Still lower molecular weight components may be fractionated by high force field SFFF (*12*). For example, the single-stranded circular fD viral DNA macromolecule was well retained at 30,000 rev/min (constant field), with peak retention corresponding to a molecular weight of $1.71 \times 10^6$. This closely compares with the reported value of about $1.7 \times 10^6$ for this material (*24*). The protein fibrinogen with a reported molecular weight of $5 \times 10^5$ has also been retained with a retention ratio $R = 0.37$, representing the approximate mass limit of separation with our present apparatus (*12*).

*Bacteria.* By utlizing low SFFF force fields it is feasible also to fractionate relatively large biomasses, such as *Escherichia coli* bacteria (*25*).

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# Reexamination of Acoustic Evidence in the Kennedy Assassination


Committee on Ballistic Acoustics, National Research Council


At the time of the assassination of John F. Kennedy, a microphone, presumably on a police motorcycle, was stuck open and transmitted continuously on Dallas Police Department channel I. The transmissions were recorded on a Dictaphone belt recorder, model A2TC. At the request of the House Select Committee on Assassinations, this belt and magnetic tape copies of it were studied by J. Barger, S. Robinson, E. Schmidt, and J. Wolf (BRSW) of Bolt Beranek and Newman Inc., and later by M. Weiss and E. Aschkenasy (WA) of Queens College. In reports in September 1978 and January 1979, BRSW concluded (*1*) that the recording contained four sounds, which they attributed to probable gunshots, and that with a probability of 50 percent one of the sounds (the third) was due to a shot from the grassy knoll area of Dealey Plaza in Dallas. Later, WA studied the echo patterns analytically, and their conclusion (*1*) was that "the odds are less than 1 in 20 that the impulses and echoes were not caused by a gunshot from the grassy knoll, and at least 20 to 1 that they were." BRSW subsequently reviewed the results of WA and concluded (*1*) that "the probability that they obtained their match because the two matched patterns were due to the same source (gunfire from the knoll) is about 95%." This conclusion, together with the fact that shots were definitely fired from another location, the Texas School Book Depository, was the basis of the finding by the House Select Committee on Assassinations that "scientific acoustical evidence establishes a high probability that two gunmen fired at President John F. Kennedy."

In response to a request from the Department of Justice, the Committee on Ballistic Acoustics was established by the National Research Council in the fall of 1980 to review the methodology employed in the evaluations of the recorded acoustic data and the conclusions about the existence of a shot from the grassy knoll. The committee was also asked to recommend the kinds of tests, analyses, and evaluations needed to obtain better information from the recording.

In the first months of its existence, the committee studied the analytical techniques used by BRSW-WA. Committee members found errors in the previous studies which were sufficiently serious that, by the end of the first committee meeting, no member was convinced by previous acoustic analyses that there was a grassy knoll shot.

The committee continued its studies to challenge its own conclusion and search for additional acoustic evidence. In particular, it followed up a suggestion that cross talk from Dallas Police Department channel II was weakly recorded with the sounds attributed to gunfire on channel I. On the day of the assassination, channel I was primarily used for normal police activities. Channel II was used for the presidential motorcade and was recorded on a Gray Audograph disk. The quality of the cross talk on the recording from channel I was so poor that the committee could not conclude by listening to the recordings from the two channels that the two messages were the same. Hence it made sound spectrograms of portions of the two recordings. Analyses of the spectrograms showed


The Committee on Ballistic Acoustics includes Norman F. Ramsey, Harvard University, chairman; Luis W. Alvarez, Lawrence Berkeley Laboratory, University of California; Herman Chernoff, Massachusetts Institute of Technology; Robert H. Dicke, Princeton University; Jerome I. Elkind, Xerox Palo Alto Research Center; John C. Feggeler, Bell Laboratories, Holmdel, New Jersey, Richard L. Garwin, Thomas J. Watson Research Center, IBM Corporation, and Department of Physics, Columbia University; Paul Horowitz, Harvard University; Alfred Johnson, Bureau of Alcohol, Tobacco, and Firearms, National Laboratory Center, Department of the Treasury; Robert A. Phinney, Princeton University; Charles Rader, Lincoln Laboratory, Massachusetts Institute of Technology; and F. Williams Sarles, Trisolar Corporation, Bedford, Massachusetts. Staff members at the National Research Council are C. K. Reed and Bertita E. Compton, Commission on Physical Sciences, Mathematics, and Resources. This article is based on the committee's formal report, which will be released in November 1982.




0036-8075/82/1008-0127$01.00/0

conclusively that a segment of channel II was recorded on channel I at the same location as the acoustic impulses attributed to gunfire. From the channel II recording it was clear that the message of concern was broadcast 1 minute after the assassination. This conclusion was confirmed by tracing time backward from a later match of clearly intelligible cross talk between the channels. In addition, features of the recorded sounds strongly suggest that the open microphone was not in Dealey Plaza at the time of the assassination.

*Summary.* Sounds recorded in Dallas at the time of the assassination of John F. Kennedy were analyzed by two research groups, whose reports formed the basis for the opinion that two gunmen fired at President Kennedy. These reports and the acoustic evidence have been studied by the Committee on Ballistic Acoustics, and further acoustic analyses, including sound spectrograms, have been performed. The committee finds that the acoustic data do not support a conclusion that a second gunman was involved in the assassination.

For the reasons outlined above and discussed in more detail in this article, the Committee on Ballistic Acoustics unanimously concluded that:

1) Analyses of the acoustic evidence do not demonstrate that there was a grassy knoll shot, and in particular there is no acoustic basis for the claim of 95 percent probability of such a shot.

2) The acoustic impulses attributed to gunshots were recorded about 1 minute after President Kennedy had been shot and the motorcade had been instructed to go to the hospital.

3) Therefore, reliable acoustic data do not support a conclusion that there was a second gunman.

## Description of Studies by BRSW and WA

The acoustic studies by BRSW and the further acoustic studies by WA have been printed (*1*). This section is a simplified presentation of the procedures as described in their reports and as later discussed when the committee met with Barger, Weiss, and Aschkenasy in 1981.

The BRSW team began by listening to tape copies of the recordings of both police radio channels for general orientation. Because the recorders were sound-activated, they could have stopped frequently for varying amounts of time, except that the channel I recorder ran continuously for 5.5 minutes when a transmitter, presumably on a police motorcycle, became stuck in the transmit mode (the channel I recorder appears to have run continuously during the period of interest). Using the frequent annotations of time by dispatchers on both channels, BRSW estimated the approximate time of the beginning and end of this 5.5-minute transmission. Because of the severe noise and distortion on the recording, the BRSW team could neither confirm that this segment contained gunshot sounds, nor eliminate the possibility that they were present, by simply listening or by examining the wave forms of sounds on the tape. Therefore, they went to Dealey Plaza on 27 August 1978 and made recordings of test shots with various kinds of guns and ammunition, two shooter locations, and many microphone locations along the approximate route of the motorcade. For each combination of shooter location and microphone location, there is a characteristic and complex pattern of echoes in the recording of the test shot. Whereas the channel I recording is noisy and distorted, the test shot recordings are clean records of the acoustical response of Dealey Plaza—except for some changes that took place between 1963 and 1978.

The BRSW team then compared, manually, each of 432 test shot wave forms with all the parts of the 5.5-minute record that could reasonably have included assassination gunshot sounds. They used a binary correlation metric, with a $\pm 6$-millisecond window, applied to strip chart recordings of the relevant waveforms. For each suspected assassination shot and each test shot, the strip chart recordings were aligned for a best match and a score was obtained by calculating the correlation coefficient. The correlation coefficient was defined as the number of impulses (large peaks) in the wave form of the suspected shot that came within 6 milliseconds of an impulse in the test shot, divided by the geometric mean of the numbers of impulses available in the suspected shot and in the test shot. This correlation procedure does not make use of all the information available (impulses that barely resemble each other affect the score as much as impulses that match each other well), but it permits relatively easy computation of similarity. Only candidate shots that gave a binary correlation greater than 0.6 were studied further. Fifteen pairs, involving only six sets of impulses on the channel I recording, survived this screening.

For each surviving pair, the location of the microphone that recorded the test shot should approximate the location of the motorcycle at the time the suspected assassination shot was fired. This time, in a relative sense, could be determined by the location of the suspected impulses along the length of the tape. In a plot of microphone position against suspected shot time, a sequence of actual assassination shots should lie along a line that describes the movement of the motorcycle during the interval of the assassination shots. Unrelated impulses (false alarms) could lie on this trajectory or elsewhere, depending to some degree on chance. Most of the pairs could be identified as false alarms in this way. The remaining pairs were judged, by the closeness of the trajectory fit, to contain at least two assassination shots and at least some false alarms. Based on an interpretation of photographic evidence, the hypothesized motorcycle trajectory was subsequently claimed to be consistent with that of the motorcycle driven by Officer H. B. McLain in the Kennedy motorcade.

Of the six sets of impulses that give high binary correlation coefficients with test shots, BRSW selected four as likely assassination shots. One of these four, the third, was judged to have been fired from the grassy knoll; BRSW stated that the probability that this set of impulses represents a shot from the grassy knoll is 50 percent.

Judging that the principal limitation on their ability to make a more definitive claim was the microphone spacings for the test shots, which led to the $\pm 6$-millisecond window, BRSW suggested that WA be asked to try a theoretical acoustic modeling technique. This procedure was applied only to the hypothetical knoll shot. Several test shots were examined, with a shooter location on the knoll, and prominent echoes were related to Dealey Plaza objects. A theoretical model of sound propagation in Dealey Plaza, incorporating possible variations in shooter position, microphone position and velocity, and air temperature, was used to predict the relative timings of echoes that would be expected in the channel I recording if the segment in question contained the sounds of a gunshot fired from the grassy knoll. In effect, for every choice of shooter position, microphone position, microphone velocity, and air temperature, WA could determine the time of impulses of a hypothetical test shot; using the binary correlation measure, they could correlate these impulses with the channel I segment identified by BRSW as a possible knoll shot—with the significant difference that matching pulses were required to be within 1 millisecond rather than 6 milliseconds. WA did not try all possibilities, but used the results of each trial to guide a search until they found a shooter position, and so on, for which the greatest number of predicted impulses in the theoretically reconstructed test shot agreed with actual impulses on the channel I tape. The best agreement was found for a part of channel I that is 0.2 second earlier than that suggested by BRSW. On seeing the WA results, the BRSW investigators agreed that the WA identification should be used.

## Evaluation of the BRSW and WA Methodologies and Conclusions

A reliable analysis of the channel I recording presents serious difficulties. The noise level is high, there is conflicting evidence about the location of the open microphone, some of the background sounds are difficult to interpret, the absence of certain expected background sounds is difficult to understand, and the transmitting and recording systems distorted the acoustic signals. As pointed out by WA, to the ear the sounds resemble static much more than they do gunshots, and it is only the poor fidelity of the radio dispatching system that might permit the latter interpretation. Such static-like sounds could be generated by a number of other acoustic, electrical, or mechanical sources in the environment and in the radio transmission, receiving, and recording equipment. Tests and analyses more discerning than the human ear are required to determine the probable cause of the sound impulses. The WA analysis is ingenious but it is novel in some aspects, and both the BRSW and the WA echo techniques for gunshot location had not been applied previously by either group to a situation with as high a level of noise and distortion as this one.

Further, the BRSW and WA studies were seriously limited by funds and fixed deadlines. A number of essential tests to confirm the analysis procedure and the interpretations were omitted. The WA studies, for example, were limited to the single conjectured grassy knoll shot. The results of such an analysis should not be considered reliable until the method has been adequately tested on some other cases. In particular, the impulses conjectured to be sounds of gunshots from the Texas School Book Depository should have been analyzed by the same method. Not only would this have provided a control on the method, it would also have provided a much stronger indication of whether the open microphone was or was not in Dealey Plaza at the correct time. Similarly, more of the test shots should have been analyzed to compare the observed echo patterns with those predicted from structures identified in the echo patterns with a different neighboring microphone location.

The original BRSW report claimed a 50 percent probability that there was an additional shot from the grassy knoll. This claim was used as a justification for the more detailed studies of WA. The result of WA's analytic echo prediction technique in the subsequent analysis of BRSW's conjectured shot would appear to improve the credibility of the grassy knoll hypothesis. However, the committee noted that the identification of shots and impulses by BRSW was completely different from that by WA, as demonstrated by the more than 200-millisecond (more than 200-foot) displacement between the two identifications. Barger pointed out that the two different identifications may be reconciled by assuming that the BRSW echo pattern had been subject to reflection from one additional wall. Even with this interpretation there remains a serious flaw, namely that the BRSW analysis missed the identification that WA considered to be the primary one.

The impulses selected for the BRSW study were not always the largest ones. Frequently, large impulses were omitted and some impulses close to the noise level were retained. Far more impulses do not fall into the BRSW classification of "probable sounds of gunfire" than do. Since the results of correlation coefficient calculations are highly dependent on the impulse and echo selection process, it is especially critical that the scheme used to distinguish these sounds stand up to close scrutiny, with the process used being spelled out in detail so that others can duplicate the analysis. From the published reports, it is impossible to do so. Furthermore, weak spikes on the Dictabelt often are selected to correspond to strong patterns in the test patterns, and vice versa.

The conclusions of the BRSW analysis were supported by some later interpretations of photographic evidence as being consistent with a motorcycle in the procession at approximately the position indicated by their analysis. However, it is not certain that this was the motorcycle with the open microphone, that its radio was improperly tuned to channel I, that the open microphone was in Dealey Plaza, or that the relative times of the four sets of impulses studied by BRSW and WA were consistent with the three known actual shots. There is evidence to the contrary on all four of these points that should not be ignored.

No siren sounds are heard on channel I at a time when they should have been heard by an open microphone in the motorcade; sirens are not heard for approximately 2 minutes after the impulses attributed by BRSW and WA to assassination shots, after which clear and unambiguous sounds from a group of sirens occur on channel I. The sirens seem to come from a group of at least three vehicles and the intensity of the sound first increases and then decreases. This is consistent with sirens heard at a stationary point if the presidential motorcade had passed close by. It is not the siren sound expected if a motorcycle with a stuck button was part of the motorcade. In the first quarter-mile of the trip to the hospital the presidential motorcade encountered a complex pattern of underpasses, roads, and ramps, but there is no trace of a siren sound in channel I during this interval of time. This initial long absence of siren sounds, followed by the sounds of several sirens passing by, suggests that the radio transmitter with the stuck button was not part of the presidential motorcade, but may have been on a parked motorcycle. James Bowles, police communications supervisor at the time of the assassination, suggests that it was on a motorcycle parked at the police command post near the Trade Mart, where it would be natural to have adjacent police radios tuned to different channels.

The BRSW report concludes: "The probability of obtaining just one match by chance in any of 180 independent tries is equal to $5.3 \times 10^{-2}$, or about 5%. Therefore, the probability that they obtained their match because the two matched patterns were due to the same source (gunfire from the knoll) is about 95%." The WA report concludes with a similar statement. Such statements do not allow for the existence of hypotheses alternative to the two primarily considered (the hypothesis of gunshots and the hypothesis of impulses randomly located according to a Poisson distribution in relevant sections of the Dictabelt). Various reasonable alternative hypotheses include nonwhite (non-Poisson) noise or other typical noise and static distributions which are ordinarily lumped together in time and therefore may give a higher correlation with the nonrandom distributions of test shot echoes. Furthermore, even if the only alternative to impulses from a gunshot were the hypothesis of randomly located impulses, a single observed result whose $P$ value under the random location hypothesis is 5 percent does not imply a 95 percent probability that there was gunfire from the knoll (the $P$ value or significance level in current statistical theory is the probability, assuming the hypothesis to be true, of observing data as or more extreme than what actually is observed). The situation is analogous to that in a card game where the probability of the dealer receiving three aces is $P = .44$, but three aces going to the dealer on the first deal does not by itself indicate a 95.6 percent probability that the dealer is dishonest if there is no prior reason for suspecting him of cheating (*2*, p. 38).

In addition, the BRSW-WA calculation of the $P$ value for the hypothesis of random pulse location is incorrect. There are several errors, of which the most serious is the failure to allow in the probability calculations for the fact that the location of the shooter in the WA analysis was adjusted to maximize the number of coincidences. With these corrections and a conservative adjustment, a $P$ value as high as .223 can be obtained for the hypothesis of random location; this is much less impressive than the BRSW-WA value of .05 (*2*, p. 35). Furthermore, even if it were granted that the hypothesis of randomly located impulses on relevant portions of the tape were in serious doubt, it would not follow that the alternative of gunfire from the grassy knoll was convincing. All plausible alternatives to both of these hypotheses would have to be eliminated, and no convincing effort has been made in this direction.

After this study of the BRSW and WA reports, no member of the committee was convinced by the arguments given that there was a grassy knoll shot. The members of the committee reached their initial negative conclusion prior to the availability of the event timings and the sound spectrograms discussed below.

## Timing Evidence from Matching Features

A private citizen, Steve Barber of Mansfield, Ohio, wrote to the committee that he was convinced from his own listening that there are clear instances in which phrases recorded on channel II tape were distinctly audible on the channel I tape as well. This is naturally explained by assuming that the motorcycle with the open microphone (channel I) was near another police radio receiving a transmission from channel II, so that transmissions over channel II would be picked up by the open microphone and rebroadcast on channel I. In addition, there are simultaneous broadcasts by the dispatcher on channels I and II. Both kinds of cross talk are perfectly clear in many cases and would allow precise time synchronizations between specific portions of the two recordings. The time synchronizations would not apply to the recordings in their entirety, because channel I ran continuously during the period of interest while channel II was sound-activated and operated intermittently.

Four such matching sections on the two tapes are quite clear, but they occur several minutes after the assassination and involve various police communications connected with the follow-up to the shooting. (They also provide a clear demonstration of channel I heterodynes suppressing the recording onto channel I of cross talk from channel II; we later show that this suppression also occurs in the interval containing the impulses and shows that the cross talk was recorded through a radio receiver.) Two events are especially important for fixing the time of the section of tape analyzed by BRSW and WA. The first is a 4-second fragment of speech that overlaps the conjectured third and fourth BRSW shots on channel I. Barber there identifies a phrase, which he says begins with the words "hold everthing," as identical to the phrase "hold everything secure until the homicide and other investigators can get there," clearly recorded on channel II. The significance of this proposed match is that the section on channel I is concurrent with the last two of the conjectured BRSW shots, whereas on channel II it is part of a clear sequence of emergency communications that followed the shooting and occurred approximately 1 minute after the assassi-

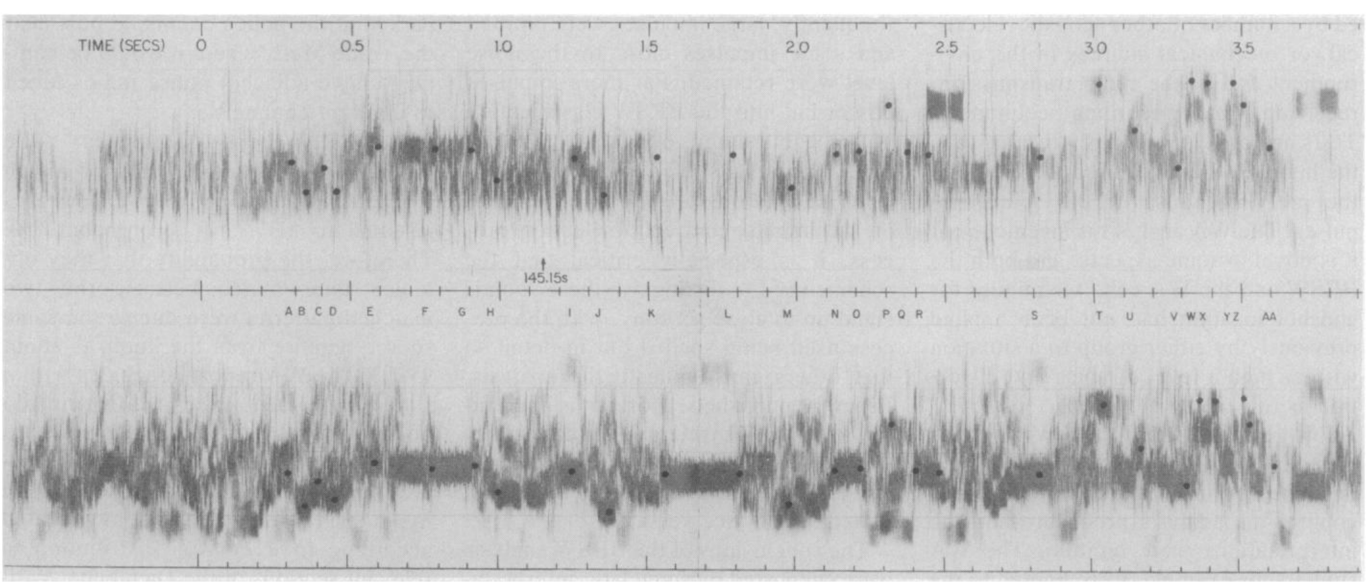


Fig. 1. Composite photograph of sound spectrograms on channel I (top) and channel II (bottom). The audible "hold everything" phrase begins at approximately zero on both channels, but there is no special significance to the exact location of zero time on either channel. The impulses initially identified by BRSW as arising from their conjectured grassy knoll shot occur above the arrow marked 145.15s, and those identified by WA occur 0.2 second earlier; the proper location for this arrow was determined by comparing this sound spectrogram with that of figure 5 in the BRSW report. The letters and black dots designate corresponding characteristic features. For reasons discussed in (*2*, p. 41), one recording was speeded up by 6.7 percent.

nation. It is, in fact, part of Sheriff Decker's instructions to his men in response to the assassination. This time synchronization, if correct, would prove that the BRSW-WA conjectured shots were unrelated to the sounds of the assassination gunshots. The section of channel I recording with the BRSW-WA conjectured shots would then correspond to a period of time well after the assassination.

The second important event is the transmission "You want me . . . Stemmons," which occurs several minutes after the assassination and is intelligible on both channels. It provides a common reference point for timing events on the two channels. We used it to determine whether the section of the recording containing the conjectured shots occurred before or after Chief Curry instructed the motorcade to "Go to the hospital."

## Sound Spectrograms

Initially, the poor quality of the "hold everything" portion of the recording made it appear unlikely that a convincing interpretation of the badly garbled speech on channel I could be made, and the committee was aware that a listener to a garbled message will often be convinced that he has heard what he has been coached to hear.

For these reasons, arrangements were made for members of the committee to use the excellent sound analysis equipment of the Federal Bureau of Investigation's Technical Services Division to obtain sound spectrograms ("voiceprints") of the relevant communications on channels I and II. The spectrograms were prepared under the supervision of committee members. The sound spectrograms first reproduced were from tape recordings provided by the Dallas police, but a sound spectrogram with a similar pattern for the "hold everything" phrase on channel I was also made from a tape supplied by James Barger, essentially identical to that used in the BRSW analysis; later sound spectrograms were also made from new high-quality magnetic tape copies of the original channel I Dictabelt and channel II Audograph disk. A sound spectrogram is a plot with elapsed time along the horizontal axis, frequency along the vertical axis, and the darkness of a trace representing the intensity at the frequency of the trace.

We then made spectrograms of the "hold everything" sections. Figure 1 is a photograph of composite sound spectrograms for the full 4-second message. The beginning of the "hold everything" phrase is approximately at zero on the time scales. The impulses for the conjectured grassy knoll shot begin approximately at the arrow marked 145.15s (the time of the conjectured grassy knoll shot on the BRSW time scale) and the WA impulses occur 0.2 second earlier. The black dots mark 27 corresponding features on the two channels.

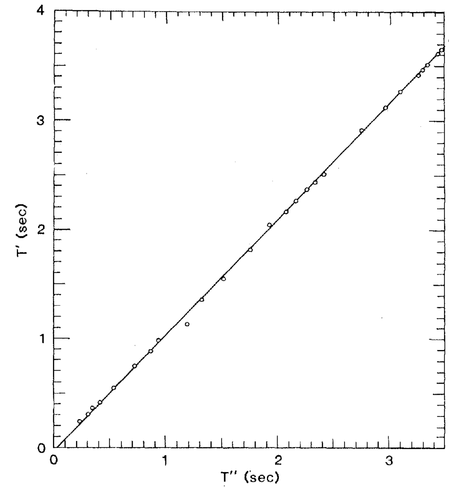


Fig. 2. Plot of $T'$ against $T''$ for corresponding characteristics. The linearity of the curve demonstrates the validity of the identification. The straight line is a plot of the equation $T' = -0.0216 + 1.0593\,T''$, which in turn is a robust linear regression fit to the plotted points. The analysis leading to this figure is given in (2, p. 41). The point furthest off the line is at $T'' = 1.195$ seconds and is for the incorrectly identified characteristic I, as discussed in (2).

It is apparent from Fig. 1 that there is a correlation between parts of the sound spectrograms of the two channels, even though the channel I recording has much more noise. The correlation is much more impressive when the spectrograms of the two channels are compared in detail. It is particularly striking when one realizes that only the initial second of the "hold everything" phrase can be heard clearly on channel I, yet the sound spectrograms contain numerous matching features for the entire 3.5-second sequence (note, for example, the match in the final segment from 3.2 to 3.6 seconds). In all cases of matching features, the text of the messages and the signal intensities show that a signal from channel II was duplicated on channel I and not the reverse.

The sound spectrograms present much more convincing evidence in this case than in their application to speaker identification. In the latter case, words spoken at different times, supposedly by the same speaker, are compared, and a trained interpreter is often required to explain why the subjective match is significant. In the present case, the need is to identify two identical messages extending over a 3.5-second interval. Not only must individual parts of the two sound spectra be alike, but they must occur at exactly correct time intervals and with exactly matching frequencies. The existence of these required time and frequency correlations between the two channels imposes rigid constraints on the messages to be matched. Furthermore, all sounds that appear on both channels are useful in correlating the channels, even though some are not spoken words. For example, in listening to channel II it is apparent that there is an intermittent tone that contributes to the flat portions common to channels I and II. However, this tone varies in both amplitude and frequency and is also useful in correlating the two channels.

## Analysis of Sound Spectrograms of "Hold Everything"

The committee used three methods in addition to visual inspection to determine whether the sound spectrograms of channels I and II contained signals from the same source (2, p. 41). In the first method we identified characteristic features that were present on both spectrograms and then determined the relation between the times of occurrence of the two sets of features. Twenty-seven features were selected (2, p. 43). The existence of correlations between the two spectrograms over a long time interval can be demonstrated by plotting T′, the time coordinate of the channel I spectrogram, as a function of T″, the time coordinate of the corresponding characteristic on channel II. The results are shown in Fig. 2. The linearity of the plot shows that the similar characteristics of the sound spectrograms of the two channels follow the same time sequence, as they must for one to be cross talk from the other. A linear fit to the recorded points gives the equation in Fig. 2; the slope of the line or ratio of recording speeds is $1.059 \pm 0.002$, which corresponds to a $5.9 \pm 0.2$ percent net difference in the recording speed. The ratio of recording speeds independently inferred from the measured frequency ratios of the same points is $1.064 \pm 0.006$. The probability of obtaining such close agreement by random occurrence of the features at their observed average spacing would be about $2.1 \times 10^{-13}$, and the probability of randomly obtaining such good agreement on the frequency ratio of the points is about $2 \times 10^{-10}$.

The second method is the calculation of the effective relative speeds from the frequency ratios for five sections with particularly well-defined frequencies on the two channels. Such a calculation gives a ratio of recorder speeds of 1.062 ± 0.005 in excellent agreement with the value in the preceding paragraph.

To help in the visual recognition of similarities of the two patterns, sound spectrograms have been made with the speed of channel I effectively changed by 6.7 percent. The results are shown in Fig. 1. Both frequencies and times of the two channels now appear to be compatible.

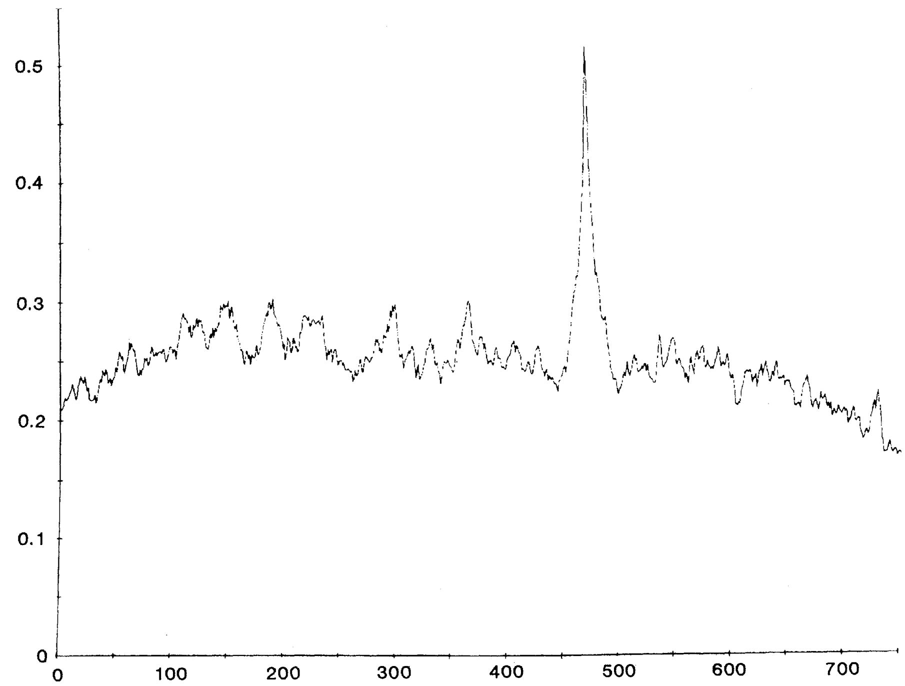


Fig. 3. Cross correlation between "hold everything" segments of channel I and channel II sound spectrograms with time scale slightly compressed to produce the best correlation peak. The curve is produced by sliding 2.50 seconds of channel I along 10.00 seconds of channel II, 0.01 second at a time, using frequencies in the band 600 to 3500 hertz.

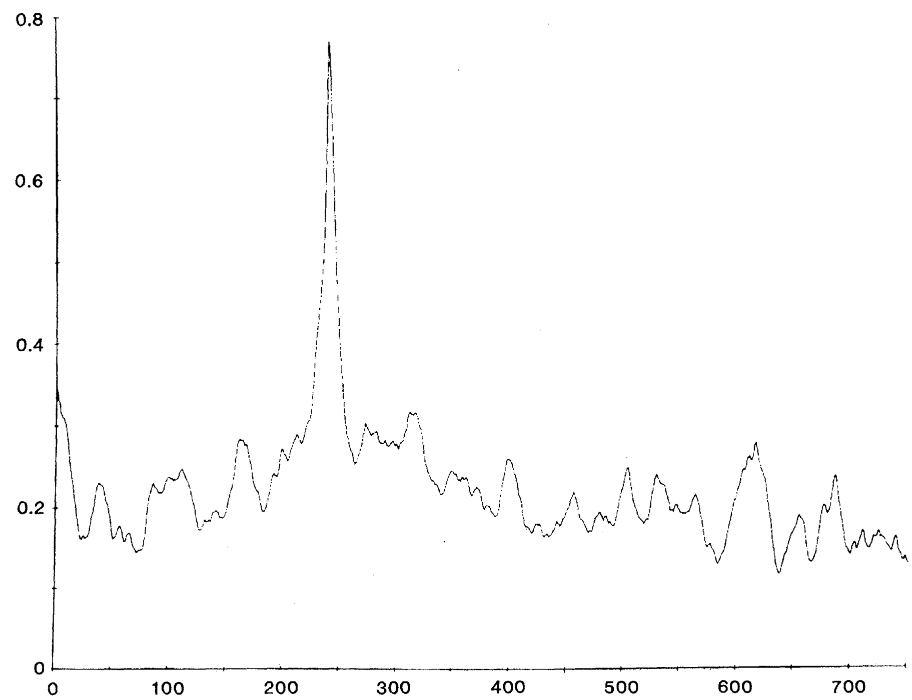


Fig. 4. Cross correlation between "You want me . . . Stemmons" segments of channel I and channel II sound spectrograms with time scale slightly compressed to produce the best correlation peak. The curve is produced by sliding 2.50 seconds of channel I along 10.00 seconds of channel II, 0.01 second at a time.

In the third approach, the channel I and channel II recordings were digitized and the short-term acoustic spectra were taken and stored in a digital computer. The printouts of these spectra are similar to Fig. 1. These digital spectrograms were computed directly from magnetic tapes and did not involve use of the FBI sound spectrogram equipment. Many of the features observable in the analog spectrograms can be seen in the digitized spectra, but no use was actually made of the spectrogram patterns. Instead, the actual data were used to test certain hypotheses, without human intervention. An objective measure of similarity of two spectral matches is obtained from the cross-correlation coefficient (*2*, p. 57), which would be reduced if one of the recordings were played at the wrong speed, or if the recording at one time were compared with the same or a different recording at a different time.

The first cross-correlation coefficients were made from the channel I and channel II recorded copies that were used in preparing Fig. 1. It was found that the biggest peak for the cross-correlation coefficient occurred for a relative warp (speed ratio) of 1.06, in agreement with the values estimated by the other two manual approaches; a 1 percent deviation of warp from optimum diminished the peak substantially. However, that channel II copy contains many repeats caused by the Gray Audograph machine in playback. Accordingly, another tape copy was prepared by members of the committee directly from the original Audograph plastic disk and by use of a standard turntable and tone arm, without compensation for the fact that the disk was originally recorded at constant linear track speed. Figure 3 shows the cross-correlation coefficient for the "hold everything" segments when the relative speed was selected to give the largest peak and the 750 correlation coefficients were obtained by sliding 2.50 seconds of channel I along 10.00 seconds of channel II, 0.01 second at a time, using frequencies in the band 600 to 3500 hertz. For comparison, the cross-correlation coefficients of the unambiguous segment "You want me . . . Stemmons" are plotted in Fig. 4. The shape of the peak is very similar to that for the "hold everything" segment. The background is somewhat smoother because there is less noise in channel I at this time. Channel I, however, in neither case gives a perfect reproduction of channel II. It has lost some of the high and low frequencies, and as one would expect there are tones present on channel I that are not on channel II.

The narrow peaks of the cross-correlation curves show by an objective test that the "hold everything" segment of channel II is present on channel I at the same location as the acoustic impulses. There is no doubt that the voice (and other) sounds of channel II are present on channel I to an accuracy in location corresponding to a few milliseconds.

We consider three sets of results to constitute overwhelming evidence that the "hold everything" sections of the two recordings are traceable back to a single acoustic signal from channel II. If there is no overrecording on channel I (as we show below), the correspondence between these two recordings of "hold everything" would be conclusive evidence that the events analyzed by BRSW and WA were not the assassination shots, since we know from channel II that the "hold everything" transmission was made at least 50 seconds after the chief instructed the motorcade to "Go to the hospital."

**Possibility of Superposed Recordings**

The committee considered seriously the possibility that the impulses analyzed by BRSW and WA were overlaid at a later time by the "hold everything" message. Such an overrecording could have occurred if the Dictabelt or the recording head was knocked backward by about 1 minute in the first minute after the assassination, or if a new Dictabelt copy, made by audio coupling while a channel II recording was playing in the background, was substituted for the original. The committee concluded that this was not the case on the basis of (i) physical examination of the Dictabelt for indications of overrecording or of substitution of a copy for the original; (ii) the unlikely nature of any of the highly contrived scenarios required to provide such an undetectable overrecording either accidentally or deliberately, (iii) the compatibility of the timing implied by the "hold everything" identification with other firmly established evidence, and (iv) the conclusive acoustic evidence on the Dictabelt itself that the cross talk recordings were made through a radio receiver with automatic gain control (AGC). These different forms of evidence are all compatible with the recordings being made at the same time, and some are incompatible with the hypothesis of later superposed recordings by audio or direct electrical coupling. Only the evidence of category (iv) will be reviewed here.

The digital analyses of the sound spectra can be used to demonstrate that the channel II imprint on the channel I recording was already present at the channel I receiver and was not added later in the recorder or as an overrecording. The by-radio nature of channel II cross talk is demonstrated by its detailed behavior in the presence of channel I heterodynes when another channel I transmitter is keyed on with a more powerful carrier signal. The frequency offset between the two carriers gives rise to a heterodyne tone in the channel I recording. However, the channel I receiver was fitted AGC to hold the output level aproximately constant; as a result, the cross talk signals decrease in intensity in a few tens of milliseconds (as does any residual transmission from the original open microphone). At the end of the channel I heterodyne, the AGC gradually increases the receiver gain, and signals on the open-microphone transmission increase in intensity in the recording. An excellent probing signal for the channel I gain would be a channel II steady tone acoustically coupled from the field loudspeaker to the open-microphone transmitter. This would come in at a constant level, and the variation in level on the channel I recorder should mimic the AGC action if the channel II signals were present in this way. Inspection of the digital spectrogram (and digital tabulations of the data) shows that numerous channel II brief tones have a constant level from beginning to end. A crucial demonstration is provided by the channel I heterodyne beginning at time 32.02 seconds in one of the spectrograms. The underlying channel II brief tone is substantially reduced in intensity at the beginning of the channel I heterodyne and gradually grows back when the channel II brief tone results after the channel I heterodyne ceases [figures B-7 and B-8 in (*2*)]. This behavior is validated by similar channel II brief tones underlying channel I heterodyne signals in the "You want me . . . Stemmons" phrase and in a phrase "I'll check" that is also present on both channels.

**Conclusions**

For the reasons discussed above and in its formal report (*2*), the committee on Ballistic Acoustics unanimously concluded that the acoustic impulses attributed to gunshots were recorded about 1 minute after the President had been shot and the motorcade had been instructed to go to the hospital, and that reliable acoustic data do not support a conclusion that there was a second gunman.

The committee's charter asked it to recommend the tests, analyses, and evaluations needed to obtain better information from the recordings. If there were to be further studies of the channel I recording in the hope of demonstrating the validity of the conjectured shot from the grassy knoll, the information listed in the committee's report (*2*, p. 92) should be sought. However, the evidence against the conjectured grassy knoll assassination shot is already so strong that we believe the results to be expected from such studies would not justify their cost.

**References and Notes**


1. *Appendix to Hearings Before the Select Committee on Assassinations of the House of Representatives Ninety-Fifth Congress* (Government Printing Office, Washington, D.C., 1979), vol. 8.
2. Commission on Physical Sciences, Mathematics, and Resources, National Research Council, *Report of the Committee on Ballistic Acoustics* (National Academy Press, Washington, D.C., 1982).