for bilateral recording of muscle electrical activity and solid-born joint vibrations (tissue pressure waves) is designed for a type of computer-enhanced examination collectively known as Joint Vibration Analysis (JVA) [14]. The JVA sensors record vibrations in the frequency range from about 20-30 Hz up to about 600 Hz. Most energy above 600 Hz is filtered away by tissues between the site, where sounds occur, and the skin.[11] The differential amplifier has an input impedance of 10^{12} Ω. The Common Mode Rejection Ratio is 129 dB at 50/60 Hz. The signal to noise ratio is 54 dB. The gain was for all recordings set at 2500. All BioPAK recordings were made with the sampling rate 4000 Hz and digitized with a 16 bits A/D card.

Naturally a possible association with crepitation is also of interest, primarily for detection of arthritis or arthroses, but was not examined in this study. The clicking sounds were noted as associated with the deviation if they occurred during the duration of the deviation and were observed in at least 4 of the 6 cycles, had a measured dB level[10] above 70 dB, and were at listening to the audio recording recognized as not being artifacts.

Jaw opening closing movements were documented by recording the position of a magnet taped to the chin with surgical tape. The recordings were used to measure vertical movements in the sagittal plane and lateral deviations in the horizontal plane[14]. Both sagittal and lateral movements were measured in mm. to the nearest tenth of an mm. In the lateral movement recordings positive values indicate left, and negative values indicate right direction.

Calibration recordings of vertical opening degree were made by letting the subject hold a round plate with known diameter between the upper and lower incisors while recording the opening degree. Vertical overbite was recorded for adjusting the calibration recording to represent vertical opening degree from CO.

TMJ and tooth tapping sounds were made for use as time markers to make possible synchronization of microphone and BioPAK recordings. The sounds were recorded with DPA miniature microphones, diameter 5.4 mm, (DPA Microphones A/S, Gydevang 42-44, DK-3450 Alleroed, Denmark) placed inside the ear canals. The frequency response curve for the microphones is flat from 20 Hz up to 20,000 Hz (±2 dB). The maximal noise level is 40 dB. Maximum sound pressure level is 144 dB before clipping. The microphone signals were amplified with a miniature microphone amplifier (Type MMA6000, DPA Microphones A/S, Gydevang 42-44, DK-3450 Alleroed, Denmark). They were recorded with the sampling rate 48 KHz, digitized using an external card, (Creative USB Sound Blaster, Audigy2NX), and stored using Adobe Audition Version 3 software (Adobe Systems Inc. USA) as 24 bits stereo wav files. A sound level calibrator – type 4231 (Bruel and Kjaer, DK-2850, Naerum, Denmark) was used to provide a sinusoid with a frequency of 1 kHz and amplitude of 94 decibel (dB) for calibrating sound amplitude levels and checking the accuracy of the recording system's sampling rate. The BioPAK and the microphone recordings were made using the same laptop computer but different programs for storage. Ideally the recordings should have started at exactly the same time but for technical reasons that was not possible. For the purpose of synchronizing the jaw movement and TMJ sound recordings the tooth tapping sounds were also recorded by the BioPAK system's skin contact sensors (Fig.3).

Test movements Each recording started and ended with the subject tapping the teeth together 2-3 times. The subjects were instructed to perform six slow opening – closing cycles between the tapping movements at beginning and end of the recording. The openings were to be to a few mm. below maximal degree to avoid injury and discomfort. The reason was that opening beyond "the pain limit" may risk aggravating the disease or cause injury in the patients. The subjects were instructed to not proceed with the movements if they felt any pain. It is acknowledged that this may cause a method error in diagnosis because of the risk to miss a recording of "late opening clicks" respectively "late closing clicks". The tooth tapping movements were checked for possible occurrence of DDR clicking close to start and end of the opening cycles but no such clicking was observed.

Future studies with subjects that agree to voluntarily open to a maximal degree, even if pain is felt, might be desirable. Closing was to be to mandibular rest position without making contact in CO.

Synchronization and analysis of BioPAK and audio recordings. Adobe recordings were saved in wav format and imported into Matlab workspace for analysis (Version R2014a, MathWorks, Inc., Natick, Massachusetts). BioPAK files are stored in TRC format and had to be converted to txt (ASCII) format inside BioPAK to be able to be imported into Matlab. In Matlab the BioPAK and the microphone recordings were synchronized using the tooth contact sounds, recorded both by the BioPAK sensors and by the microphones, as time markers.

A new jaw movement variable (*ubd*) was used for the movement characteristic, rapid, short duration, change of movement direction from, and back to, a normal smooth path in the horizontal plane. If the deviation was associated with TMJ sounds of the clicking type the variable was named *ubdS* (Fig.2).

The identification of *unbalanced* versus *balanced deviation* was based on judgement by one observer. It is acknowledged as always desirable to have a team of calibrated observers making such judgements, but that was not possible in the present study. It is the goal to have more advanced hard- and software and/or calibrated observers in future research.

The collected data for *ubd* and *ubdS* are listed in Table 1. Statistical analysis was performed using SPSS (Version 21, SPSS Inc., Chicago, Ill, USA). Comparisons between groups, regarding degrees of maximal deviation, a numerical variable measured in mm., were made using one-way ANOVA. Multiple comparisons within groups were based on Tukey's test. Comparisons across the three groups regarding the proportions of the signs *ubd* and *ubdS*, both being binary variables, were made using chi-square analysis, and comparisons **between** groups by the z-test. Sensitivity and specificity[15] were calculated for *ubdS* and *ubd* as signs of DDR when comparing between healthy subjects and patients with the MRI dx DDR. The level of alpha = 5% was chosen as the significance level.

Results

The degrees of maximal lateral deviation *per se* during opening-closing were in mm. for healthy subjects (N=28, mean 4.10, SD 2.969 mm.), for patients with DD (N=22, mean 4.63, SD 2.533 mm. and for patients with DDR (N=16, mean 3.79, SD 2.467 mm.). They did not differ significantly between any of the groups, healthy subjects, patients with DD, or patients with DDR.

The proportions of both *ubd* and *ubdS* across the three groups (healthy, DD, DDR) were significantly different ($p<0.001$). These proportions were significantly higher in patients with DDR than in healthy subjects and also significantly higher than in patients with DD ($p < 0.001$). No such differences were observed between healthy subjects and patients with DD. When comparing proportions between healthy subjects and patients with DDR the degrees of significance was < 0.001 both for *ubdS* and for *ubd*. The sensitivity as a sign of DDR was 68.75% for *ubdS* and 100.00% for *ubd*. The specificity was 89.29% for *ubdS* and 64.29% for *ubd*. (Table 1)

Method errors and observations.

The microphones, but not the JVA sensors, were observed to be sensitive to external sounds. Both the JVA accelerometers and the microphones were, as far as could be judged by listening to audio playback, sensitive in about the same degree to internal artifact sounds produced by the subjects such as low level grunts, coughs, heavy breathing, and vascular sounds. When listening to the audio recordings it was, however, easy to hear differences between such artifacts and TMJ sounds, such as clicking and crepitation.

There were differences between how presence, amplitudes, frequency distribution, and prevalence of TMJ sounds were recorded by JVA sensors vs. microphones (Figs.3, 4, 5). Those observations indicate that results obtained by these two types of sensors are not directly comparable.

Some group 1 subjects were found to have clicking TMJ sounds of DDR type as recorded by microphones. Such sounds were not detected at the clinical examination of prospective healthy subjects for group 1 when only palpation and auscultation with stethoscope were used.

Discussion

The results in this study are of clinical interest because they support that deviations in the mandibular path during wide opening-closing can have significant diagnostic interest, especially if associated with TMJ sounds of the clicking type. They showed that the proportions of both unbalanced lateral deviations per se, and such deviations associated with audible clicking TMJ sounds, are larger ($p < 0.001$) in patients with DDR than in healthy subjects. Regarding the measures sensitivity and specificity it was found that adding the characteristic "*association with TMJ sounds*" to *unbalanced lateral deviation* decreased the sensitivity from 100% to 68.75% and increased the specificity to 89.29% from 64.29%.

Some of the results may have been wrong because MRI, like other methods, cannot be expected to always give 100% correct results. Also some of the healthy subjects did have clicking sounds of the DDR type meaning that they may have had pain free disc dysfunction. Future studies are needed where subjects are examined with MRI. The MRI dx should, if possible, be based on evaluation by a group of Specialists. Most important is that future testing with larger groups and calibrated MRI specialists is made before comparisons with other methods for diagnosis are performed.[7, 8]

The proportion of unbalanced deviation associated with reproducible clicking was also significantly larger (p < 0.001) in patients with DDR than in patients with DD. This may be of interest in differential diagnosis between DD and DDR in patients where the examiner is convinced that the patient has disc displacement but is unsure if it is with or without reduction.

If it is accepted that TMJ sound recording is of value, it should be obvious that electronic recording is preferable. Comparisons using auscultation with stethoscope are less reliable because the quality of scopes can have too great variations even if they are of the same brand.[16,17] This means that stethoscopes used in research should be calibrated, which they seldom, if ever, are. It is also clear that hearing ability can have a great variation between examiners, especially between young and old surveyors. So far it does not seem that studies of prevalence of TMJ sounds recorded by auscultation, have been performed with examiners tested regarding hearing ability.

There was a small part of the healthy group with subjects having typical DDR type of sounds associated with unbalanced lateral deviations. For obvious reasons, economic and others, it is not possible to perform MRI on all healthy subjects in all clinical studies, even if the patients are examined with MRI for medical reasons. There is a possibility that those subjects had DDR without any other signs or symptoms such as pain or discomfort. Future studies should preferably include MRI recordings of all subjects.

It is realized that recordings of jaw movement with the present method is a recording of the anterior central part of the mandible, and not of the condyles, as can be done by electronic axiography.[5] However, chin movements are associated with condylar movement in a predictable way. The primary jaw movers are the lateral pterygoids' lower heads. Unilateral activity in one head moves the same side condyle forward and downward and the chin to the contralateral side while coordinated activity in both heads moves the condyles and chin straight forward and downward. In clinics a qualitative evaluation of translation of condylar translation can be made by finger palpation and is felt as increased pressure on one or both sides. The movements can also be recorded using electronic axiography[5] but so far there are no methods published regarding combining such recordings with simultaneous microphone recordings of TMJ sounds.

The results support that finger palpation of condylar lateral movements[5] has value in examination of patients with suspected DDR.[3] The results indicate that the specificity can be increased by including simultaneous TMJ sound recording. The finger top skin contains a variety of mechanoreceptors. They are also sensitive to vibrations which means that they can be expected to detect tissue born vibrations caused at DDR. The dynamic parameters of fingertips vary, however, in such a large degree between fingers and persons[18] that it seems improbable that finger palpation can be used in research for comparison of sound/vibration recordings between examiners. Calibration of finger top sensitivity is most probably not a task to be lightly undertaken in any studies. Finally, it should be mentioned as a comment that it is not possible to record *sounds* by finger palpation. Feeling vibrations is not hearing. This is noted because it is not unusual to find authors and lecturers recommending finger palpation as a method for TMJ sound recording.

Skin contact transducers are in most clinical applications used for recording the TMJ sound-vibrations before they enter air space. Most energy in the frequency area above 600 Hz is, however, filtered away by the soft tissues between the TMJ and the skin.[11] Miniature microphones placed in the ear canals record significantly more of the sound energy area of audible TMJ sounds, 20 Hz to 20,000 Hz[9] (Fig. 4). High quality miniature microphones have a flat frequency response between about 20 Hz and 20000 Hz. Placement in the ear canal has the advantage that the tissue layer between the ear canal and the TMJ is thin, only a few mm. and free of adipose tissues. This makes the variability between subjects less because the variances in amplitude and frequency content are dependent on variations in the thickness of adipose tissue between the TMJ and the surface of the face where skin contact transducers are placed. When it is of interest to record a maximal amount of the TMJ sound energy, microphones are the best tools because of the wider frequency range.

Due to differences in frequency response and placement the JVA and microphone recordings do not always give identical, or even similar, results. The JVA contact surface of the sensors is soft. Accurate recording of the frequency response curve of transducers can only be made if the contact surfaces are hard as in metal, not only in the sensor but also in the object for recording. This is naturally not possible in human subjects.

There were cases where potentials, similar in shape to sound potentials, were recorded only by the JVA sensors or only by the microphones. This difference depends primarily on differences in frequency response but also because accelerometers are also sensitive to movements.[19] Tooth tapping sounds are always well recorded both by microphones, as observed in this study, as well as with skin contact transducers.[20]

Only the association with clicking sounds was studied here because there is a general consensus regarding its frequent association with DDR.[1] Crepitation is, as is well known, one of the cardinal signs of arthritis but its possible association with deviations is less clear and was not considered in this study.

The patient group was too small to look for possible differences between sides in patients with unilateral vs. bilateral DDR or DD, nor were the patients with DDR on one side and DD on the other included. No attempts were for the same reason made to look for differences due to variances in displacement direction. In addition, the presently available methods are not good enough to make a reliable analysis of the "side factor". So called "mirror images" can be true signs of "contralateral location" but only if the degree of phase shift is well known.[21] Echoes may occur with the same shape or as mirror images depending on the size of the phase shift.

The analysis of side factors is also complicated by the fact that we cannot yet measure the exact time for transfer of sounds from one side of the head to the other. There are too many less known variables such as reflections in sinuses and the fact that the same clicking sound can travel directly through the short route through the skull base and also by the much longer way via the mandible, to the contralateral side.

The characteristics of deviations from normal movement patterns during opening closing are most probably affected by a large number of variables such as opening degree, anterior-posterior movement path, movement velocity and acceleration, muscular reflex contractions, co-contraction between agonists and antagonists, but they need very much larger samples to be included in a comprehensive analysis. Future studies on larger groups are motivated but a few methodological problems need to first be solved.

As mentioned earlier some healthy subjects had sound signs typical for TMD patients. They may have had disk displacement without pain or jaw movement dysfunction. In future studies the examination should preferably be complemented with MRI imaging of all subjects. Also important is that the MRI images should preferably be evaluated, not only by a single examiner as in this study, but by a group of calibrated judges.[22]

Improvements of the recording system are desirable in future studies because synchronization of the type used here is time consuming and cannot be perfect. Selecting sections from two different graphs involves recording of measuring points with techniques that give the position in figures with decimals while the displays of synchronized recordings only accept information about positions as integers. The starting point of sound and vibration potentials are seldom distinct enough for ideal use as time marker. Instead a more accurate, but still not perfect, method, namely the peaks of the amplitudes were used. The time location and direction of the amplitude peak is dependent on several factors, such as frequency distribution and filtering by tissues between the location where the sound originated and the position of the sensor, and they cannot be controlled or measured by the examiner. Due to differences in frequency distribution the time location of JVA and microphone recorded potentials may differ. Future studies should rather use a common amplifier for all signals recorded, thus eliminating the need for synchronization.

External sounds can easily cause artifacts in microphone recordings but seldom, if ever, when using skin contact accelerometers. The best way to avoid those artifacts is to secure silence during recording. This is not a problem in a private practitioner's office but it was here because it is difficult, sometimes impossible, to avoid in hospitals where many people work with patients in neighbor clinics. There a well isolated recording room may be needed.

External electrical noise caused by the use of electronic devices is a serious problem in hospital environment for all types of sound/vibration recording sensors. Some recordings had to be discarded for such a reason.

Internal sounds from the patient's body can also be severe artifact sources. However, contrary to external sounds, they affect both skin contact accelerometers and microphones in about the same degree. It was observed that low level coughs, grunts, and heavy breathing are recorded looking similar to TMJ crepitation recordings. Heart sounds and vascular pulse were sometimes recorded. The subject has to be silent both during recordings with JVA sensors and with microphones. A benefit of microphone and audio recordings is that the artifacts can easily be recognized and separated from TMJ clicking and crepitation sounds by repeated listening to the stored audio recordings. That made it possible to differ between artifacts and sounds in the graphic analog recordings.

Conclusion

The results strongly support that recording of lateral unbalanced deviations during jaw opening-closing movements and associated TMJ clicking sounds has diagnostic value when examining patients for suspected TMJ disc displacement, especially in screening for DDR and in differential diagnosis between DD and DDR if displacement is already confirmed. To be more easy to use and more reliable, a system is, however, needed where jaw movements and TMJ sounds are recorded using only one and the same amplifier or transferred via a shared interface between two amplifiers and the computer. It is important to continue research in this area regarding methods that are not invasive and less expensive than many other procedures routinely used in diagnosis.

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Table 1. This table contains the numbers of subjects with positive and negative signs of unbalanced lateral deviation with (*ubdS*) and without (*ubd*) associated TMJ sounds in the 3 groups, healthy subjects, patients with disk displacement without reduction (DD) and patients with disk displacement with reduction (DDR). Negative (-) and positive (+) signs indicate *without sounds* vs. *with sounds*.

Total N = 66	**Healthy N = 28**	**DD N = 22**	**DDR N = 16**
***ubd*S -**	**25**	**19**	**5**
***ubd*S +**	**3**	**3**	**11**
***ubd* -**	**18**	**10**	**0**
***ubd* +**	**10**	**12**	**16**

Figure legends

Fig.1. This figure of two opening-closing cycles illustrates the shape of large (~ 9 mm.) but smooth lateral deviations.

Fig.2. The figure illustrates the association between sudden changes of direction in lateral deviations and their association with TMJ sounds/vibrations recorded with a skin con-

tact accelerometer vs. a microphone. The graphs are:

Row number 1. Two opening-closing movement cycles. Vertical axis in mm. The horizontal arrow marks the area of mandibular rest. The vertical double-headed arrow points to the smooth area in the vertical graph where no disturbance is noticed and to the displacement in the lateral movement (row 2). This illustrates the need for display both in vertical and lateral planes.

Row number 2. Lateral movement in the horizontal plane. Deviation degree in mm. Positive values indicate left, and negative values right movement. The lateral movement during opening is smooth and to the left. During closing there is a sudden unbalanced deviation to the right when the opening degree (see row 1) is about 20 mm. It is associated with strong TMJ sound (see row 4).

Row number 3. JVA recording from left side contact sensor.

Row number 4. TMJ sound recording from left side miniature microphone in ear canal.

It is obvious that JVA and microphones give data that differ regarding amplitude ratios between sounds recorded by same side sensors. The large clicking during closing was repeated in 6 consecutive cycles with a level of about 120 dB. The two types of sensors give information that in some cases is similar but in other can differ significantly. This is mentioned to point out that analyses based on each type cannot be compared except when used for synchronization as in this study where the aim was to study association between lateral deviation and microphone recorded TMJ sounds.

Fig.3.This figure illustrates how the JVA and audio recordings of the TMJ sounds were synchronized in time. The recordings could not be started exactly at the same time so the subjects tapped the teeth together a few times as soon as both had started. Two tapping sound recordings are seen at the beginning of each trace. The traces were synchronized by adjusting their lengths before the tapping potentials to have the same time. The tapping sounds were here much stronger than the joint sounds and are not displayed with their full amplitude. The relationship between amplitudes in skin contact sensor and microphone recordings is not linear. The differences can be large as seen by comparing the potentials at about 33 s. The reason is that an accelerometer and a microphone have very different fre-

quency responses and record from different locations.

Fig. 4. This figure is a contour plot[23-29] of a TMJ clicking sound recorded with one of the two microphones used in this study. It illustrates why microphones are needed for recording a maximal amount of the energy in the TMJ sounds. Those can have frequencies well above 1000 Hz, here close to 4000 Hz, which cannot be recorded with the skin contact transducers. The colors represent energy levels on a scale from low (blue) to high (yellow). The plot shows that the energy peak is at about 1500 Hz, which is within the area with highest audibility for the human ear.

Fig. 5. This contour plot[23-29], illustrates that microphones also record TMJ vibrations that may have their energy peaks in the low, not audible, frequency area. The vibrations and the low frequency sounds were recorded with one of the two microphones used in this study. The energy peak is at 15 Hz, a frequency not audible by humans.

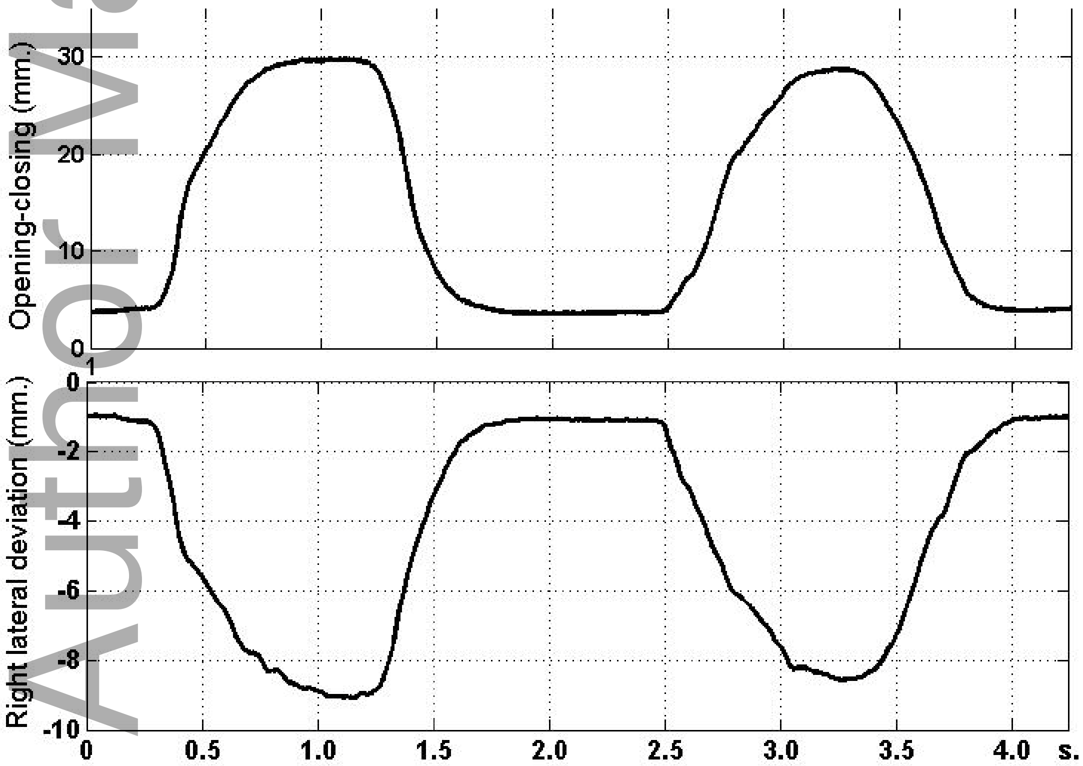


Figure 1.

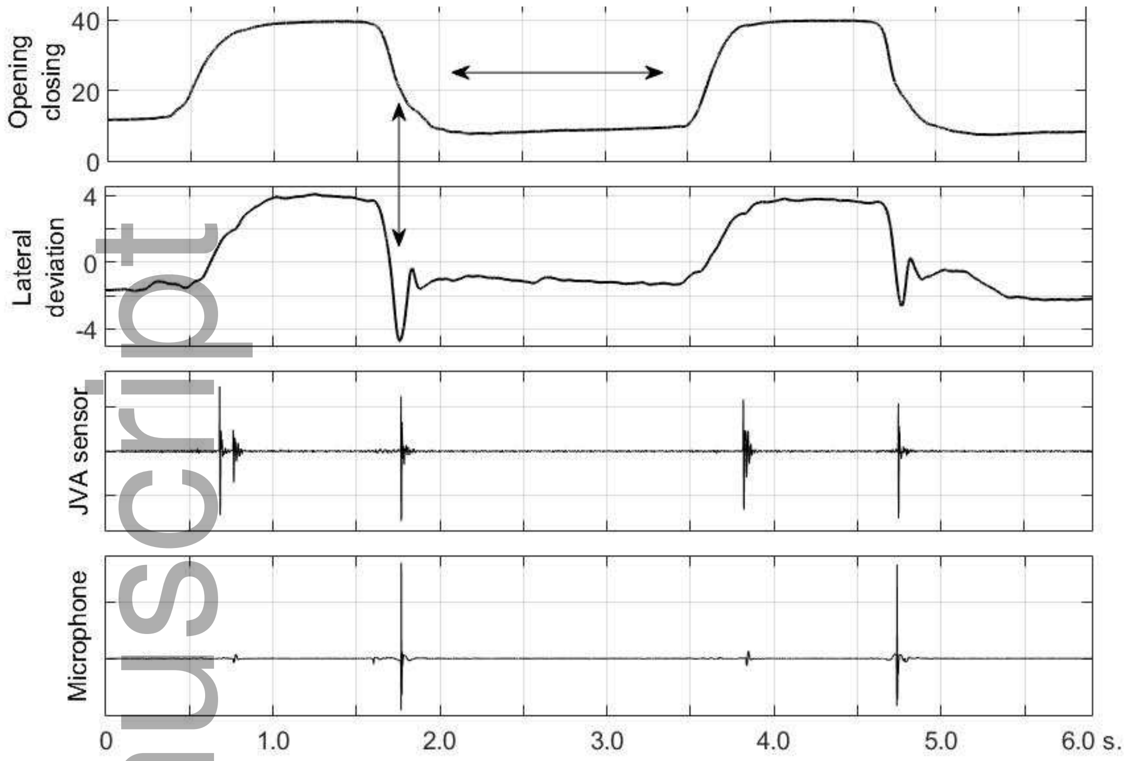


Figure 2.

Figure 3.

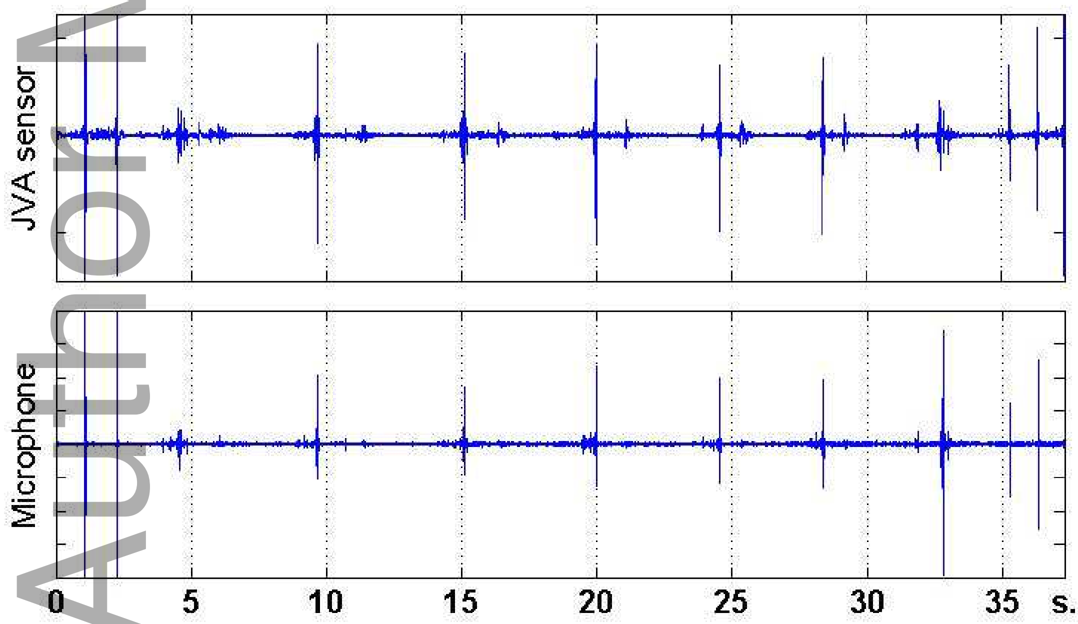


Fig. 4

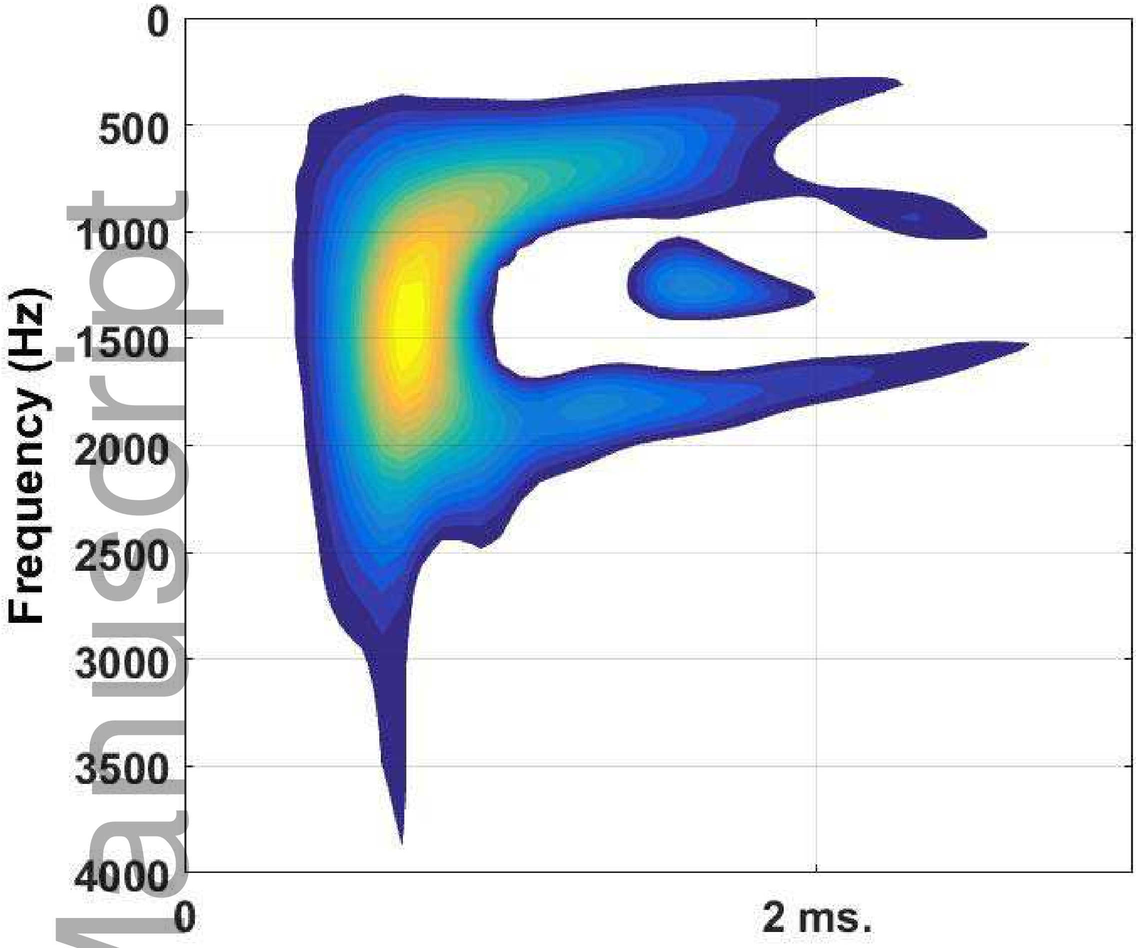
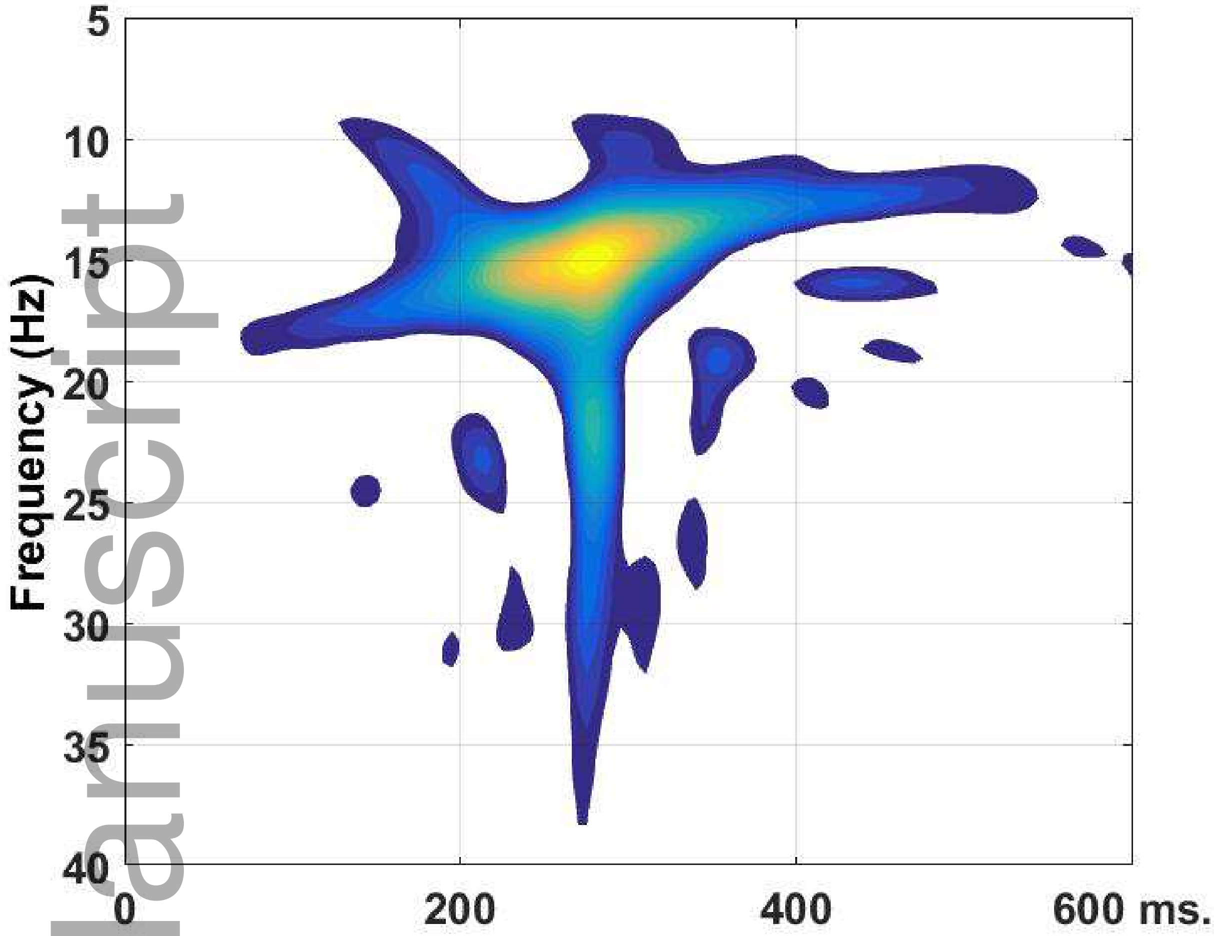
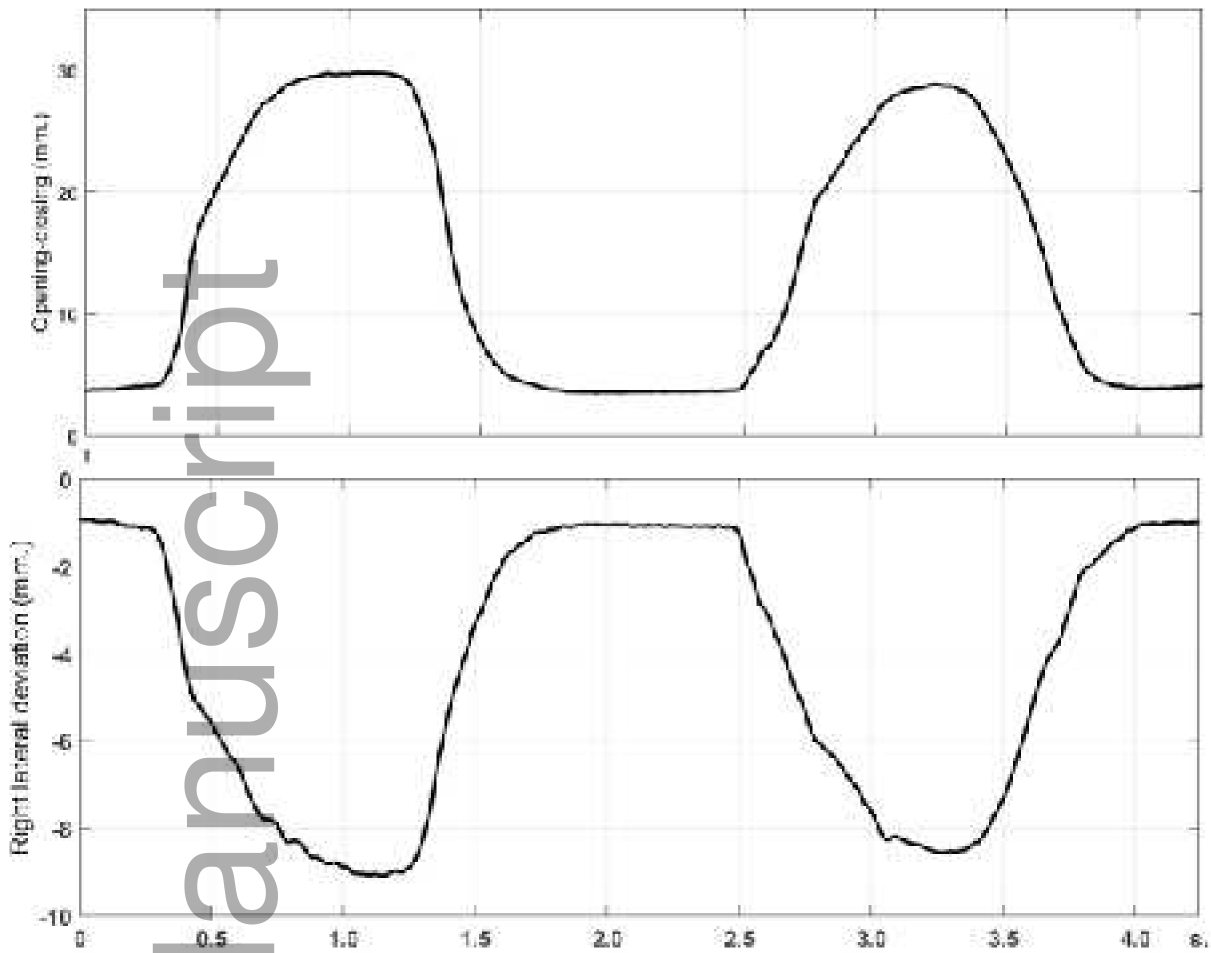


Fig. 5.


Frequency (Hz)
5
10
15
20
25
30
35
40
0
200
400
600 ms.



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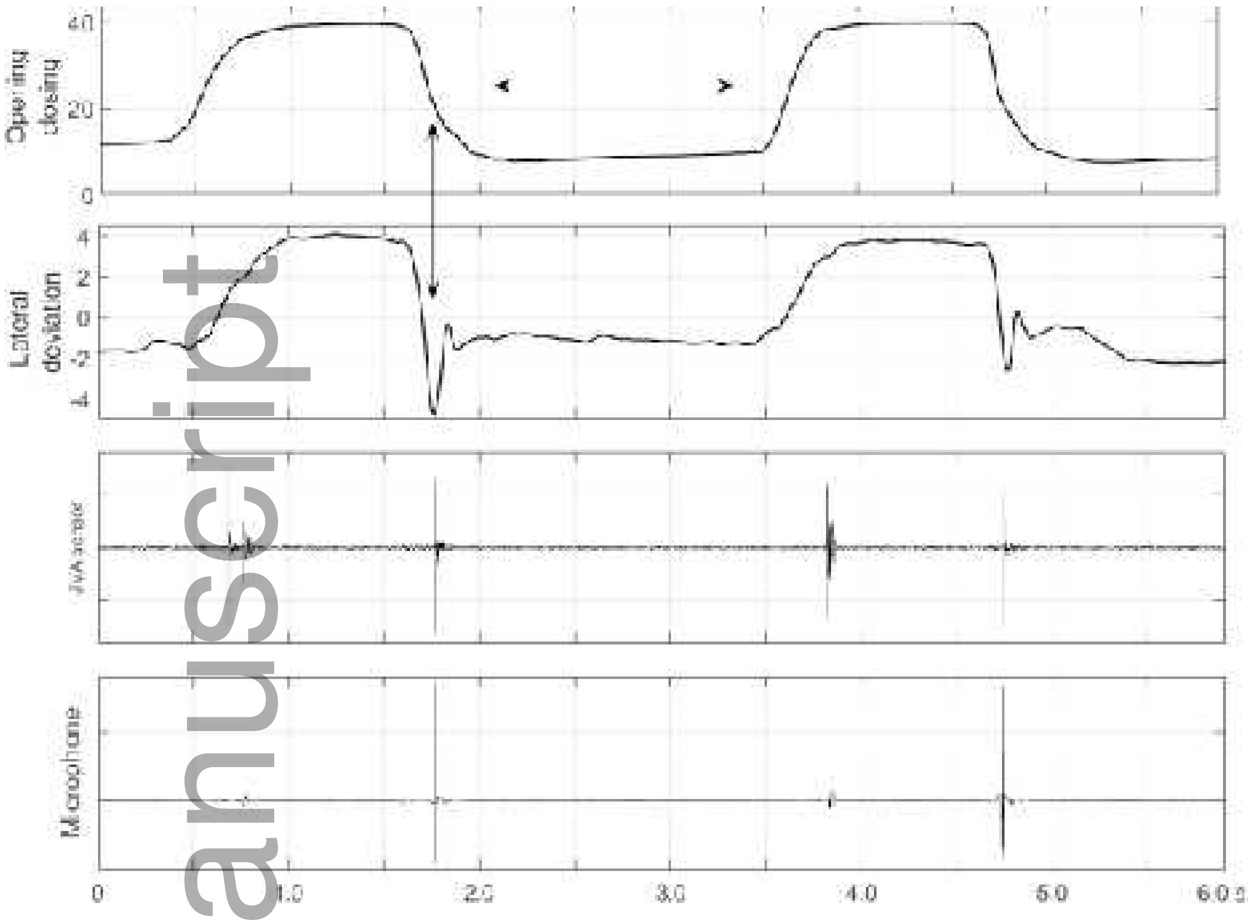

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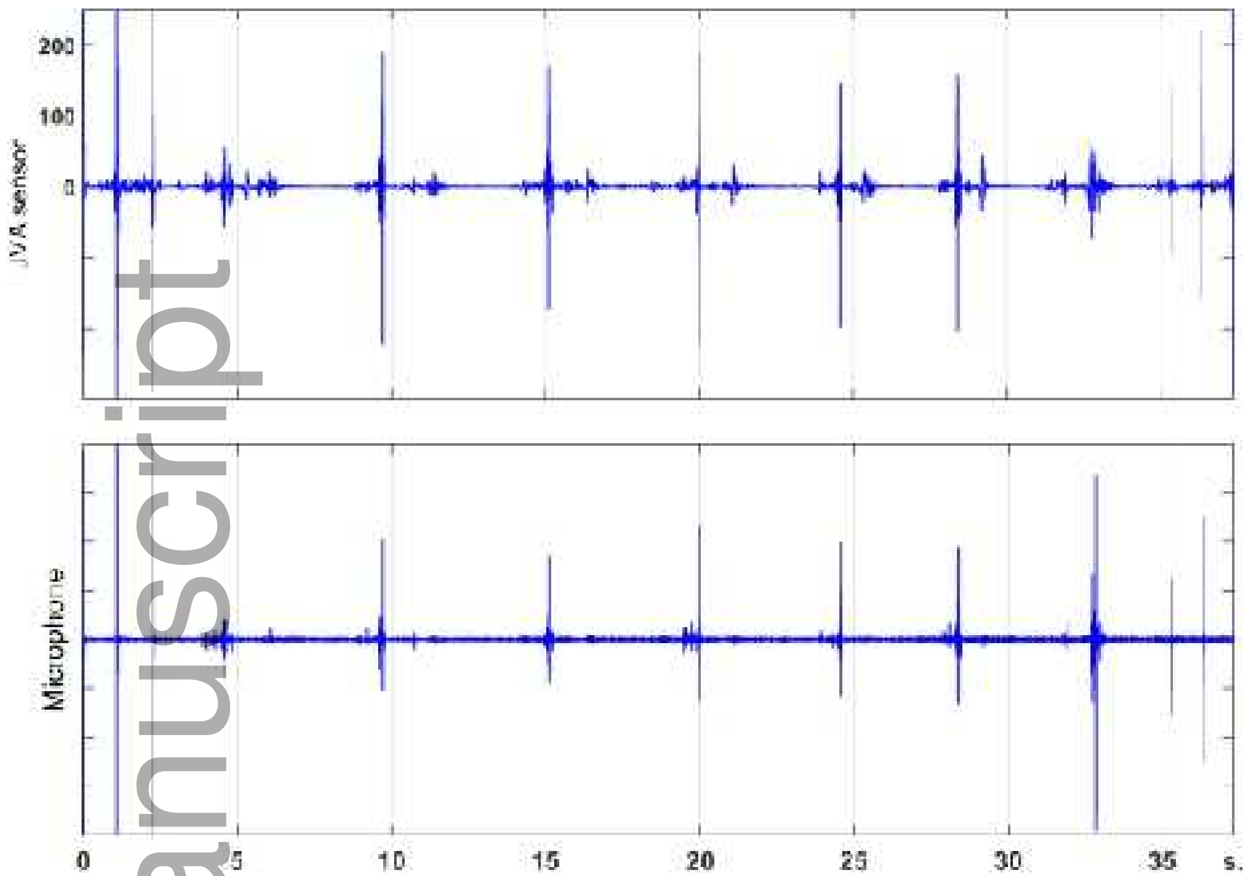

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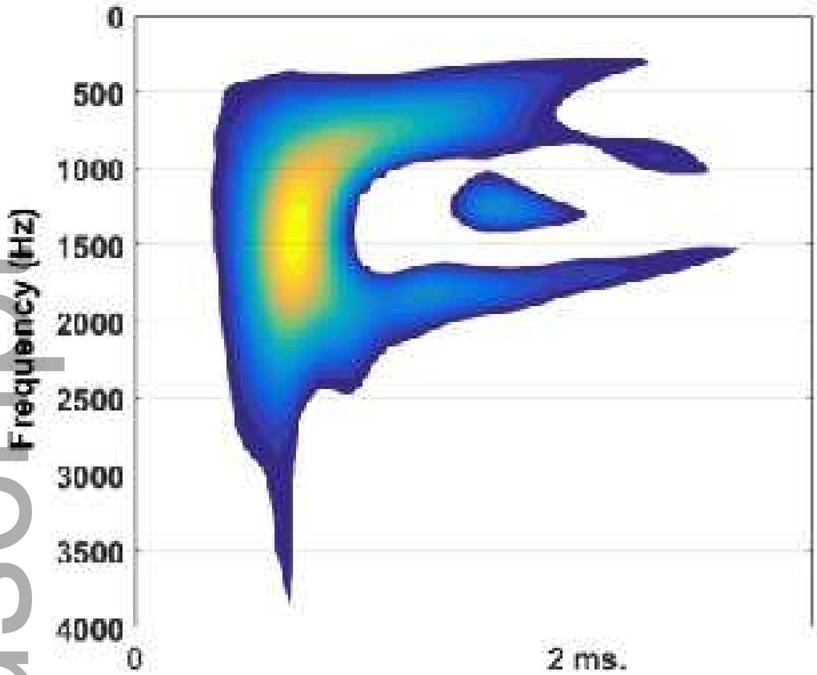

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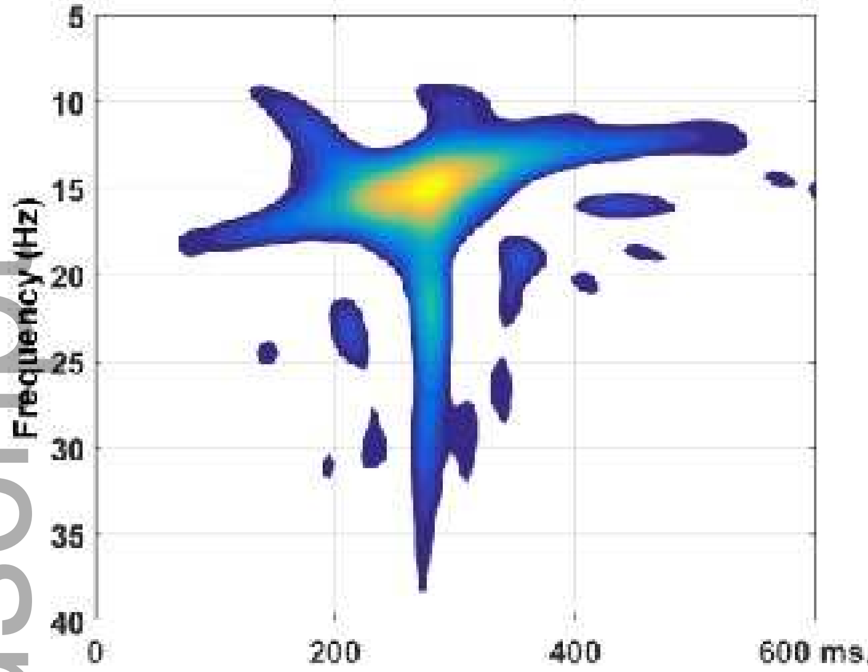

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