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A NEURONAL PROCESS INVOLVED IN INVOLUNTARY DETECTION OF ENVIRONMENTAL CHANGES

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INTRODUCTION

Event-related brain potential (ERP) studies have revealed a negative component, N2a, called mismatch negativity (MMN) in response to occassional deviant stimuli presented in a sequence of homogeneous repetitive 'standard' stimuli(1). An auditory MMN is disclosed by the difference wave obtained when the ERPs elicited by the standard stimuli are subtracted from the ERPs elicited by the deviant stimuli. When attention is concentrated on the same stimulus sequence, the deviant stimuli also elicit this modality-specific MMN and additionally, another negative, modality-nonspecific component, N2b, which is superimposed on the MMN(1,2).

The MMN is probably a reflection of an automatic cerebral mismatch process occurring when the sensory input does not match the prevailing neuronal representation of the preceding stimuli(1). The existence of a neuronal-mismatch process implies neuronal representation of a stimulus. This is established by repeating the same standard stimulus with short intervals (eg, 1-2 sec). By varying the duration of the interstimulus interval (ISI), it is possible to study the duration of the neuronal representation of a standard stimulus. The idea is that an MMN can be elicited by a deviant stimulus only if the neuronal representation of a standard stimulus still exists at the moment that a deviant stimulus occurs.

The neuronal mismatch has been suggested to be an automatic and basic sensory process unaffected by cognitive factors (eg, attention). Neuronal representations probably serve an essential role in passive attention, ie, our ability to become aware of changes in some repetitive aspects of our environment. Such changes are thought to elicit an involuntary, automatic neuronal mismatch process, so that the mismatch 'signal' emerging in this way has privileged entry to the 'single channel' and is reflected by the MMN. The MMN has been interpreted as reflecting passive detection of changes in environmental stimuli(1,2).

The present study concerns the duration of the assumed neuronal representations for a pitch while ignoring or actively attending a sequence of tone stimuli in silence and noise. Two types of noises with different intensity levels were introduced to study the sensitivity of the mismatch process to deviant tones presented in noise. The hypothesis was that a deviant tone can elicit an MMN only when the neuronal representation of the previous standard tone is still vivid. The subjects (Ss) were stimulated with homogeneous stimuli interspersed with occassional deviant tones while they attended the stimuli and counted the number of deviants. In the reading task the auditory stimuli had to be ignored; the Ss read a book. It was expected that the ISI-MMN function is the same in these tasks, but that noise would distract both passive attention, ie, mismatch process, and the detection of deviant tones during active attention.

METHODS

Eight healthy male students (ages 21-28 years) were paid for their participation. The subjects (Ss) listened via headphones to a sequence of pure tones 30 msec in duration and 65 dB (SPL) in intensity.

In a stimulus block, two tones, a 'standard' (950 Hz) and a 'deviant' (1150 Hz) one, were randomly presented to the right ear. In a block the ISI was constant but varied between the blocks, being either 1, 2, 4, or 8 sec. In the blocks, from the fastest to the slowest stimulus rate, the deviant tone occurred with a probability of 10%. The stimuli were generated by a sound generator, timed, and randomized by a computer. The duration of a stimulus block was c. 30 min.

Two types of noises were used to simulate the noise in a shipyard. Continuous pink noise simulated the noise of a ventilation system (termed background noise, B). Impulse noise (I) originating from hammering with a sledge (platers) was simulated by artificially generated bursts of tones (200 Hz square waves; 50 msec with 9 Vvp and 450 msec with 0.4 Vvp). In a stimulus block impulse noise occurred in sequences which could consist of one or several impulses with an interval of 1 sec. The sequences of impulses were timed and randomized by a computer. In a block, the average rate of impulses was c. one for every 3 sec. Impulse noise was inserted into background noise, and the two were presented via two loudspeakers (Yamaha CA1010) placed diagonally behind the subject. For both types of noises, two intensity levels were used: weak (W) and loud (L), of which the background noise was either 60 or 75 dB (A) and impulse noise 75 and 90 dB (A), respectively.

Every subject participated two sessions a day: counting and reading. On the first day, the Ss ran the sessions in silence, on the next day in weak noise, and on the third day in loud noise. In the counting task, the Ss were instructed to count the number of deviant tones and to report the count at the end of every block. In the reading task, the Ss were instructed to read a book (own choice) and ignore the stimuli. Half of the Ss started with the counting session, the other half with the reading session. There was a 3-min. rest period between the blocks and a 1.5 h lunch break between the two daily sessions. The noise exposure was put on at the beginning and switched off at the end of the session. The duration of the noise exposure was 5 h a day.

The electroencephalogram (EEG) was recorded from midline scalp locations at Fz, Cz and Pz in 10-20 system with chlorided silver-silver cup electrodes. Electrodes attached to the ear lobes were linked for reference. An electrode was taped to the infra-orbital and supra-orbital ridge of the left eye to measure eye movements with the electro-oculogram (EOG). An electrode for the ground was taped onto the right mastoid.

After amplification (high-frequency cut-off 15 Hz, time constant 10 sec) the EEG signals were stored on disk by a PDP-11/23 computer. Whenever a voltage detector revealed EOG signals exceeding $\pm$ 30 μV on-line, the computer cancelled the EEG of that trial.

The EEG was digitized with a rate of 3 msec over a 768 msec epoch beginning 20 msec before stimulus onset. The ERPs were averaged separately for the standard and deviant tones in each ISI condition and in the two tasks for the silent and noise conditions. Additionally in the noise conditions, the ERPs were averaged for four stimulus categories depending on whether during the presentation of the stimuli there was only background noise (weak 'WB' and loud 'LB') or whether the impulse noise coincided with the standard and deviant tones (weak 'WI' and loud 'LI') in the background noise.

The ERP deflections were measured as peak amplitudes, within designated latency windows relative to the baseline (average EEG in the period of 20 msec pre-stimulus). The difference waves were obtained by subtracting the ERPs for the standard tone from the ERPs for the deviant tone sample by sample for the conditions.

An analysis of variance (ANOVA, modified for repeated observations of the same subject) was performed for the peak amplitudes of the N1, P2, N2, and P3 waves of the ERPs and for the amplitudes of the difference waves in different latency periods. The ISI effect was tested for the silent and noise conditions using three ISIs (1, 2, and 4 sec) as treatments. The noise effect was tested separately for the ISI conditions, using as treatments the silent and four noise conditions: 1) standard; 2) deviant tone in weak (WB) and loud (LB) background noise; 3) standard; 4) deviant tone coincided with weak (WI) and loud (LI) impulse noise. Differences between the ERPs for the standard and deviant tones were tested by a t-test.

RESULTS

Performance

Table 1 shows the average error percentage as a function of ISI for the silent and noise conditions in counting the deviant tone. In general, the differences were not large between the ISI conditions in silence and weak noise, but a tendency to produce somewhat less errors in the short (1 and 2 sec) than in the long (4 and 8 sec) ISIs. Nearly three times more errors were produced in loud noise than in silence and in weak noise when the ISI was both short and long.

Event-related potentials (ERPs)

In the counting task, the standard and deviant tones elicited N1 and P2 waves in every condition, whereas N2 and P3 waves were most

Table 1. Average error percentage in counting the deviant tone as a function of ISI for silent and noise conditions

Variables	COUNTING PERFORMANCE ERROR (%)		
ISI(sec)	Silence	Weak noise	Loud noise
1	4.4	4.4	13.8
2	2.5	4.4	7.4
4	7.5	5.1	22.1
8	5.4	7.3	14.9

clearly discernible to the deviant tone in silence and weak noise in every ISI (fig. 1; A and B). In loud noise P2, N2, and P3 were flattened. In the reading task, the standard and deviant tones elicited an N1 wave in every condition, whereas a P2 wave was discernible only in silence and weak noise (fig. 1; A and C). Instead, in loud noise, particularly in the short ISIs in impulse noise, a small steady negative shift was observed for the deviant tone continuing to the end of the sampling epoch.

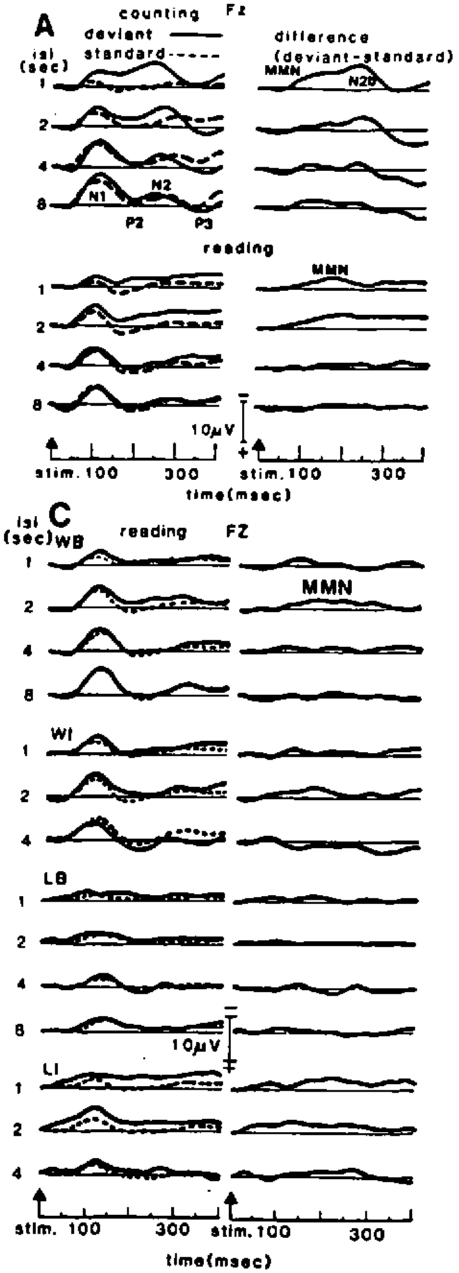
Difference waves
The difference waves in figs. 1 A, B and C displayed a negativity which started at about 35-75 msec after stimulus onset and could last over 200 msec, depending on the conditions in both tasks. This negativity was maximal in the latency periods of 195, 225, and 255 msec depending on the conditions. The ANOVA was performed on the amplitudes in the latency periods of 105, 135, 165, 195, 225, 255, and 285 msec for the ISI effect and for the noise effect in the counting and reading tasks.

ISI effect in the counting task.
In the silent condition, the amplitude of the negative difference wave was affected by ISI in every latency period measured except in 285 msec (table 2). In weak background noise the ISI affected the amplitude, but only in the period of 165 msec. The amplitude was the largest in the short ISIs (1 and 2 sec). In the other noise conditions no ISI effect was found (table 2).

Noise effect in the counting task.
Noise affected the amplitude of the negative difference wave only in the shortest ISI (1 sec) in the latency periods from 135 msec to 225 msec ($F(4/39)$-values=2.71-3.34, $p<.05$). The amplitude was smaller both in weak impulse noise and in loud background noise in 135 and 165 msec, and in weak impulse noise and loud noise in 225 msec than in silence.

ISI effect in the reading task.
The ISI affected the amplitude of the negative difference wave in the periods of 105, 165, and 195 msec only in the silent condition (table 2). The amplitude was the largest in the short ISIs.

Noise effect in the reading task.
Only in the 2-sec ISI was the amplitude of the negative difference wave larger in the silent than in the noise conditions in the period of 195 msec ($F(4/39)=3.72$, $p<.05$).



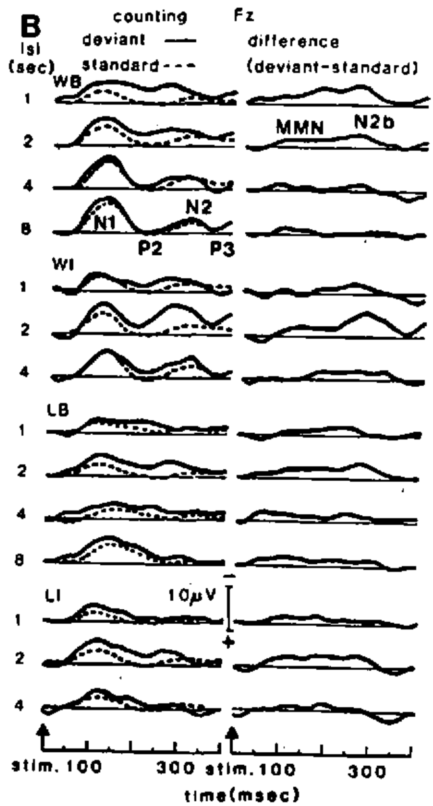


Figure 1. A) The frontal (Fz) event-related potentials (ERPs) averaged across 8 subjects for the standard and deviant tones as a function of ISI and the respective difference waves for the silent condition in the counting and reading tasks. B) The respective data for the noise conditions in the counting task, and C) in the reading task. WB and WI refer to weak background and impulse noise, and LB and LI refer to loud background and impulse noise conditions.

Counting versus reading difference waves.
When the difference waves obtained in the counting task were compared with those obtained in the reading task, the difference waves differed only in the short ISI conditions. As is seen in fig. 1A, the difference waves for the counting task displayed an N2b wave for the deviant tone in the short ISIs. In the silent condition, the amplitude of the negative difference wave was larger in the counting than in the reading task in the latency periods of 225 and 255 msec when the ISI was 1 sec ($t(14)=2.19$ and 2.17, $p<.05$). In weak background noise this was the case in 165 and 195 msec ($t(13)=3.89$ and 3.03, $p<.01$) and in 255 and 285 msec ($t(13)=2.62$ and 2.35, $p<.05$). In the 2-sec ISI the difference waves only differed in weak impulse noise in 255 msec ($t(13)=2.16$, $p<.05$). The amplitude of the negative difference wave was larger in the counting than in the reading task.

It was also tested whether the amplitudes of the negative difference waves deviated significantly from zero. In the counting task in silence, the deviation from zero was significant in the 1-sec ISI from 75 to 225 msec and in the 2-sec ISI in 165 and 255 msec. In weak background noise this was the case in the 1-sec ISI from 45 to 285 msec, in the 2-sec ISI from 135 to 255 msec, and in the 4-sec ISI in 75 msec. In weak impulse noise the amplitude deviated from zero only in the 2-sec ISI in 255 and 285 msec. In loud background noise this was the case in the 2-sec ISI in 285 msec and in the 4-sec ISI in 75 and 105 msec. In loud impulse this was also the case in the 2-sec ISI from 105 to 225 msec and in 285 msec (all t-values ($df=6$ or 7)$=2.37-8.02$, $p<.05-<.001$). In the reading task, the amplitude deviated from zero in silence in the 1-sec ISI from 135 to 195 msec, and in the 2-sec ISI from 35 to 315 msec. In weak background noise this was the case in the 1-sec ISI in 135 msec and in the 2-sec ISI in 165, 195 and 225 msec and in loud impulse noise in the 2-sec and 4-sec ISIs in 135 msec (all $ps<.05-<.001$).

For the ISI effect it can be summarized that, in the counting task, the ISI affected the amplitude of the negative difference wave only in silence and in weak background noise. The amplitude was larger for the short than for the long ISIs. In the reading task this was the case only in silence.

For the noise effect it can be summed up that the amplitude of the negative difference wave was reduced in weak impulse noise and in loud noise in the shortest ISI. In the reading task, the amplitude was reduced in every noise condition in the 2-sec ISI.

CONCLUSIONS

The present study confirms previous results (2) indicating that deviant stimuli can elicit the MMN (fig. 1) when an auditory stimulus sequence is ignored, whereas when this stimulus sequence is attended the deviant stimuli also elicit an N2b component when the ISI is as short as 1 or 2 sec. It appears that the stimulation rate of 4 sec is already too slow for a notable MMN to emerge in

TABLE 2. Amplitudes of the difference waves (dev.-stand.) as a function of ISI at different latency periods measured for the counting an reading tasks in the silent and weak and loud noise conditions. WB and LB refer to the stimulus situations in which stimuli occurred in background noise, and WI and LI refer to those stimulus situations in which stimuli coincided with impulse noise in background noise. The data are from Fz.

Variables	Fz Difference wave amplitude (μV)																			
	Latency period (msec)								Counting											
	Silence				WB				WI				LB				LI			
ISI(sec)	105	135	165	195	105	135	165	195	105	135	165	195	105	135	165	195	105	135	165	195
1	-2.9	-4.0	-4.4	-5.0	-1.9	-2.5	-3.6	-3.3	-0.2	0.3	-0.8	-1.2	-0.6	-0.8	-1.1	-1.6	-1.9	-2.2	-2.0	-1.8
2	-0.5	-1.2	-1.6	-1.8	-1.6	-1.7	-1.9	-2.0	-1.7	-2.2	-1.7	-1.6	-1.9	-2.6	-2.5	-2.0	-2.6	-2.6	-2.4	-3.0
4	-0.9	-1.1	-0.4	-0.3	-0.9	-0.9	-0.6	-0.6	-0.4	-1.1	-2.1	-2.2	-1.9	-1.5	-1.4	-1.1	-0.7	-1.2	-0.4	-1.5
F(2/23)	6.16	5.06	8.37	16.74	1.36	2.31	4.04	2.85	3.08	3.16	0.70	0.25	0.87	0.92	0.73	0.13	0.97	0.57	1.33	1.02
p<	.01	.05	.01	.001	n.s.	n.s.	.05	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
									Reading											
ISI(sec)	105	135	165	195	105	135	165	195	105	135	165	195	105	135	165	195	105	135	165	195
1	-1.4	-2.1	-2.8	-2.6	-0.8	-1.5	-0.7	-0.3	-0.8	-1.5	-0.7	-0.9	-0.4	-0.3	-0.6	-1.0	-1.2	-1.1	-2.4	-3.1
2	-2.0	-2.6	-3.3	-3.6	-0.6	-1.2	-1.9	-1.9	-1.1	-1.5	-2.3	-1.3	-0.6	-0.3	-0.4	-0.3	-1.4	-2.1	-1.9	-1.6
4	-0.2	-0.8	-0.8	-0.9	-1.4	-0.9	-0.5	-1.1	0.9	1.6	1.1	0.8	0.4	-0.6	-0.4	0.5	-0.3	-1.0	-0.7	-0.7
F(2/23)	3.43	1.56	3.50	4.15	0.37	0.41	2.56	2.98	0.96	2.58	2.27	1.20	0.53	0.07	0.02	1.07	0.31	0.51	0.85	1.32
p<	.05	n.s.	.05	.05	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

response to the deviant stimulus, suggesting that the neuronal representation of the standard stimulus has decayed within 4 sec; thus a deviant stimulus no longer elicits any MMN.

The MMN was interpreted to reflect passive detection of environmental stimulus changes while the subject's attention was concentrated on counting and reading. There is evidence that the cerebral mechanism generating the MMN is not involved in active discrimination of stimuli (3), as no sharp deterioration of discrimination performance is observed when the ISI between successive stimuli is prolonged over 2 sec or beyond 10 sec (4) when no MMN can be generated. In fact, the accuracy in pitch discrimination deteriorated mildly as a function of ISI in silence and in weak noise, whereas in loud noise the accuracy was considerably reduced in every ISI.

In the counting task, the MMN occurred in silence and in weak background noise in the short ISIs, whereas the ISI did not significantly affect the difference wave amplitude in weak impulse and loud noise. However, the amplitude deviated from zero in weak impulse noise in 225 and 285 msec in the 2-sec ISI, in loud background noise in 285 msec in the 2-sec ISI, and in the 4-sec ISI as early as in 75 and 105 msec. In loud impulse noise this was the case in 105-225 and285 msec in the 2-sec ISI. The amplitude deviation from zero in these later latencies, 225 and 285 msec, are suggested to indicate the N2b component of the ERP, whereas the amplitude deviation from zero in 75 and 105 msec are suggested to be a reduced MMN elicited by the deviant tone presented in continuous LB and in loud impulse noise. These results could imply that the neuronal representation of the standard stimulus could survive the impact effect of impulsive sound bursts although they were louder than the standard tone and coincided with the standard tone. The occurrence of the N2b for the deviant tone in loud noise could indicate that active stimulus discrimination is partially defected by relatively loud noise when the time interval between two stimuli is not too short or long. This may also mean that in addition to passive detection system reflected by MMN there has to be a separate mechanism for the active discrimination performance despite competing noise stimulation or long ISIs in noisless conditions.

In the reading task, the ISI affected the MMN only in silence. However, the difference wave amplitude deviated from zero in weak background noise in 135 msec in the 2-sec ISI. In loud noise this was the case also in 135 msec in the 2 and 4-sec ISIs. These findings could imply that also in conditions in which the stimulation is ignored, the deviant stimulus presented in background noise can elicit a reduced MMN, whereas the deviant stimulus coinciding with the noise bursts may only together elicit an MMN; as 'two deviant stimuli' are presented at the same moment, the louder one may mask or summate with the weaker one and a smaller MMN is elicited. No MMN was observed in those stimulus situations in which the standard tone coincided with impulse noise. Interestingly, the passive detection mechanism involved in the mismatch process appears to be highly sensitive in that even changes near the discrimination threshold-level are registered, since they elicit a (small) MMN (3). These issues, however, need further investigation as does the finding that attention related N2b was only elicited in the shorter ISIs. This concerns also the relationship to the Orienting reflex(5).

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A PRACTICAL SYSTEM FOR SPATIAL TRANSFORMATION OF SOUND FIELDS

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Introduction
The spatial transformation of sound fields technique (STSF) has been developed to meet the growing interest among researchers about how and where noise is radiated from a source and how noise propagates into the far-field. The automotive industry in particular is interested in making acoustical measurements in one plane and then calculating all the descriptors of the sound field (e.g. sound pressure, sound intensity, particle velocity) in all other planes closer to and further from the motor or vehicle under test. This paper presents a practical system for STSF measurement and analysis together with some measurement results.

Theory
The STSF technique employs a combination of Helmholtz integral equation and near-field acoustical holography (NAH) modified for application to partially incoherent sound fields. Helmholtz integral equation and acoustical near-field holography technique described in [1] are based on the fact that any sound field, described in terms of sound pressure or particle velocity, satisfies the homogeneous wave equation in source free space. Both methods assume that the acoustic field is known in amplitude and phase over some measurement surface. These two methods are therefore in their basic form restricted to coherent sound fields, unless simultaneous probing of the field at every measurement point is employed. The way in which this limitation is overcome in STSF is a development of the approach described by Ferris [2]. As the STSF technique uses the information contained in the evanescent waves, the resolution of the system is not limited by the wavelength of the sound of interest.

Measurement technique
Direct application of the Helmholtz integral would mean performing measurements over a closed surface. For field calculations in a half space this closed surface can be enlarged so that in the limit it becomes a plane, the plane of integration, enclosed by a hemisphere at infinity. Suitable choice of a Green's function simplifies the Helmholtz integral to the so-called Rayleigh Integral. A finite scan area in front of the object under test is defined on the plane of integration. A grid of measurement points is then defined on the scan area, the spacing depending on the size of the source and the frequency range of interest. Ideally the cross spectra should be measured between each pair of grid points. In this optimised measurement procedure, two sets of microphones are used to obtain the cross spectra information; a set of fixed reference microphones distributed over the scan area and an array of microphones which is traversed over the scan area in the course of the measurement.

The cross spectra from each scan point to a set of reference points are measured in the scan plane close to the test object by means of a modified one third octave, real-time analyser. From this data the STSF system enables all the descriptors of the sound field to be calculated in the half space not containing the source.

Calculation facilities and applications
The three main calculations which the STSF system can perform and some of their potential applications are:

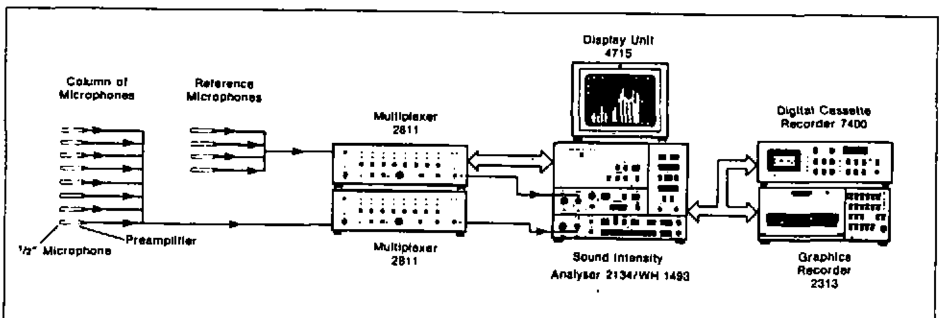

Fig. 1. Typical instrumentation for STSF suitable for a completely automated measurement system

A PRACTICAL SYSTEM FOR SPATIAL TRANSFORMATION OF SOUND FIELDS

1. **Helmholtz' integral equation**

   - Plot of sound pressure level along a line
   - Plot of sound pressure level spectrum at a specified point
   - Plots of active and reactive intensity
   - Plot of radiation pattern

2. **Near-field holography**

   - Plots of all acoustic descriptors (e.g. pressure level, particle velocity level, active or reactive intensity) for study of the near-field and for localisation of noise sources.

3. **Simulation of source attenuation**

   - To investigate which part of the source under test should be attenuated or damped to produce a specified reduction in the noise level at a particular point or region.

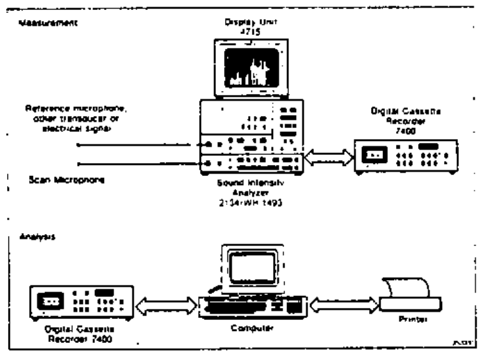

Fig. 2. The minimum instrumentation required for STSF data collection and analysis

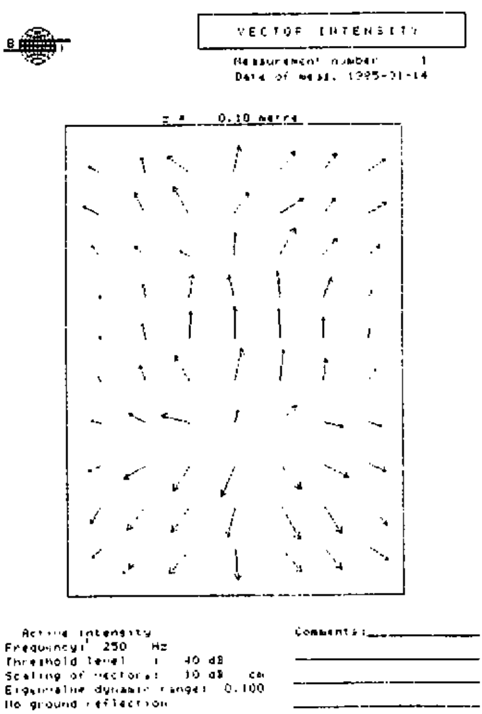

Fig. 3. Active intensity calculated in front of two loudspeakers driven in antiphase with wide-band noise. Only one source is evident

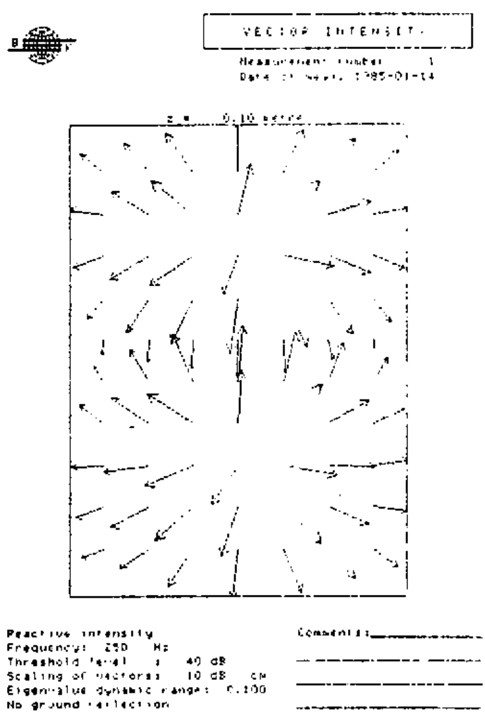

Fig. 4. Reactive intensity calculated as for fig.3. The positions of the loudspeakers are clearly seen

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Instrumentation
The typical instrumentation for STSF (fig.1) is based on 8 array microphones and 4 reference microphones. With the present system up to 32 array microphones and 16 reference microphones may be employed although one can also use fewer microphones and perform multiple traverses over the measurement plane. The software is written so as to enable a step motor to be employed to move the column of array microphones from one traverse position to the next thus making the measurement system completely automated.

The necessary data may also be collected using a minimum of instrumentation shown in fig.2. The reference signals need not come from microphones; other transducers such as accelerometers may also be used.

The system depicted in fig.1 can gather the necessary data and also perform a number of calculations under the control of a dedicated Application Package. The user is guided through the setting up of instruments, calibration and measurement procedure by a series of prompts from the Application Package. Before proceeding to post processing the validity of the measurements should be checked using the special facilities provided e.g. by comparison of the computed sound pressure levels to the measured sound pressure levels at the microphone positions. These checks help one to decide whether enough reference microphones have been employed.

The post processing facilities available with the Application Package are the calculation of the sound pressure along a specified line and calculation of vector intensity, both the active and reactive intensity. The use of reactive intensity in locating noise sources is illustrated in fig.3 and fig.4. For near-field acoustical holography (NAH) and simulation of source attenuation, the measured data must be transfered to a computer and processed using a more extensive STSF program.

Results
Measurement of sound intensity in the near-field region allows an estimation of the radiated sound power, but cannot predict the directional properties of the source, due to a lack of correlation and related phase information between the measurement points.

Considering the partial noise sources on the radiating structure, intensity measurements allow a ranking of these partial sources according to their contribution to the radiated power. The effect on the radiated power of an attenuation of one of them can therefore be simulated under the assumption of no mutual correlation.

If, however, correlation is present, attenuation of one partial source will affect the radiation from the others. In this case phase information is needed to predict, how the radiation from the other partial sources will be changed and therefore how the radiated power and the directional properties of the entire source will be changed. In STSF the phase information is contained in the cross-spectra measurements.

To illustrate the use of STSF in engine development, measurements were performed over the front end (belt drive end) of a car engine, mounted in an engine test cell. The dimensions of the scan area were 1,4 m by 1,3 m. 14 array microphones and 8 reference microphones were used.

Example of simulation of source attenuation on a car engine.
From NAH calculations it çan be seen that an active intensity plot in the measurement plane in front of the engine did not reveal sufficient details about the three pulleys. Using the NAH routine, the intensity plot was drawn in planes closer to the engine (Fig.5.) revealing that the belt drive pulley was the most important noise source. A significant reduction in the noise level could thus be obtained by replacing the original belt drive pulley with a damped pulley. The effect of such a replacement on the far-field sound pressure level was investigated first mathematically using the simulation of source attenuation capability of the STSF system and then by physically replacing the pulley [4].

The introduction of the damped pulley was simulated by attenuation of the particle velocity field by 20 dB over the area of the pulley in a plane 20 cm closer to the engine than the scan plane i.e. as close as possible. The modified particle velocity field was then employed to compute the pressure level along the line 1,0 m from the scan plane. To verify the simulated results the 1/3 octave pressure spectra were measured along a line parallel to the scan plane and at a distance of 1 m using first the standard pulley and then the damped pulley. Reflections from the walls of the test chamber prevented control measurements being performed at distances greater than 1m from the engine. The apparently large discrepancy at 630 Hz at the off axis position was due to the fact that the measured values at this position were influenced by the noisy exhaust outlet which was led out of the test chamber via a channel in the floor.

Conclusion
The relatively new sound intensity technique has proved extremely useful for real-time source location and for measuring radiated sound power. The STSF technique, based on similar instrumentation seems to be the next logical step in the investigation of noise sources as STSF yields phase and correlation information which the intensity technique lacks.

A PRACTICAL SYSTEM FOR SPATIAL TRANSFORMATION OF SOUND FIELDS

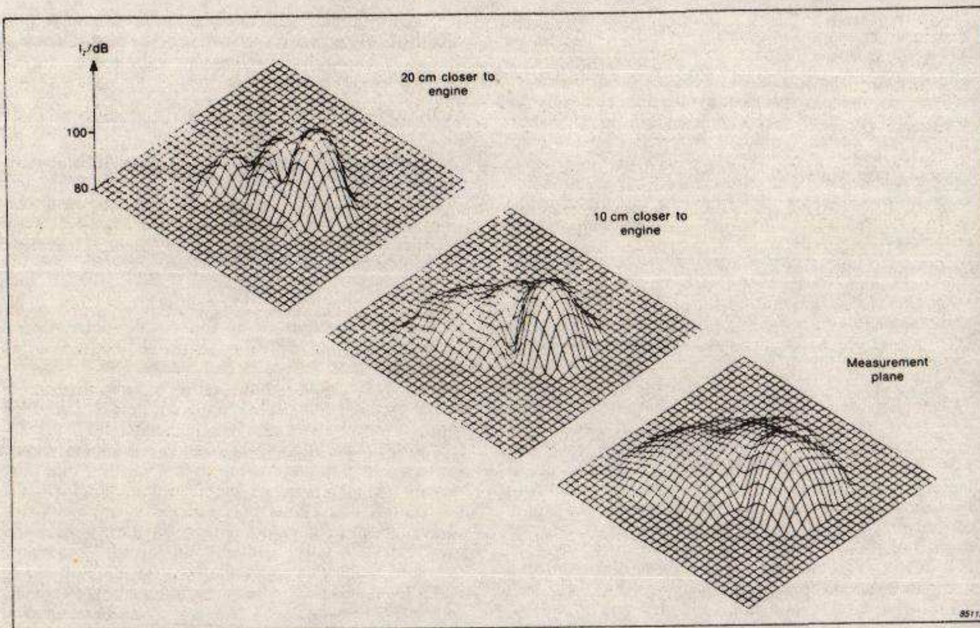

Fig. 5. Near-field holography intensity plots over the front of engine for an area 1,4m by 1,3m as calculated using the extensive STSF program. The belt drive pulley is seen to be accentuated as the NAH plot approaches the engine

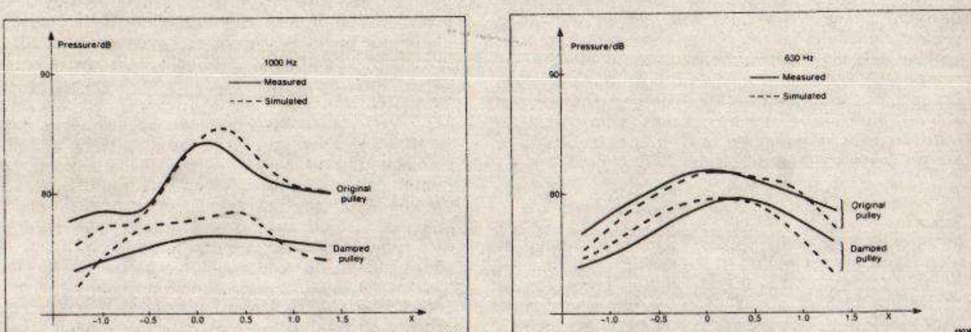

Fig. 6. Simulation of damping of belt drive pulley on engine. The curves represent the sound pressure along a line at 1,0m from the scan plane

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