ATTACHMENT 3

Reprint of a scientific article on speech analysis in an American accident investigation (6 pages)

TECHNICAL NOTE

Speech Analysis as An Index of Alcohol Intoxication—The Exxon Valdez Accident

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As part of its investigation of the EXXON VALDEZ tankship accident and oil spill, the National Transportation Safety Board (NTSB) examined the master's speech for alcohol-related effects. Recorded speech samples were obtained from marine radio communications tapes. The samples were tested for four effects associated with alcohol consumption in available scientific literature: slowed speech, speech errors, misarticulation of difficult sounds ("slurring"), and audible changes in speech quality. It was found that speech immediately before and after the accident displayed large changes of the sort associated with alcohol consumption. These changes were not readily explained by fatigue, psychological stress, drug effects, or medical problems. Speech analysis appears to be a useful technique to provide secondary evidence of alcohol impairment.

SHORTLY AFTER MIDNIGHT, on March 24, 1989, the U.S. tankship EXXON VALDEZ grounded on Bligh Reef in Prince William Sound, near Valdez, AK. About 258,000 barrels of crude oil spilled when 8 cargo tanks ruptured, resulting in catastrophic damage to the environment.

The National Transportation Safety Board (NTSB), an independent agency of the United States government, conducted an official investigation to determine the cause of the accident and to make recommendations to prevent a recurrence (7). The Safety Board concluded that the accident reflected the following problems: "the failure of the third mate to properly maneuver the vessel because of fatigue and excessive workload; the failure of the master to provide a proper navigation watch because of impairment from alcohol; the failure of Exxon Shipping Company to provide a fit master and a rested and sufficient crew for the EXXON VALDEZ; the lack of an effective Vessel Traffic Service because of inadequate equipment and manning levels, inadequate personnel training, and deficient management oversight; and the lack of effective pilotage services."

The present paper focuses on one of these factors, the relation of alcohol to the behavior of the master. It summarizes a technical speech analysis completed by the Safety Board to supplement toxicological and eyewitness information concerning the master's condition. In the case of the EXXON VALDEZ accident, samples for toxicology testing were not obtained by the Coast Guard until about 10.5 h after the accident. Samples from the master tested positive for alcohol at levels of 0.06% in blood and 0.09% in urine. Eyewitness information indicated the master drank alcohol on the evening of March 23, and indicated the master may have smelled of alcohol during time periods before and after the accident. However, eyewitnesses stated unanimously that the master did not appear impaired. Against this mixed background, it was anticipated that speech information might provide a secondary source of evidence concerning the master's physical condition at or near the time of the accident.

Speech examination has long been recognized by the law enforcement community as a source of information on drug use. For example, the Department of Transportation recently developed a Drug Evaluation and Classification Program (6) which trains officers to recognize many characteristics of speech that may be produced by alcohol/drug impairment. These include "thick, slurred speech," "difficulty in speech," "repetitive speech," "low, raspy speech," and "slow, mumbled, and incoherent" speech. Recent scientific papers have reported measurable changes in speech associated with alcohol consumption (4,5,9,10,12–14). In its work, the Safety Board reviewed this literature and solicited assistance from expert consultants active at developing the scientific literature: Mark B. Sobell and Linda C. Sobell, of the Addiction Research Foundation, Toronto,

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Canada; and Keith Johnson, David B. Pisoni, and Robert H. Bernacki, of the Speech Research Laboratory, Indiana University, Bloomington, IN.

Description of the Available Recordings

All the recorded statements selected for analysis were excerpted from radio transmissions from the bridge of the EXXON VALDEZ. The radio microphone on the EXXON VALDEZ was contained in a hand-held telephone style transmitter and employed standard FM radio transmission. Transmissions were relayed by microwave links, via towers in the vicinity, to the U.S. Coast Guard Vessel Traffic Center (VTC) facility at Valdez where they were recorded on a multi-channel tape recorder operated continuously at the facility (Magnasync Model 2-R/P-30). Speech intelligibility of the recordings was very good.

The master and three officers of the EXXON VALDEZ were authorized to make radio transmissions from the bridge, and 42 statements by the master were readily identified. The master made these statements during the five periods noted below; each has implications for issues of alcohol consumption:

(1) *Thirty-three hours before the accident.* These statements were recorded about 1500 on March 22 as the EXXON VALDEZ was inbound to Valdez after several days at sea. The master's alcohol level was not determined, but there was no eyewitness evidence of alcohol use.

(2) *One hour (about 45 minutes) before the accident.* These statements were recorded from 2324.50 to 2330.54 on March 23 during the outbound passage. Eyewitness evidence indicated alcohol consumption by the master in town prior to departure of the vessel about 2115.

(3) *Immediately after the accident.* These statements were recorded from 0026.41 to 0038.47 on March 24 and include the initial report of the accident.

(4) *One hour after the accident.* These statements were recorded from 0107.29 to 0131.36.

(5) *Nine hours after the accident.* These statements were recorded from 0912.00 to 0938.19 on the morning following the accident while the master discussed salvage of the cargo. U.S. Coast Guard personnel boarded the vessel about 0335, and remained in frequent contact with the master until a blood sample was obtained for toxicology testing at about 1050.

A composite recording of all statements made by the master was used in evaluations by Safety Board staff members and by the expert consultants.

Evidence of Effects Produced by Alcohol

Alcohol is associated in the scientific literature with four effects on speech: (a) slowed speech; (b) speech errors; (c) misarticulation of difficult sounds; and (d) changes in vocal quality. These four effects were evaluated in the master's speech and are summarized as follows:

(a) *Slowed Speech:* Several scientific experiments indicate that speaking rate slows in response to alcohol (5,9,10,12,13). Fig. 1 summarizes speaking rate evidence from two experiments with relatively large numbers of subjects and data points. In the first experiment, 16 male volunteers who had a history of alcoholism participated (12). The subjects read an identical prose passage aloud on three separate occasions: once while they were sober, once after drinking a medium level of alcohol (estimated blood alcohol concentration (BAC) = 0.10 percent), and once after drinking a high level of alcohol (estimated BAC = 0.25 percent). In the second experiment 16 male college students who had no history of heavy alcohol use took part (13). These subjects also read an identical prose passage while under the effect of three levels of alcohol consumption. Fig. 1 summarizes the degree of speech slowing found for each group in response to different levels of alcohol.

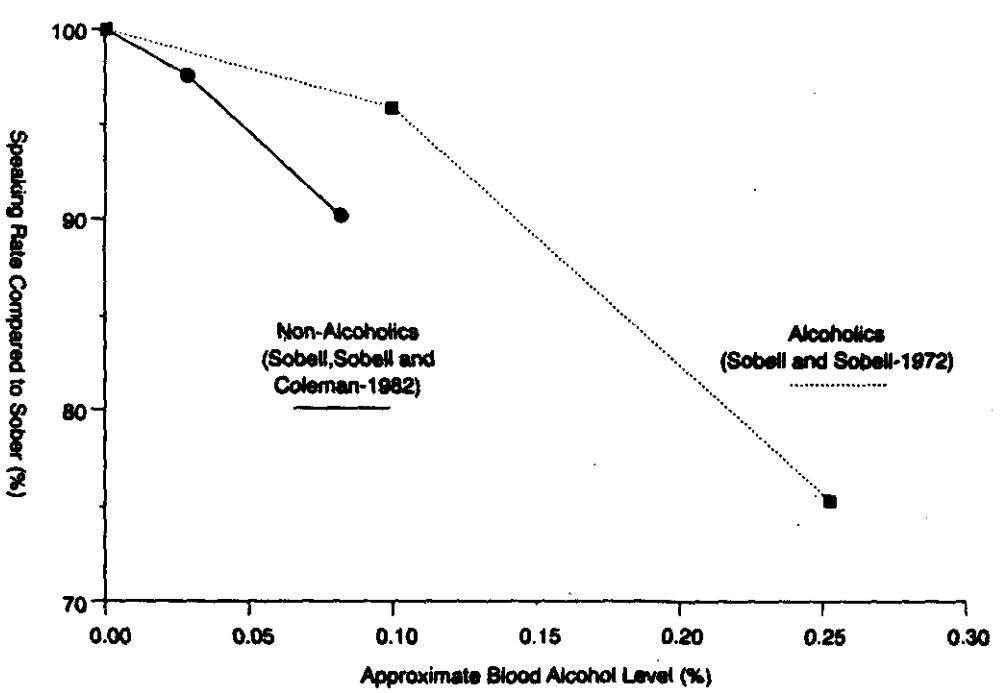

Fig. 1. Speaking rate changes with blood alcohol level.

Measurements of speaking rate, completed at the Safety Board's audio laboratory, were made on all 36 extended statements by the master. Using a high-capacity host computer (Digital Equipment Corporation MICROVAX II), the composite tape was recorded digitally at a rate of 16 kilohertz (using a Data Translation Board, Model DT1771). Statements were played back and examined visually and aurally using a color graphics workstation to display the waveform (Tektronix 4107A workstation) and professional headphones and speakers to listen to the selection being played. When the exact start and stop times of a desired statement were captured, these times were recorded and provided a precise measurement of segment duration. The software for the system was written primarily in Fortran with several routines using VAX assembly language.

Table I is a mathematical table that summarizes the speaking rate measures obtained. Fig. 2, based on the data of Table I, is a graph that summarizes the master's average speaking rate during each of the five time periods. An analysis-of-variance test confirmed the statistical significance of the differences observed at the five time periods ($F(4/31) = 9.0$, $p < 0.001$). Contrast tests confirmed that the master's speech 1 h before the accident was significantly slower than his speech 9 h after the accident ($F(1/31) = 15.6$) and that it was significantly slower than his speech 33 h before the accident ($F(1/31) = 21.0$).

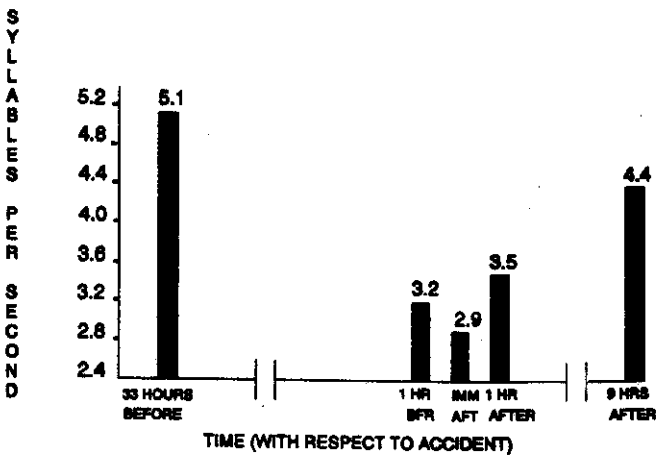

Fig. 2. Average speaking rate of the EXXON VALDEZ master in statements made during five time periods close to the accident.

Researchers at the Indiana University Speech Research Laboratory completed measurements of speaking rates for the phrase "EXXON VALDEZ" spoken by the master during each time period (3). This phrase should be well rehearsed, and provide a measure of the

TABLE I. SUMMARY OF SPEAKING RATE MEASURES FOR 36 STATEMENTS THAT PROVIDED SUFFICIENT DATA FOR ANALYSIS (7 OR MORE SPOKEN SYLLABLES).

Statement Number	Number of Syllables Analyzed	Measured Duration (s)	Speaking Rate (syllables/s)	Hours with respect to accident
1.	12	2.18	5.5	−33
2.	88	19.28	4.6	−33
3.	11	3.79	2.9	−1
4.	42	16.20	2.6	−1
5.	50	16.16	3.1	−1
6.	48	15.24	3.1	−1
7.	16	4.18	3.8	−1
8.	17	4.35	3.9	−1
9.	78	24.20	3.2	−1
10.	11	3.50	3.1	−1
11.	66	35.43	1.9	0
13.	16	3.83	4.2	0
14.	7	1.67	4.2	0
15.	25	10.36	2.4	0
16.	7	2.56	2.7	0
17.	18	9.54	1.9	0
18.	7	1.94	3.6	+1
19.	58	19.54	3.0	+1
20.	68	17.49	3.9	+1
21.	65	20.34	3.2	+1
23.	15	5.83	2.6	+1
24.	16	4.11	3.9	+1
25.	33	9.06	3.6	+1
26.	15	3.37	4.5	+1
27.	94	22.10	4.3	+9
28.	50	14.05	3.6	+9
29.	39	7.61	5.1	+9
30.	28	6.08	4.6	+9
33.	9	1.86	4.8	+9
34.	21	4.97	4.2	+9
35.	38	10.91	3.5	+9
36.	52	11.73	4.4	+9
37.	48	12.56	3.8	+9
40.	13	2.88	4.5	+9
41.	13	2.81	4.6	+9
42.	7	1.33	5.3	+9

master's speaking rate with a minimum of thinking or hesitation difficulties. The results were as follows: at −33 h, the master required 706 ms to say the phrase; at −1 h, 934 ms; immediately after the accident, 1087 ms; at +1 h, 980 ms; at +9 h, 883 ms.

The largest change in speaking rate shown in Fig. 1 is for alcoholics who have consumed a large amount of alcohol; their rate of speech is only about 75% as fast as it is when they are sober. By comparison, the master of the EXXON VALDEZ showed a similar change between his speech at 33 h before the accident and 1 h before the accident. For the phrase "EXXON VALDEZ," his speaking rate was 76% as fast; for overall speech, his rate was 64% as fast. The slowing of speech by the master is consistent with alcohol impairment demonstrated by test subjects after drinking a high level of alcohol.

For purposes of comparison, speaking rate measurements were completed on 45 statements by speakers other than the master. The average observed speaking rates were as follows: chief mate, 4.4 syllables per second; second mate, 5.8; pilot, 5.7; VTC watchstander who conversed with the master 1 h before the accident, 6.5. The master, during the period before and after the accident, spoke slower than any other speaker tested.

(b) *Speech Errors:* Speech errors occur as a normal part of speech, but scientific literature indicates that errors tend to increase with alcohol consumption (12). Many speech errors have been demonstrated when a speaker under the influence of alcohol simply reads aloud a prepared text. These include omitting words in the text, misreading words, interjecting extraneous statements, and reading words incorrectly but correcting oneself aloud before completing the text.

Speech errors are more difficult to recognize in conversational speech because there is no prepared text with which to confirm the speaker's intention. However, about 1 h before the accident, four obvious speech errors of the sort associated with the influence of alcohol appeared in the master's speech:

- Statement 3. "EXXON BA ah VALDEZ"
- Statement 4. "We've ah departed the pilot or disembarked the pilot. Excuse me."
- Statement 5. "by our radar, I we'll probably"
- Statement 9. "ice out of Columbia Gla . . . Bay"

(c) *Misarticulation of Difficult Sounds:* Scientific literature indicates that people under the influence of alcohol tend to mispronounce certain sounds. This effect probably forms the basis for what is described as "slurring of speech."

Based on laboratory evidence, researchers at the Indiana University Speech Research Laboratory have described sounds that are especially subject to misarticulation due to alcohol (9,10). They indicate that the speech sounds most affected tend to be those which require fine sensory-motor control and timing.

For the present analysis, members of the Indiana University Laboratory examined the master's speech for similar evidence of misarticulation (3). The examination involved detailed phonetic transcription plus power spectra displays of individual sounds. Examples of misarticulation observed included the following:

- misarticulation of "r" and "l", demonstrated by the master in words such as "northerly," "little," "drizzle," and "visibility";
- changing the sound "[iz]" to the sound "[is]", demonstrated by the master in his pronunciation of the final sound in "VALDEZ" in certain statements;
- changing the sound "[s]" to the sound "[sh]", demonstrated by the master in his articulation of "EXXON" in the time periods close to the accident. It should be noted that this effect may be especially characteristic of alcohol impairment.

(d) *Vocal Quality Changes:* Researchers from the Addiction Research Foundation indicated that they observed marked changes in vocal quality within the master's speech during the five time periods. They characterized speech from 33 h before the accident as "rapid, fluent, without hesitation, and with few word interjections (i.e., "ah")." They characterized speech immediately before and after the accident as markedly different, with considerable word interjections, broken words, incomplete phrases, corrected errors, and increased speaking time and hesitations. The researchers indicated that the samples "sound so impaired" that "crew members who could also be considered untrained raters, would probably have noticed changes in the person's speech." With regard to content, the master described the accident site inaccurately as "north of Goose Island off Bligh Reef" (instead of on Bligh Reef, more than 8 miles from Goose Island).

The researchers indicated that the master's vocal quality appeared to change again 9 h after the accident, when "the speaker sounds more fluent (more rapid speech, more responsive) and makes fewer word interjections."

Explanations Other Than Alcohol

Scientific literature indicates that factors such as fatigue, psychological stress, drug effects, and medical problems can affect speech (1–3,11). For purposes of speech analysis, information related to these factors was examined for alternate explanations of changes in the master's speech.

(a) *Fatigue:* Information on the master's work/rest schedule was reviewed to evaluate the possibility that fatigue rather than alcohol caused the changes in his speech.

The master's sleep schedule was not determined during the investigation. The master, unlike the mates, was not involved in any watchstanding duties on the night before the accident. Evidence suggests continuous activity by the master from about 1030 on March 23, when he went ashore to meet the ship's agent, until the time of the grounding (with the possible exception of a 1.5-h period during the outbound passage when the captain retired to his quarters). According to the available evidence, including statements from Coast Guard personnel who boarded the vessel, the master remained awake and active all night from the time of the grounding until 1050 on March 24 when he provided toxicology specimens.

For purposes of speech analysis, speech samples ob-

tained 9 h after the accident were examined as exemplars of effects from normal fatigue. As noted above, these samples provided less evidence of speech impairment than did samples obtained before and after the accident.

(b) *Psychological stress:* Psychological stress has been shown to affect speech, and the master was probably subjected to tremendous psychological stress as a result of the accident.

For purposes of speech analysis, speech samples obtained 1 h and 33 h before the accident were examined as exemplars of effects not subject to psychological stress from the accident. As noted above, there was evidence of speech impairment 1 h before the accident.

(c) *Drug effects:* Toxicology tests for all major drugs of abuse were completed on the specimens provided by the master. The blood tested negative for all drugs except alcohol.

(d) *Medical problems:* Medical problems likely to produce speech impairment would be neurological problems such as those related to stroke, trauma, drug use, and mental states. Such problems would normally be associated with symptoms in the master's medical history.

According to the health insurance carrier employed by Exxon shipping, the master did not submit any claims for medical expenses in the year prior to the accident. The master was treated for alcohol problems in 1985. He was arrested on motor vehicle offenses involving alcohol in 1985 and 1988. The latter arrest, in September, 1988, involved a charge of speeding and the master was reported by Breathalyzer test to have a blood alcohol level of 0.19%.

For purposes of speech analysis, alcohol abuse was treated as the only medical problem in the master's history because it was the only medical problem for which there was any evidence.

Analysis

In their report to the Safety Board, consultants from the Addiction Research Foundation indicated that "a constellation of factors suggests that the individual probably had consumed an amount of ethanol sufficient to affect his speech" and that "various selections on the tape definitely sound impaired. The speech characteristics are consistent with those we have observed in highly intoxicated individuals whom we have evaluated in our laboratory."

In their report to the Safety Board, consultants from the Indiana University Speech Research Laboratory indicated that "acoustic-phonetic changes" observed in the master's speech "revealed a number of changes in speech behavior which correlate well with the findings of previous research on the effects of alcohol on speech production."

No single aspect of speech is conclusive in itself, but collectively, several difficulties noted in the master's speech were considered significant. The master displayed slow speech, speech errors, misarticulation characteristic of alcohol, and degraded speech quality in the time period around the accident. Two sets of researchers—from the Addiction Research Foundation and the Indiana University Speech Research Laboratory—concluded independently that the speech changes shown by the master were consistent with those produced by alcohol impairment.

The evidence suggests that speech changes of the sort produced by substantial alcohol consumption occurred just before the accident, and this conclusion is consistent with the extrapolated blood alcohol estimation determined from toxicological results which indicated a high BAC in the master at this time. Explanations based on fatigue, psychological stress, drug effects, and medical problems did not explain the pattern of results observed as readily as did an explanation of alcohol impairment.

This information based on speech analysis may contradict information from eyewitnesses, who reported unanimously that the master did not appear impaired on the evening of the accident. Two considerations seem relevant to the possible contradiction. First, eyewitnesses might have difficulty recognizing impairment because of the master's ability at masking it. The master had a long history of alcohol abuse, including the possible use of alcohol aboard the vessel, and had probably developed a considerable tolerance for alcohol. Individuals with such a history are commonly adept at masking the effects of alcohol on their performance of routine and familiar tasks.

A second consideration concerns eyewitness credibility and the possibility that some witnesses were unwilling to acknowledge officially an alcohol situation with which they may have been well acquainted. The many possible motivations for such reluctance include protecting the master, protecting themselves from legal exposure, and protecting their employment. Issues of eyewitness credibility have surfaced in previous Safety Board investigations concerning the issue of alcohol impairment (8). Eyewitness credibility issues also surfaced in the current investigation in several areas, especially in the presence of contradictory statements from the radio electronics officer and the third mate concerning a previous incident in which the master allegedly drank alcohol aboard the vessel while several other crewmembers were present. The recordings suggest that the master was impaired to a degree that he was unable to mask speech difficulties before the accident, and it seems likely that everyone on the bridge would have been aware of this situation.

During the outbound voyage, the master made a series of questionable decisions—he was absent from the bridge during the passage through Valdez Narrows, he ordered the autopilot engaged when departing the traffic lanes, he failed to advise the third mate that the autopilot was engaged, and he left the third mate as the sole officer on the bridge as the vessel approached a critical course change to maneuver around the ice. These actions provide a picture of impaired judgment that is consistent with toxicological and speech evidence.

The Safety Board concluded that the master of the EXXON VALDEZ was impaired by alcohol at the time the vessel grounded on Bligh Reef and that impairment of his judgment due to alcohol consumption caused him to leave the bridge at a critical time. In reaching its conclusion, the Safety Board examined speech analysis

as a new investigative technique and found it provided useful information for scientific investigation.

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