METHODS & DESIGNS

Practical aspects of the use of radio telemetry in the behavioral sciences*

DONALD R. MIKLICH†

National Asthma Center, Denver, Colorado 80204

KENNETH PURCELL

University of Denver, Denver, Colorado 80210

and

JONATHAN H. WEISS

Yeshiva University, New York, New York 10003

This is a practical guide for the technologically unsophisticated behavioral researcher who wishes to use voice radio telemetry (RTel). Points discussed include how to determine suitability of RTel for a project, selection of consultants, suitable locales for RTel, costs, ethical/legal issues, and operating procedures.

Behavioral research has lacked an unobtrusive naturalistic observation methodology. Many (Pronko, 1968; Schwitzgebel, Schwitzgebel, Pahnke, & Hurd, 1964) view the development of miniature radio transmitters as a means of correcting this deficiency, and studies exist demonstrating the feasibility of using such transmitters in behavioral research (Hoshiko & Holloway, 1968; Moos, 1968; Nordquist, 1971; Purcell & Brady, 1966; Soskin & John, 1963). This paper discusses practical aspects of the research use of radio voice telemetry (RTel) based on our 10 years' experience with the methodology. Readers interested in RTel with physiological variables are referred to Mackay (1970).

SUITABILITY OF RTel FOR A GIVEN STUDY

RTel is not suitable for all kinds of naturalistic observations. While it is excellent in the study of verbal behaviors and many psychophysiological responses, most nonverbal behaviors can only be inferred from the vocal record. Notable exceptions to this are gross activity levels (Herron & Ramsden, 1967a; Sprague, 1971) and walking (Herron & Ramsden, 1967b). Even verbal behavior may be unsuitable for RTel monitoring if that behavior is insufficiently strong, clear, frequent, or

discriminable, or if it cannot be reliably scored. Typically, pilot studies are conducted to determine feasibility. Pilot data may be gathered from audio recorders placed where the behavior of interest occurs. It is desirable to have the S wear or carry a microphone, since merely placing a microphone in a room often does not provide a usable record. Small portable cassette tape recorders can be carried by an S, and they are excellent for pilot work. In fact, if the monitoring periods are short, these recorders may substitute for RTel, an especially desirable alternative in an environment in which RTel functions poorly. Initial data may be used to resolve the following issues: (1) Can different persons' voices be distinguished? (2) In particular, can Ss be identified? (3) Does ambient noise prevent recovery of the data? It is also well to use pilot recordings to develop a scoring system. If sufficient scoring reliability cannot be achieved, one need not develop an RTel system. Independent behavioral observations of Ss, made during pilot recording sessions, can help to determine the validity of the scoring system, as well as the extent to which nonverbal behaviors, being inferred from the verbal record, are missed.

PRELIMINARY PROBLEMS

If a researcher decides to use RTel, he should learn something about radio. *The Radio Amateur's Handbook* (Myers, 1973) is a good source. Schwitzgebel and Byrd (1970) discuss many technical aspects of behavioral RTel not covered here; the article is highly

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†Requests for reprints should be sent to D. R. Miklich, National Asthma Center, 1999 Julian, Denver, Colorado 80204.

recommended for psychologists planning to use this technology. These authors also identify and discuss relevant aspects of FCC regulations. Unfortunately, we found these regulations to be much too technical to be of any help to the electronically unsophisticated. A phone call to the local FCC Engineer in Charge will provide guidance in most cases. A bibliography of psychological uses of RTel is available (Miklich, 1972).

The physical setting is a primary factor in determining RTel's feasibility, and one which is at least indirectly under the researcher's control. The greater the area to be monitored, the more difficult the technical problem. The relationship is not linear, however, because beyond single rooms, given increases in area lead to proportionately greater increases in difficulty. Topography is crucial. Open, flat land, devoid of structures (no fences, telephone lines, or power lines, etc.), provides the ideal locale. As the surface becomes more irregular and/or covered with structures, problem difficulty increases. Buildings or natural features (e.g., hills) that intervene between S and the receiving antenna can create blind spots blocking receipt of the telemetered signals. Wooden buildings cause the least difficulty—concrete and steel the most. Many, and large, windows facilitate RTel, but metal (e.g., metal lath, plumbing, fences, sashes, fire doors, electrical wiring, etc.) impedes it. In general, in any complex physical environment, there are certain areas that present problems. Though some of these blind spots can be specified *a priori* (e.g., RTel is seldom possible when an S and transmitter are in a windowless basement and the receiving antenna is outside), their locations usually depend upon the placement of the receiving antenna. Blind spots also vary slightly from time to time, due to weather, the state of maintenance of the system, and/or the S's orientation.

One must also consider the radio frequency environment. Electronic devices (even a wire carrying electricity) produce electrical signals like those of a radio transmitter. Since such signals usually have characteristic frequency bands, their presence is not necessarily a problem, provided that their frequencies are different from the one used for telemetry. Certain broad-frequency or high-power radiators, however [e.g., x-ray, diathermy, large industrial electronic equipment, and nearby transmitters (AM, FM, TV, or radar)], are always a problem. Radio or TV receivers may also interfere with reception if located close to the RTel receiving antenna.

To determine if a location is suitable for RTel, tune your radio to the frequency bands at which the system will operate. If your radio has a noise control or squelch circuit, clear spots will be completely noiseless because the radio, in effect, turns itself off when it does not encounter an incoming signal. However, many receivers do not contain this circuit, in which case clear spots will contain background static. In general, it is better to listen with a receiver without a squelch control, since a

signal too weak to overcome the squelch control may still be strong enough to interfere with very weak RTel signals. If few clear spots are found, one must either operate at a different frequency or install antenna filters. Schwitzgebel and Byrd (1970) discuss frequency selection. Listen repeatedly to find intermittent interference (e.g., x-ray). The most common sources of intermittent interference are amateur radio and citizen's band operations, which transmit on no fixed schedules. In these frequency bands, a clear spot at one moment will often be saturated with interference at the next. We strongly recommend against these bands.

If the area to be covered is large (more than approximately 1 acre) or involves transmission through and around several structures, or if it is necessary to operate outside the commercial radio bands, one may need a contractor. At the least, the unsophisticated (in radio) psychologist will need a consultant. Engineers from local aerospace firms, TV or radio station (especially FM) staffs, as well as faculty from university electrical engineering departments, are possibilities. Expertise in electronics, but not radio *per se*, is of little use, and individuals with radio knowledge may know little about microminiaturization and RTel. If a contractor is required, ask your consultant for help. Only a few with successful experience in voice RTel are available. We obtained excellent service from one firm (Spacelabs, Inc., Chatsworth, Calif.), but very poor service from a major military-aerospace company. A full study by the contractor of the setting you wish to monitor is a *sine qua non* before any purchase contract is signed. The cost of such a study is a necessary investment if the contractor will not provide it free, and may vary from a few-hundred dollars to \$10,000 or more. Require fixed-price contracts with firmly specified delivery dates, and provision for maintenance and repair.

DO-IT-YOURSELF RTel

Some researchers without special training in radio technology have developed their own RTel systems (Hoshiko & Holloway, 1968; Nordquist, 1971). The key is the use of small portable transmitters called "wireless microphones" (WM). Many exist, but those that transmit in the commercial FM band are best. They require no license, are relatively free of static, and there is available an abundance of high-quality, ready-made components to complete a system in this band. However, should one interfere with radio or TV reception, the FCC will require that the interference be eliminated, or the use ended. WMs have such low power output that interference is unlikely. Purcell and Brady (1966) used both a custom- and a ready-made WM in a single-story masonry dormitory, with 14 rooms and 8 baths on either side of a 30 x 50 ft dayroom. The receiving antenna was a wire strung around the dayroom clerestory and fed into an ordinary hi-fi tuner. A wire from the tuner was strung about 50 yd, over the roofs of

adjacent buildings to a tape recorder. This system gave excellent coverage of the dormitory and the area about 20 yd around it.

WMs can be obtained from most radio and electronics suppliers (e.g., Lafayette Radio Electronics, 111 Jericho Turnpike, Syosset, 11791; Allied Electronics, 2400 W. Washington Blvd., Chicago, Ill., 60680). If locating a supplier is difficult, it may be possible to obtain assistance through a local member of the Electronics Representatives Association (Room 1002, 223 E. Erie, Chicago, Ill. 60611). Radio amateur stores have some suitable equipment, and often knowledgeable clerks. Hi-fi shops have more suitable equipment, but clerks are generally unfamiliar with radio transmission. Much trial and error is necessary to obtain functional RTel; when possible, borrow equipment before you purchase.

Choose a WM that broadcasts on frequencies that your preliminary investigation shows to be open. It is desirable to have a unit that can transmit in several of the open frequencies. Transmission power is the attribute to maximize in selecting a WM. While FCC regulations determine power maxima, there are differences in power output, not only between different designs, but also between two copies of the same design. Test power in an uncluttered area where the RTel system is to be operated. Have an assistant carry the WM as an S would. He should walk slowly away from a receiver and continuously identify his location at a constant volume. The WM that produces the strongest signal, from the furthest distance, is the most powerful. In making this determination, it is helpful to tape-record the receiver output, and it is important that everything (including the transmitting and receiving antennas; receiver and amplifier and their volume settings; and time of day and meteorological conditions), other than the WMs being tested, remain constant from test to test. Incidentally, although time and weather do not, theoretically, affect FM transmission, we have found that stormy weather often degrades performance.

It is better to use a tuner (a receiver that does not amplify the audio signal it outputs) than a radio, since distortion is caused when the radio's amplified audio output is fed into a tape recorder. In a tuner, the primary quality to seek is "sensitivity" to weak signals, and the second most important quality to seek is "selectivity" (i.e., the ability to eliminate interfering stations). Sensitivity may be tested in a similar manner to WM power tests. Set volume controls so that the background-noise level is equal in all of the tuners tested. The loudness of the signal, above the noise level, will then be a meaningful guide in selecting a tuner. Be sure that all tuners are tested with the same receiving antenna. Fixed frequency tuners with excellent selectivity are available but should be avoided since the need to change frequency sometimes occurs. Avoid tuners with squelch controls, or have the control disabled. Such tuners usually require a stronger signal than a WM can produce.

The selection and location of the receiving antenna is most important in improving the range and strength of RTel. A receiving antenna designed for a particular frequency can amplify the signals received at that frequency (in fact, no other component in the RTel system remotely approaches the receiving antenna's power gain/cost ratio). The locating of antennas to maximize performance, and to some extent even the design and construction of antennas, is something a researcher can do himself. The information on antennas in *The Radio Amateur's Handbook* (Myers, 1973) and in Mackay (1970) should be carefully studied.

The orientation of an antenna, with respect to ground (polarization), is important. Vertical polarization is generally preferable for RTel. It tends to yield a stronger signal and is omnidirectional, i.e., is equally sensitive to signals from any direction. The polarization of the receiving and transmitting antennas should be the same.

Locate the receiving antenna at that point from which one can see the maximum number of places from which transmission is desired. Electrical devices and metal objects should be avoided. Metal objects not only can screen the signal from the antenna, but also cause signals to be received "out-of-phase" (i.e., to be cancelled).

Usually, the best antenna location is not practical for placement of the receiver, and lead-in wires must be run from the antenna to the receiver. If good reception is obtained when a tuner is coupled to an antenna, but not when a long antenna feed-in line intervenes, place antenna amplifiers in the antenna line near the antenna. Antenna amplifiers can be purchased at any radio store. Alternatively, place the receiver at the antenna site and have the long distance occur between the receiver and recorder. This does not require an antenna amplifier, and the output quality theoretically should be better.

When no single antenna location provides complete coverage, a multiple-antenna system may; but this is often difficult and/or costly. If two or more areas are completely isolated (i.e., from radio transmissions arising in each other), simply place an antenna in each and attach all antennas to the receiver. As the degree of isolation decreases, so does the utility of this method, because the signals from the different antennas will be out-of-phase when the transmitter is in certain locations, creating blind spots. One can experiment with different antenna locations in an attempt to place these blind spots in relatively unimportant areas. Blind spots can also sometimes be eliminated or reduced by the use of antennas with strong directional characteristics. Since blind spots occur when two antennas pick up an out-of-phase signal from the same spot, pointing the insensitive part of a directional antenna toward that spot may solve the problem. Antenna arrays, such as commercial FM antennas, are most suitable for this use since they are highly directional. They also have the added advantage of providing more signal amplification than single-element antennas.

Blind spots and difficulty increase exponentially, as

the number of antennas increases, so the number should be kept to a minimum. The elegant solution to the multiple-antenna problem is to provide a special switching circuit at the junction of the input from the several antennas. This circuit senses which of the several signals is the strongest and connects only that signal to the tuner. Mackay (1970, pp. 242-246) illustrates such a circuit. A more expensive approach is to place a tuner with each antenna and to merge their audio output. This reduces, but does not eliminate, the out-of-phase problem. With only two tuners, a unique solution is possible by feeding one into the right channel of a stereo recorder and the other into the left channel.

Transmitting (as opposed to receiving) antennas provide fewer options to the technologically unsophisticated behavioral researcher. For a WM operating in either the AM or FM band, the practical antenna length will be shorter than the optimum length. The WM's circuitry may not compensate for this, and some power gain may be achieved with a longer antenna. One can test the effects of antenna length in the same way as that suggested for testing WM power. Increasing power in this way may cause a WM to exceed FCC power limits. In order to determine if this has happened, considerable technical equipment and competence is required. A practical test is to monitor various radio and TV broadcasts while the WM is on the air. If no interference results, the FCC is unlikely to object, even if power exceeds regulations.

Although there may be some circumstances in which the research problem requires only listening to the data as they occur, in most cases you will want a permanent record. Tape recordings are probably best for this. Although exceptional fidelity is not needed, it is wise to select a good quality recorder. Seek low internal noise, high rewinding speed, and durability of the tape transport mechanism. The ability to reverse tape directions rapidly without backlash is vital, since scoring of such recordings often requires much listening, rewinding, and relistening. Considerable savings on tape costs can be achieved with four-channel recorders with slow speeds (1 7/8 ips, or even 15/16 ips).

TESTING, OPERATING, AND MAINTAINING AN RTel SYSTEM

As suggested earlier, test an RTel system by placing the transmitter on an assistant, as you would on an S, and have him walk systematically through the entire monitoring area while continuously describing his location. It is most helpful to have a reliable backup means of communication (e.g., walkie-talkie) between the person transmitting and the individual at the recorder. If RTel is OK from some locations but not from others, relocate the receiving antenna. Transmission from an area is improved by: (1) moving the antenna closer to that area, (2) removing obstacles between the area and the receiving antenna, and (3) eliminating metal objects that may be causing

multipath (i.e., out-of-phase signals) or relocating the antenna to minimize the problem.

Maintaining a do-it-yourself RTel system should not be difficult for a good FM technician. Unfortunately, many TV and radio repairmen are not in this category, so choose with care.

Choose microphones that can be clipped to Ss' lapels. Those that hang from the neck generate considerable noise by brushing against clothing, etc. We use very cheap lapel microphones, of the kind sold in hobby shops. Their sound quality is good, and they are lighter and smaller than those of better quality. Though easily broken, they can be replaced many times for the cost of a good microphone. Microphone cables should be no longer than necessary and should be taped to the S (dangling cables are easily broken and can generate noise). Microphones built into the transmitter case do not work well, probably because they must be located too far from the S's mouth.

Attaching microphones to transmitters is a difficult problem. Plug and jack connectors tend to become disconnected. Small screw-type connectors attached to the transmitter case break easily and are expensive to repair. Wiring the microphones directly to the transmitter complicates replacing broken ones. The solution is to attach 6 in. of a relatively heavy gauge wire firmly to the transmitter so that any pulls on the wire are not born by the electronic circuitry. This wire can then be attached to the microphone with a miniature microphone connector (Amphenol, Type 75).

We have used three methods of mounting transmitters on Ss. One involves the use of holsters and belts, made either of leather, or elastic webbing with Velcro buckles. This method is good with horizontal polarization because the antenna can be placed on the belt. Some Ss did not like this particular method because the transmitters poked them during some body movements. Fortunately, most Ss did not find this to be a problem. This method has been used without problems with sleeping children. Most frequently, we place the transmitter in a shirt breast pocket, either taping it in place or buttoning it with the pocket flap. This technique works well with vertically polarized antennas. Elastic tape (Transpore, by 3M) is used to attach the antennas (and microphone cables) to Ss' shirts. The elastic seems to help them stay attached, despite Ss' movements. This method worked well with young males, but girls of the same age found it unbecoming. A harness with a belt and holster around the chest, and shoulder straps to hold the belt in place, was not acceptable to Ss. Researchers working with infants and small children have used vests into which the transmitter, microphone, and antenna are sewn.

Mercury batteries provide the most economical power over the long run, despite their relatively high initial cost. Batteries last longer when used for several short periods than when used for an equivalent total time over one period. Test with a battery tester (a voltmeter will not do) before each usage. The tester should indicate battery

condition on a continuum, rather than a simple "good" or "bad," since a battery may be good to a general critical point, after which it falls off drastically. We have been able to determine this point with some precision, and suggest that researchers using RTel expend some effort to determine the critical point and to discard batteries as soon as they are past it. Since batteries degenerate even when not in use, do not buy vast quantities in advance.

With a few-hundred dollars, and perseverance, an unaided behavioral scientist can build an RTel system capable of monitoring Ss in an open area the size of a football field, in a home, or in a few adjacent laboratory rooms (provided interfering factors are minimal). A few wooden buildings in an area of up to about 10 acres is acceptable but they make the job more difficult and more costly (several thousand). More buildings and/or masonry construction located on such a large area will probably require professional engineering. Our system, designed to monitor two data channels (voice and respiration), on each of four Ss, simultaneously, from any point in an area of 8 acres that includes eight masonry and metal buildings, cost \$45,000 in 1970 and would cost twice that today.

ETHICAL AND OPERATIONAL ISSUES

Data reduction is a major task. The usual first procedure is to have a typescript made of the recordings. For normal-conversation tapes, this takes 2 to 4 h/tape h. Once a coding system has been developed and judges are well-practiced in its use, it may be possible to omit typescripts. We were able to do this with little loss of interjudge reliability. In the coding system we used, undergraduate assistants judged the presence of respiratory behaviors (coughing, laughing, yelling, heavy breathing) with high reliability (.80s-.90s) and emotions (anger, excitement) with good reliability (.60s-.80s). Boys' voices are much easier to distinguish than girls'.

It is illegal to monitor an unconsenting person (Section 605 of the Communications Act of 1934, as amended). Also, for grant-supported research, HEW regulations require that Ss be advised of any potential violations of their rights. Therefore, we obtain informed consent authorizations from the parents or legal guardians of children. We also obtain permission from persons who are frequently and intimately involved with any S, and we try to warn all persons who might be monitored, that this possibility exists. Everyone is assured that any information obtained via RTel, including that concerning immoral and/or illegal acts, will be treated with the strictest confidentiality, except in cases where there might be a serious threat to life or physical well-being.

Recordings and typescripts should be kept under lock and key, and research assistants should be hired only after producing three good character references. Assistants should be fully instructed in the ethical and legal necessity of maintaining confidentiality, and should sign an acknowledgment that they accept full legal responsibility for any damages arising from unauthorized and/or negligent disclosure. Provisions can be made for the institution's liability insurance to cover any claims that might arise from such disclosures.

A problem in using the FM band is that anyone with a nearby FM radio can eavesdrop, though we have had no indications that this has happened. It would be prohibitively expensive to develop an RTel system, especially in any commercial broadcast band, completely free from this possibility. Therefore, eavesdropping should be considered a low-probability act but one that could present a potentially serious, though unavoidable, problem, of which the "informed consent" regulations require that Ss be advised.

Other concerns that many RTel researchers express do not appear to be serious. Moos (1968), studying hospitalized psychotic adults, and Purcell and Brady (1966), studying asthmatic children in a residential treatment center, have concluded that Ss' wearing of transmitters has had little effect upon their behavior. Of course, a short period of S adaptation is necessary. In the Purcell and Brady study, this period generally lasted no longer than about three 30-min sessions, on as many days. With our Ss, one daily session of from 4 to 6 h seemed sufficient for adaptation.

A second concern is that Ss may not be willing to be monitored. With children from 10 to 16 years of age, we have had only 1 refusal and about 50 consents. When we monitored Ss for several hours daily for months, maintaining Ss' interest was difficult. This was due to the inconvenience of the procedure, not to reluctance to being monitored. Ss' cooperation for periods of up to 3 months of 4- to 6-h sessions each weekday evening was secured with small payments. Excessive inducements are inadvisable because of the invasion-of-privacy issue.

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