Voice Calling Detection Distance in Land Search and Rescue

W. H. Finlay, PhD, PEng

Edmonton Regional Search and Rescue Association

Edmonton, Alberta, Canada

Email: warren.finlay@ualberta.ca

http://dx.doi.org/10.61618/SSOV3472

Abstract

The distance d_i at which shouts from a caller remain intelligible to a listener were measured in a wilderness coniferous forest and separately in an aspen parkland forest with the aid of members of the Edmonton Regional Search and Rescue Association. Values were determined for calling at an average sound intensity of approximately 88 dB at 1 m by both a male and a female caller. An equation based on existing models in the sound engineering literature was then developed that predicts this distance. This equation is given by $d_i = 5619 * e^{-0.0978\, dB_{amb}}$ where d_i is in meters and dB_{amb} is the ambient environmental sound level in dB at the listener's location, the latter measured using a smartphone with a sound decibel app. Although the spatial resolution of our d_i measurements is relatively low (measurement locations were 25-50 m apart in pine forest, and ≈ 5 m in poplar forest), and dB_{amb} fluctuated rapidly and considerably, giving considerable scatter to our data, predicted values agree with measured values of d_i, with a correlation coefficient of r^2=0.5. The equation captures the strong dependence of detection distance on ambient noise levels. This equation is an easily implemented tool requiring only a smartphone in the field. It allows prediction of voice detection distances when performing voice searching sweeps by SAR teams.

KEY WORDS: *voice detection range, acoustic search, calling, listening, shouting, speech intelligibility*

Introduction

A recent study (Costigan 2024) on the effectiveness of calling and listening during off-track ground searching for a lost person highlights the potential superiority of voice searching compared to visual searching for responsive subjects. The advantage of acoustic searching is its typically greater range of detection compared to searching by sight, although this depends on environmental conditions. Koester et al. (2013) found the average maximum detection range for searchers listening for shouting subjects was 322 m.

Auditory searching is of course useful only with responsive subjects, such as a lost hiker, angler, camper, gatherer, hunter, mountain biker, runner, or skier. Search areas for such subjects can be vast, as well as being difficult for off trail ground search travel. For example, 50% of lost hikers were found at distances greater 3.1 km from the initial planning point (Koester 2008). The considerably larger range of detection provided by auditory detection when doing sweeps of the search area can dramatically reduce search times for such subjects. However, auditory search requires two-way communication with the subject. Young children may not respond even if they are capable of doing so, while lost adults may be unable to respond if their physical condition has deteriorated. Thus, auditory searching is not suitable in some situations.

Whistles are commonly used in the search community to generate a signal during auditory searches, while the most common auditory response by subjects is shouting (Koester et al. 2013). Since whistles can typically produce a louder signal than shouting, they have a greater range of detection than shouting. This produces a mismatch where subjects may hear a searcher's whistle, but searchers cannot hear the subject's shouted response. Thus, if sweeping an area with multiple searchers proceeding along parallel lines, it is important to space searchers at a distance where they can hear shouts, not whistles.

It should be noted that the distance at which sound can be heard may be affected by a number of factors. Two of the most important such factors are the sound pressures (i.e. dB level) of the source sound and ambient noise. For example, a 6 dB change in either results in geometric attenuation halving the detection distance. Studies on sound attenuation in general also find secondary dependencies on sound frequency, ambient humidity, air temperature (ISO 1993), wind speed and topography (Kleiner 2012). Haupert et al. (2023) examined changes in sound attenuation of a white noise source between different forest habitats, finding it minor compared to geometric and atmospheric attenuation, although sound attenuation in forests can become considerable at higher frequencies (when trunk diameter is larger than the sound wavelength).

With so many factors possibly affecting the effective range of voice calling and listening, a logical approach to determining spacing between points where searchers call and listen would be for searchers to empirically determine the distance that shouts remain intelligible at each search. An analogous approach is frequently used to determine the visual range of detection and sweep widths in visual searching (Koester et al. 2014).

However, as noted above, the detection range for sound may be several hundred meters (Koester et al. 2013), and requires coordinating calling and listening by radio to determine detection range. This makes its measurement considerably more time consuming and involved than for visual range of detection. Despite this, efficient use and management of sound searching requires knowledge of sound detection sweep widths when spacing searchers in an auditory search, and for use in estimating probability of detection (POD) of sound sweeps.

Given the above, it would be useful if a simple model was available to predict distances over which searcher's calls can be heard. As noted by Bowditch et al. (2018), if multiple searchers are calling, it is important for callers to be intelligible in order that listeners can distinguish a responding lost person from the calls of other searchers. Thus, it is the distance d_i between a caller and listener over which speech remains intelligible that would be most useful for such a model to predict. Predictions of d_i for short distances were first made for male voices with application to speech communication inside aircraft shortly after World War II, and later modified (Weber 1973) and subsequently compared to experiments that included female voice (Waltzman and Levitt 1978). Standard curves of d_i (see e.g. Foreman 1990) for different levels of vocal effort (normal voice, raised voice, very loud, shout, maximum vocal effort) plotted as a function of Speech Interference Level (SIL), which is the average ambient sound level in dB measured at a number of different frequencies, were subsequently adopted by the sound engineering community to aid in design of human communication spaces, such as conference rooms and work spaces. In the present work, we measure d_i between search and rescue (SAR) searchers in two outdoor wilderness settings consisting of either pine or poplar forest. We also develop a simple model to predict d_i based on the existing literature noted above. The ability of this model to predict our measured values of d_i is then examined.

Methodology

Experimental Methods

Members of Edmonton Regional Search and Rescue Association (ERSARA) were recruited to volunteer in voice detection range experiments. Experiments were performed in a coniferous forest, composed of mature, dense lodgepole pine (trunk diameters of approximately 0.2 m) located in remote wilderness in western Alberta, Canada in a relatively flat area (all listening locations were within 13 m of elevation of each other) in the Wildhay River valley within the Rocky Mountain foothills near 53.50382^0 N 118.01143^0 W. Figure 1 shows a satellite image of the location. Experiments were performed the afternoon of June 8, 2024. At the start of the experiments, measured ambient temperature was 8^0 C, relative humidity was 48%, atmospheric pressure was 86.6 kPa and ground wind speed was 4-6 km/hr from the west. Data acquisition was completed within 2.5 hours, over which time ambient weather conditions did not change measurably.

Sound pressure levels (in dB with 20 mPa reference sound pressure) were measured using the participants' smartphone pressure transducers with either Sound Meter (Splend Apps) or Sound Meter Decibel (Sweetvrn), which are free smartphone apps. No calibration of the smartphone measured dB values was done.

Figure 1. Satellite image captured on Oct 15, 2015 of the location of the sound detection experiments in coniferous forest. The calling location is marked by the white star. Searchers listened at points located on the white line. The three grey lines show schematic examples of straight line sound ray paths from the caller to the listeners through the forest. Copyright free satellite image courtesy of Environmental Systems Research Institute.

One volunteer remained as a caller at the calling location. The remaining searchers traveled away from the caller and then stopped to listen at points in time, coordinated by radio communication. The caller could not be heard at the initial listening point. Radio contact was made with the callers at each location and the straight line distance and bearing to the caller was recorded by each caller. The caller and listeners then faced directly toward each other on this bearing. The caller then confirmed via radio that the listeners were ready, and the caller then proceeded to shout three words, which were different each time and chosen randomly from the names of Canadian provinces and US states. Each time the caller shouted, the peak dB value of the set of three words was recorded using a smartphone directly facing the caller on a tripod at a measured distance of 1 m. Each listener individually recorded what words they understood, as well as the environmental ambient dB level (dB_{amb}) at that approximate time and their location. Incremental distances between the listening locations varied, but were approximately 25 m for locations within 100 m, and 50 m for distances > 100 m from the caller.

One set of measurements was performed with a male caller shouting to three male listeners and one female listener. Another set of measurements was performed with a female caller with the same three male listeners. The volunteers ranged in age from 30-62, with median age 43.

To explore the effect of caller/listener orientation, one set of measurements was also performed with the male caller facing directly away from the listeners, and the four listeners facing directly away from the caller. As usual, the caller recorded the peak dB value of the set of three words with their smartphone directly facing them on a tripod at a measured distance of 1 m.

To further examine the effect of facing away from the listeners, three measurements of the peak dB value of the male caller were obtained with the smartphone placed 1 m directly behind the caller.

For each listener, the distance d_i at which the caller was considered intelligible was determined as being halfway between adjacent locations where two words were correctly understood at the closer location and one word was correctly understood at the further location. This corresponds to approximately 50% speech intelligibility. The caller could be heard at much larger distances than d_i, but words could not be understood at those distances.

In a final set of measurements in the coniferous forest habitat, the male caller instead played bagpipes and the above three male listeners recorded the maximum distance at which the bagpipes could be heard when facing the listeners. The dB level at a distance 1 m in front of the bagpipes was recorded.

To explore the effect of vegetation habitat on d_i, we collected a smaller set of data in a deciduous aspen parkland forest (trunk diameter of approximately 0.2 m). This data was obtained on Aug. 18, 2024 within the Cooking Lake-Blackfoot Provincial Recreation Area near 53.47162^0 N 112.89556^0 W, a 97 km^2 forested area east of Edmonton, Alberta, Canada. Volunteers from ERSARA were again recruited. One female listener and two male listeners, median age 41, participated. These were different individuals than in the coniferous forest experiment. The same male caller was used as in the coniferous forest experiment. Ambient temperature at the start of data acquisition was 21^0 C, ambient pressure was 92.98 kPa, relative humidity was 46.6% and winds were 0-5 km/hr from the west. Data acquisition was completed within 2.5 hours, over which time ambient weather conditions did not change measurably. Unfortunately, one listener's smartphone recorded dB levels approximately 20 dB less than the other three participant's smartphones; it was assumed that the pressure transducer on that smartphone was faulty, so values of the other nearby participants' measurements of ambient dB levels were used instead when predicting d_i for this listener. The model described below was used in the deciduous forest experiment to predict listener starting locations. This saved time and allowed us to achieve finer spatial resolution in the deciduous forest, with listening locations approximately 5 m apart on either side of the critical spacing in this habitat. The initial listening location was at a distance of approximately 200 m, at which distance no words were intelligible to any of the listeners. The forest at the caller's location facing the listeners is shown in Figure 2. Similar forest habitat occurred over the entire straight line distance between the callers and listeners i.e. there were no intervening meadows, water bodies or open areas. All listening locations were within 3 m of elevation of each other.

Figure 2. The view of at the deciduous forest calling location, looking toward the listeners.

The Model

While more recently developed models of speech intelligibility than those noted in the Introduction are typically used by sound engineers and audiologists today, these more sophisticated models are more complex and require specialized audio spectral measurement and analysis equipment. To maximize the possible adoption of a model by civilian SAR agencies, minimizing analysis and specialized equipment was prioritized. For this reason, we chose to work from the Speech Interference Level (SIL) curves noted earlier (Foreman 1990). These curves plot the distance d_i at which speech is intelligible for different vocal efforts as a function of measured SIL. However, determining SIL requires averaging the values of ambient noise dB levels at a number of specific frequencies, which requires acoustic equipment that is unlikely to be available to SAR personnel. Instead, here we replaced SIL in these curves with the average ambient environmental sound dB value measured by the smartphone decibel measuring apps noted earlier.

For vocal effort in the published SIL curves, we chose to interpolate a curve halfway between the curve for shouting and the curve for maximal vocal effort. The standard SIL curves assume geometric attenuation of sound (i.e. sound intensity decreases as $1/r^2$ where r is distance from the sound source), which implies a 6 dB attenuation for every doubling of r, whereas Kleiner (2012) notes that atmospheric turbulence and excess absorption (due to heat conduction, viscous losses and relaxation phenomena) results in slightly higher measured total attenuation values near 7 dB. Thus, here we create a curve that interpolates SIL values of 107.5 dB at 0.15 m and 65 dB at 9.8 m, which gives 7 dB attenuation for each distance doubling and is expected to approximate typical intelligibility distance for a loud shout including geometric and atmospheric attenuation.

The resulting model for distance d_i at which a shouting individual is expected to be intelligible enough for SAR purposes can then be found to be given by

$$d_i = 5619e^{-0.0978\, dB_{amb}} \quad (1)$$

where d_i is in meters, and dB_{amb} is the ambient sound level as measured with a smartphone sound decibel app.

Since not all SAR field personnel may be comfortable using the exponential function, eqn. (1) can equivalently be written as

$$d_i = 5619 * 10^{-0.04247\, dB_{amb}} \qquad (2)$$

Eqns. (1) and (2) assume the caller exerts a vocal effort midway between a shout and maximum vocal effort i.e. a loud shout, which corresponds to an SIL of 88 dB at 1 m. Callers shouting with lower dB than 88 dB at 1 m can be modeled by replacing dB_{amb} with dB_{amb}+(88-$dB_{\_caller}$) in these equations i.e.

$$d_i = 5619e^{-0.0978\, (dB_{amb}+88-dB_{caller})} \qquad (3)$$

Note that it can be shown that eqns. (1) and (2) imply that sound intensity attenuates with distance r from the sound source as $1/r^{2.35}$, rather than $1/r^2$ as occurs for purely geometric attenuation.

Results

Figure 3 shows predicted values of the distance that loud shouts are intelligible as a function of ambient dB, calculated using eqn. (1) or equivalently eqn. (2).

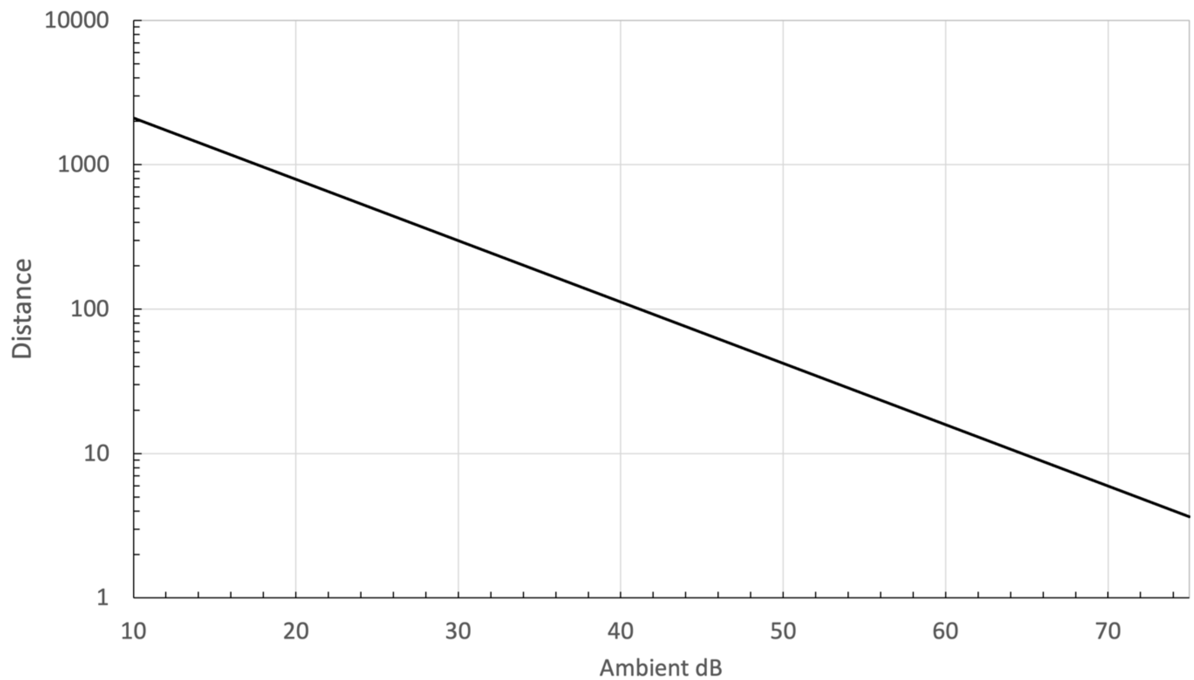

Figure 3. The distance d_i (in meters) that loud shouts are predicted to be intelligible are shown as a function of ambient noise levels (in dB).

In our field experiments in coniferous forest, the peak dB levels measured at 1 m for the male caller shouts varied from 84-95 dB, while those of the female caller varied from 82-92 dB. The value of the caller's peak dB measured at 1 m for the two locations that sandwiched d_i when facing toward the caller was 87 dB for the male caller, and 89.5 dB for the female caller, while the average for both callers was 88 dB ± 1 dB (mean±s.d., n=7). The average peak dB of both male and female callers overall was 88.8 dB±4 dB (mean±s.d., n=21) at 1 m. The average value of the caller's peak dB at the two locations that sandwiched d_i when the caller and listeners were facing directly away was 88±1 dB (mean±s.d., n=4) at 1 m. The average reduction in peak dB of shouts measured 1 m directly behind the caller versus directly in front of the caller was 7±1 dB (mean±s.d., n=3). Ambient noise levels measured at each listening location by each listener varied from 25-60 dB, with a mean value of 43 dB ± 10 dB (mean±s.d., n=64), sometimes varying over nearly the entire range between one listening time and the next, due to wind gusts. Beyond a distance of approximately 200 m in the coniferous forest, listeners were unable to hear the caller; ambient noise levels ranged from 45-60 dB when listeners were at those distances.

In the deciduous forest, the average peak dB level at 1 m from the caller was 89±3 (mean ± s.d., n=21) and varied from 86-95 dB. Ambient dB levels ranged from 32-52 dB with a mean value of 40±7 dB (mean±s.d.,n=21). The two male listeners were unable to hear the caller at all beyond distances of approximately 270 m, while the female listener could not make out any sound from the caller beyond approximately 329 m. Ambient noise levels ranged from 32-40 dB when listeners were at those distances.

Figure 4 shows predicted values from eqn. (1) versus measured values of the distance d_i for both forest habitats. The Pearson correlation coefficient is r^2=0.5 when facing toward the caller (the case for which eqn. 1 it was designed). For the case of the male caller facing away from the listeners (who were also facing away from the caller), we have used eqn. (3) with 88-dB_{caller}=7 dB.

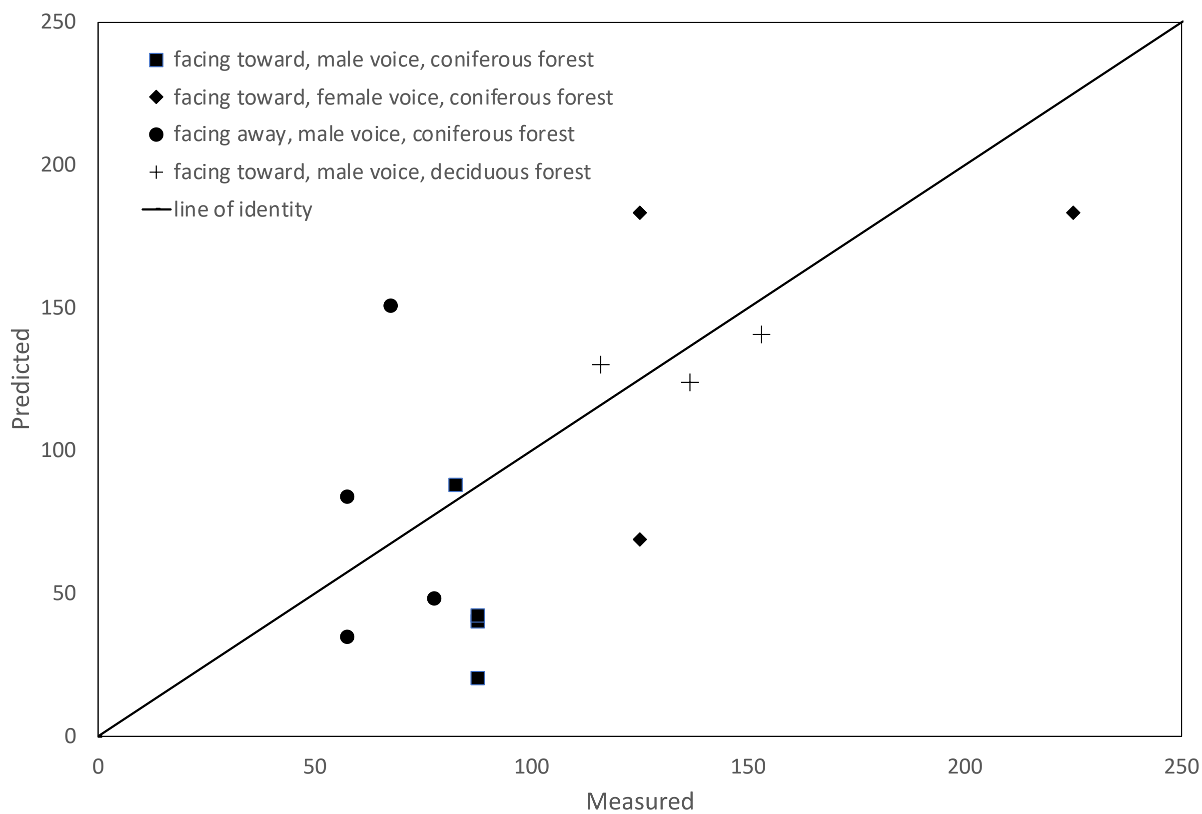

Figure 4. Predicted values of the distance d_i at which the caller is intelligible are shown versus measured values for a male caller and a female caller facing the listeners, as well as for a male caller with both caller and listeners facing away from each other, all in a coniferous forest. The three data points obtained in deciduous with only a male voice calling are also shown. The line of identity (where predicted and measured values would be equal) is shown for reference.

The measured peak sound intensity of bagpipes at a distance of 1 m was measured to be 97.3 dB±2.5 dB (mean ±s.d., n=3) and could be heard out to a distance of approximately 450 m in the coniferous forest.

Discussion

Considering that the model given by eqn. (1) was developed *a priori* without any adjustable or fitted parameters, it is surprisingly predictive of the measured data, with an r^2 value of 0.5 when considering all data facing toward the caller in both forest habitats. The scatter seen in Figure 4 is unsurprising given the low resolution of many of our measured d_i values, probable interdevice smartphone variability in measured values of dB levels (Murphy and King 2016), as well as the high variability and rapid changes in ambient noise levels when listening. The latter made it difficult to specify a reliable single value of ambient noise (dB_{amb}) at the listening time/location; the sensitivity of d_i seen in Figure 3 to dB_{amb} amplifies uncertainty here and adds to the scatter seen in Figure 4.

The average magnitude of the difference between predicted and measured values of intelligible shouting distance was 29 m± 20 m (mean±s.d., n=7) when facing toward the caller in the pine forest, which is 25% of the average d_i. This is similar to the spacing between listening locations, and this accuracy may be all that can be expected from a model when comparing to our low resolution experimental data. For the deciduous forest data, the average magnitude in the difference between predicted and measured d_i values was 13 ± 1 m (mean±s.d., n=3), which is 10% of the average d_i. The smaller difference between predicted and measured values in the deciduous forest is presumably due to the closer spacing between listening locations in the deciduous forest data (approximately 5 m), which itself was the result of using equation (1) to predict starting locations for the listeners, allowing time to achieve better spatial resolution in the deciduous forest.

Some variability in our data may be due to differences in measured dB values by our uncalibrated smartphones. Previous studies have shown that different smartphones and noise measurement apps give different measurement values for the same noise source (Murphy and King 2016). Most of our measurements were made using the Sound Meter app, which Murphy and King (2016) found gave an average error of 2 dB with a standard deviation of 9 dB among 140 individual smartphones. Thus, either calibrating smartphone dB values against a dedicated dB meter, or at least using the average of multiple smartphones for measuring dB measurements, would be useful in future studies or application of the present work.

The SIL curves upon which the present model was developed were based on data with subjects facing toward each other at short distances (< 16 m) in inside settings. Despite extrapolating these curves to much larger distances here and to an outdoor forest setting, we find eqn. (1) remains predictive. In retrospect, the lack of attenuation by intervening forest habitat is not surprising, since Haupert et al. (2018) found attenuation due to forested habitat is minor. In their experiments, they measured attenuation out to 100 m away from a 78 dB or 83 dB (measured at 1 m) white noise sound source in a coniferous forest and a neotropical rainforest, finding an average attenuation of 0.02 dB/kHz/m. The overall average d_i measured here was 98 m in coniferous forest (and 135 m in deciduous forest), and assuming a voice frequency of 0.5 kHz, the data of Haupert et al. (2018) would imply approximately 1 dB of attenuation over this distance due to the presence of forest, although this attenuation is linearly proportional to frequency (Haupert et al. 2018). This is negligible compared to the 40 dB geometric attenuation and 7 dB atmospheric attenuation predicted over a distance of 98 m by the 7 dB per distance doubling associated with the model given by eqn. (1). The presence of forest vegetation on voice detection distances in SAR thus appears not to meaningfully affect the ability of eqn. (1) to predict these distances. This is supported by the ability of equation (1) to also independently predict the limited data we obtained in aspen parkland, although it may be worthwhile to obtain data in still other habitats and ambient meteorological conditions.

Extending eqn. (1) to callers and listeners facing directly away from each other by using a measured 7 dB reduction in shout volume (due to vocal directivity shadowing by the caller's head) in eqn. (3) reduced the overall r^2 value to 0.4. Note that differences in pinna response between facing directly toward and directly away have been previously found to be small (Kleiner 2012), so the difference observed here is presumably due to voice directivity, rather than listening directivity. While the number of datapoints here is small and are scattered (10 values of d_i facing toward and 4 values facing away), this reduction in r^2 might be due to unaccounted for differences in voice directivity when callers and listeners are at angles other than facing toward each other. Indeed, differences in voice directivity due to shadowing of the head are quite frequency dependent, and with speech intelligibility dependent more on higher frequencies (Kleiner, 2012), it may be that using a single caller dB attenuation to account for voice directions other than face on is too simplistic. Despite this, the clear reduction in detection distance we observe when facing away from the listener indicates that voice searchers should call facing multiple directions at each calling location to mitigate voice directivity e.g. searchers should call in both directions perpendicular to the search path, as well as forward and backward along the search path.

The eight callers in the SAR study by Bowditch et al. (2018) shouted at 75±2 dB measured at 5 m. This corresponds to 89 dB at 1 m assuming purely geometric attenuation. This is the same value of average loudness as the two callers we measured here. Thus, the dB of calling used here to validate eqn. (1) may be considered within the range of typical values of loud shouts. Searchers may consider calibrating their shout loudness using a smartphone decibel app at a distance of 1 m to achieve an approximate 88 dB average shout sound intensity when using eqn. (1) to estimate detection distances. An alternative to calibrating call intensity would be to measure calling dB levels and then use eqn. (3).

The use of bagpipes allowed us to examine detection distances of a louder sound. With an assumed 7 dB attenuation per distance doubling, the average 8.5 dB increase in sound intensity of the bagpipes compared to shouting here implies detection distances should be 2.3 times larger for bagpipes than shouting. Since speech intelligibility is irrelevant for detecting bagpipes, comparison between voice and bagpipe detection distances needs to done based simply on the distance at which the caller shout is heard (but is unintelligible). We did indeed find bagpipes could be heard approximately 2.3 times further away than shouting. Given that it is difficult and potentially hazardous to the vocal cords to maintain a voice level > 85 dB for extended periods (Waltzman and Levitt 1978), bagpipes may be a useful tool worth considering to attract response over an extended period of time of a lost subject that may be within bagpipe detection range of the last known point. While whistles are commonly used to generate a signal by SAR searchers, they may not be as loud as bagpipes (two whistles we measured gave signals of 90 and 95 dB loudness at 1 m). In addition, the possibility of providing longer duration sound with bagpipes that is not associated with distress, like whistles are, may be advantageous in garnering a response from certain subjects e.g. children. Because of the much greater detection range of the bagpipes, the use of a parabolic mic for listening at the last known point would be useful, which Bowditch et al. (2018) find extends the range of detection by a factor that is similar to the 2.3 times factor that we see here for bagpipes vs voice range of detection.

Eqn. (1) (or equivalently eqn. 2) may be useful in estimating the distance between calling-listening locations and critical spacing when executing voice searches. A simple measurement of ambient sound levels on a smartphone decibel app allows eqn. (1) to directly predict the voice detection range. Assuming the sound from the caller propagates hemispherically above flat ground (which neglects the previously noted voice directivity effects), the range of detection is then a circle centered on the caller's location. If no response is detected at that location, then if the search team proceeds a distance 2*di from that location to call again, the range of detection circles from the two locations would just touch, as seen in Figure 5. If the distance between calling locations is a straight line along a search path, there is then an area that is beyond the detection range but still within d_i of the search path, shown as the shaded region in Figure 5. This area is easily calculated by numerical integration. From a probability of detection (POD) perspective, it can then be shown that sweeping along a search path with calling/listening locations separated by a distance of $2d_i$ results in voice coverage of c=78.5% of the area within d_i on either side of the path. Moving the calling-listening locations closer yields c=89.6% and c=95.7% coverage for separations of $1.5d_i$ and d_i respectively. If searching an area, then as a first approximation, POD can be estimated by simply multiplying the searched path length by f=0.02 c d_i (i.e. (c/100)*2*d_i) and dividing by the search sector area. For calling-listening points separated by 2*d_i, f=1.57 d_i.

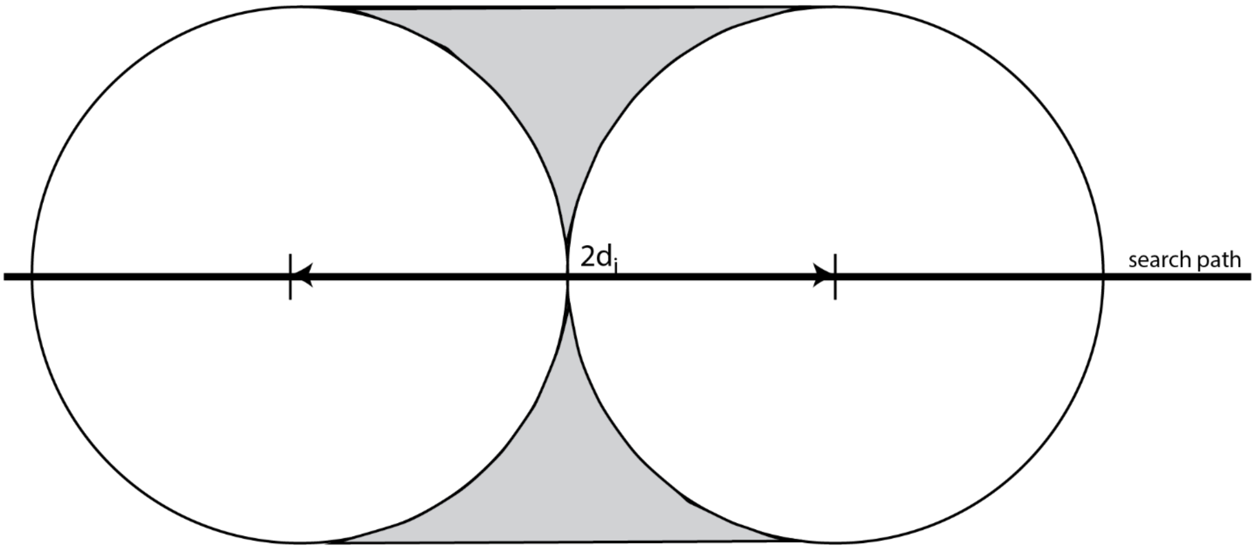

Figure 5. Schematic drawing of the intelligible detection area that results when calling and listening occurs at two points separated by two times the detection range d_i along a search path. The shaded area is outside the intelligible detection range and can be shown to leave 21.5% of the area within d_i of the search path beyond the intelligible detection range.

A subject in the shaded region in Figure 5 is beyond the intelligible speech detection range, so intelligible voice communication between the searchers and subject is not possible. However, given the much larger range that we find shouts remain detected but unintelligible, searchers would presumably move closer to the subject if they hear a response, albeit at an unintelligible distance, to establish intelligible vocal communication and result in a successful search. Regardless, the above noted POD estimate may be useful as an approximate measure for use in search management.

Operationally, auditory sweeps that use shouts for signaling are probably best limited to higher probability areas, since searchers are likely to find it difficult to shout at loud levels throughout an entire operational period. A typical operational application of eqn. (1) would be for a sound sweep of e.g. a 600 m x 600 m square centered on the last known point. In this case, measurement of ambient environmental sound levels, preferably averaging values from several smartphones or using a smartphone whose measured dB values have been calibrated against a dedicated dB meter, provides a value of dB_{amb} to use in eqn. (1) to predict a value of the distance d_i at which shouts are heard with approximately 50% intelligibility. A set of parallel lines at a chosen bearing and separated by a distance of 2d_i should then be decided upon that most efficiently traverses the search area. Individual searchers would then position themselves on these individual parallel lines separated by a distance of 2d_i, stopping at locations every 2d_i to shout forward, backward, and perpendicular to each side of the line they are following. For example, if d_i=100 m, then a 600m x 600m square would be swept by three searchers spaced 200 m apart and stopping 100 m, 300 m and 500 m from one side of the square, each having walked 500 m along parallel lines and shouted 12 times (once in each of 4 perpendicular directions at three locations along their sweep line). Figure 6 shows a schematic representation of the above operational implementation of this with d_i=100 m and three searchers. With a different value of d_i, replacing the 100 m distances with d_i in Figure 6 and the 200 m distances shown in Figure 6 with $2d_i$ would result in the same operational procedure sweeping a square with side $6d_i$.

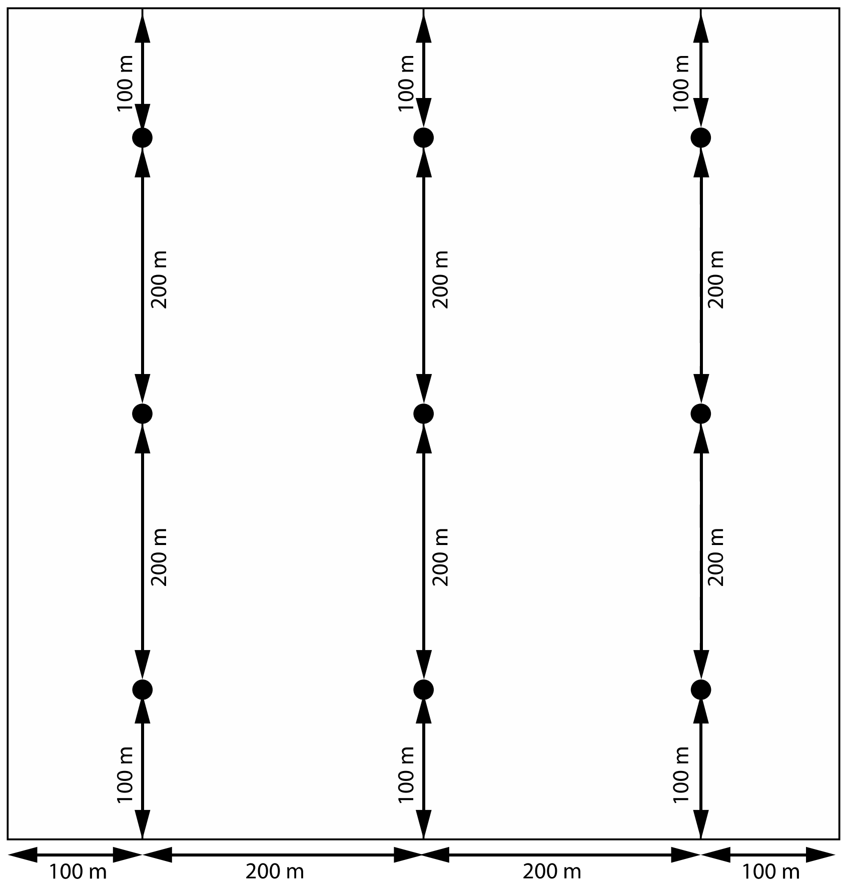

Figure 6. Schematic of auditory sweep distances for a detection range d_i=100 m with three searchers following parallel lines to search a 600m x 600m square shown by the solid line boundary. Calling locations, where searchers stop to shout and listen in four different directions (forward, backward and to each side), are indicated by the solid circles.

Searchers may want to agree on what words they are shouting e.g. if the subject's name is Jane, then perhaps 'Hello Jane; calling Jane; are you there Jane'. In this example, there would be no need to coordinate the timing of searcher calls since each searcher would be intelligible to each neighboring searcher (since they are separated by a distance of d_i) and distinguishable from the subject's response. The distance between searchers could be modified during the search if neighboring searchers are unable to make out any words that adjacent searchers are shouting, or if every word is very clear and intelligible. This would empirically optimize searcher spacing to accommodate varying searcher shouting and hearing levels, as well as temporally varying ambient noise levels. Once the searchers have traversed the width of the search area, the above noted procedure for estimating POD can be used.

Limitations of this study

The effect of local topography, such as hills or cliffs, on sound propagation is not included here; neither are the effects of temperature and wind speed variations with height, which can bend sound ray paths to create sound shadows and result in d_i being different from that predicted and measured here. We did not clinically assess the hearing abilities of the participants. However, none of the participants in our field measurements had a diagnosis of hearing loss, so the effects of hearing loss are not included. Eqn. (1) does not account for differences in atmospheric losses at different relative humidity, temperature or atmospheric pressure. Standard equations are available for this purpose (ISO 1993), which predict atmospheric losses that vary from 0.01-8.5 dB over a 100 m distance for frequencies varying from 100-3150 Hz, humidities from 10%-100%, and temperatures from -20^0 C-+30^0 C at 101 kPa atmospheric pressure. These are small compared to the 40 dB of geometric attenuation over this distance. Given that these losses are minor compared to geometric attenuation, as well as being strongly frequency dependent, our inclusion of them as a 7 dB loss over a 100 m distance may be of sufficient accuracy for the intended SAR applications of our model.

Conclusions

We present a simple equation given by $d_i = 5619e^{-0.0978\, dB_{amb}}$ that requires only the measurement of ambient environmental noise levels dB_{amb} using a smartphone to then predict the distance d_i over which a shouting person remains intelligible when shouting at a typical loud shout sound intensity of 88 dB (measured at 1 m). We then compare the predictions of this equation to measurements we have made of d_i in a coniferous forest wilderness and in a deciduous forest. Despite the relatively low spatial resolution of our field measurements (listening distances were separated by 25-50 m in the coniferous forest and approximately 5 m in the deciduous forest) and highly variable ambient noise levels (due to wind gusts), this equation is predictive of the measured values (r^2=0.5). Forest habitat attenuation is expected to be negligible compared to the much greater geometric and atmospheric attenuation that are captured by this equation. Thus, the present model may be useful for SAR teams wanting to predict voice searching detection distances in general.

Acknowledgements

The assistance of Edmonton Regional Search and Rescue Association (ERSARA) and in particular ERSARA members Peter Bezeau, Michael Cooley, Danielle Everitt, Ethan Mason, Kyle Schole, Nancy St. Hilaire, and Richard Willimus, who participated as field subjects in this study, is gratefully acknowledged.

About the Author

Warren Finlay is a Search Manager with Edmonton Regional Search and Rescue Association. He holds a PhD in Mechanical Engineering, is a Registered Professional Engineer, and has published more than two hundred refereed archival journal papers in aerosol mechanics and fluid dynamics during his tenure as a Professor at the University of Alberta. He is a Fellow of the Royal Society of Canada.

References

Bowditch, N. L., Searing, K. S., Thomas, J. A., Thompson, P. K., Tubis, J. N., Bowditch, S. P. (2018) "Use of a Parabolic Microphone to Detect Hidden Subjects in Search and Rescue", Wilderness and Environmental Medicine 29:11-17.

Costigan, R. (2024) "The Value of Searching by Voice in LandSAR", J. Search and Rescue 7 (1):1-29.

Haupert, S., Sebe, F., Sueur, J. (2023) "Physics-based model to predict the acoustic detection distance of terrestrial autonomous recording units over the diel cycle and across seasons: Insights from an Alpine and a Neotropical forext", Methods Ecol. Evol. 14:614-630.

ISO International standard "Acoustics - Attenuation of sound during propagation outdoors - Part 1", ISO 9613-1:1993(E).

Foreman, J. E. K. (1990) *Sound Analysis and Speech Control*, Van Nostrand Reinhold, NY, NY.

Kleiner, M. (2012) *Acoustics and Audio Technology*, 3rd Edition, J. Ross Publishing, Ft. Lauderdale, Florida.

Koester, R. J. (2008). *Lost Person Behavior*, dbS Productions LLC, Charlottesville, Virginia.

Koester, R. J., Gordon, R., Wells, T., Tucker, R. (2013) 'Auditory and light based two-way effective sweep width for responsive search subjects in New Zealand mountainous terrain', J. Search and Rescue 1:1-18.

Koester, R. J., Chiacchia, K. B., Twardy, C. R., Cooper, D. C., Frost, J. R., Robe, R. Q. (2014) "Use of the Visual Range of Detection to Estimate Effective Sweep Width for Land Search and Rescue Basedon 10 Detection Experiments in North America", Wilderness and Environmental Medicine 25:132-142.

Murphy, E. and King, E. (2016) "Testing the accuracy of smartphones and sound level meter applications for measuring environmental noise", Applied Acoustics 106:16-22.

Waltzman, S. B. and Levitt, H. (1978) "Speech Interference Level as a Predictor of Face-face Communication in Noise", J. Acoust. Soc. America 63:581-590.

Webster, J. C. (1973) "The effects of noise on the hearing of speech", in *Proc. Internation. Cong. Noise as a Public Health Problem*, Dubrownik, Yugoslavia, pp. 25-57, US EPA, Washington.