Evolution of Audio Recording in Field Surveys

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Abstract:

The tools of field survey administration change quickly. By taking advantage of new technology and adapting it for time-honored needs, survey managers can boost the effectiveness, efficiency and quality of data collection. One method which has evolved rapidly is computer audio-recorded interviewing (CARI), an approach to ensuring the quality of data through unobtrusive recording by the computer of the audio portion of in-person interviews, much as silent monitoring has been used to ensure quality at call centers.

Several developments in the past few years have improved the technical feasibility of CARI for routine and inexpensive use in field studies. Advances in file compression and available bandwidth enable collection of longer recordings with little strain on transmission capacity and no burden to the interviewer. Use of a simple external file for specifying items to be recorded in a Blaise instrument offers great flexibility in selecting portions of the interview for auditing, even permitting modification of the recorded-item list while an instrument is in production. A web-based monitoring application, for use by trained reviewers in evaluating the audio files, can now provide access to centrally located audio files by geographically distributed staff.

Progress has also been made from an operational viewpoint. Work has been done to determine the minimum amount of recording needed to achieve agreement among reviewers as to the authenticity of the recorded session, and cost modeling shows that CARI can provide quality assurance at equal or reduced costs compared to more traditional approaches of re-interview or telephone verification.

Use of CARI on several national surveys has provided production experience to bolster laboratory tests. This article reviews the progress of CARI technology in the years since it was introduced, with an emphasis on feasibility for routine use with field surveys.

Key Words: survey technology; audio recording; computer audio-recorded interviewing (CARI); sound file; quality assurance; performance management; field interview; in-person interview

1. Introduction

Monitoring the performance of field staff and the quality of data collection has been challenging since the earliest in-person surveys. Traditionally, field staff have worked largely unobserved, with occasional shadowing by supervisory personnel or re-contacting the respondent to confirm the interview's authenticity and inquire about the professionalism of the interviewer.

It can also be difficult to evaluate or confirm the effectiveness of questionnaire items in field surveys, whether from a usability perspective, such as the ability of interviewers to read the questions in a fluent and understandable manner, or from the perspective of clarity for the respondent, such that the response provides the desired information without the need for explanation or probing. While focus groups or cognitive interviews in advance of data collection may offer insight into presentation and response patterns, the practice does not fully anticipate field conditions.

Now the situation has changed. Many computers now have audio recording capabilities, and some have built-in microphones. With this technology, surveys can be set up to collect digital audio recordings in an unobtrusive manner while the interview is taking place. With computer audio-recorded interviewing (CARI), sound files can be created electronically without the need for external equipment and can be transmitted along with response data files and tracking information. Because the recording process is "invisible," once consent has been given, it can provide a faithful representation of the reality of in-person data collection.

The technology provides a potent tool for deterring and detecting falsification, providing performance feedback and enabling study of questionnaire item effectiveness.

2. Audio Recording Technology, Past and Present

From the marketing of the Dictaphone in 1907 (Nuance Communications 2005) to the availability of miniature recorders embedded in portable electronic devices today (Dwyer et al,1998), people have been discovering ways to take advantage of audio recording tools to capture voices for later review. While the early acoustic recorders proved helpful for journalistic interviews, they were not usable for large-scale research surveys; the introduction of cassette tapes improved convenience for interviewing (Stockdale, 2002).

With the advent of digital recording, and as computers began offering built-in sound cards, the task of capturing audio records became easier and sound

quality improved. Sound files now can be recorded electronically through sound cards and software on laptops, handhelds and other portable devices, making this technology handy for use in field surveys.

Figure 1. Milestones of audio recording history

Audio Storage	Invention	Widespread Use
Wax cylinder	1885	Early 1900's to 1940's
Magnetized wire	1898	1940's
Magnetic coatings on plastic tape	1928	1930's to present
Compact cassette	1963	1960's to 1990's
Pulse code modulation	1937	1990's
Digital audio microprocessor	1971	1990's
SoundBlaster audio card	1989	1990's
First use of CARI	1999	Present
Portable digital voice recorders	2003	Present

In 1999, use of digital audio recording was first developed and deployed on a national field survey, as the result of innovative work by RTI developers R. Suresh, A. Bethke and P. Cooley. Use of CARI has grown since then, as the feasibility and utility of the approach have been confirmed. Electronic recording requires little attention during the interview, as there are no tapes to change, no additional equipment to set up and no distraction during the interview. Feedback from respondents and interviewers indicates that most people forget about digital recording when the microphone is internal, once the interview gets underway.

Many laptops now have built-in microphones, sound cards and adequate disk space for conducting audio recording. Handheld digital recorders from some companies offer audio recording capabilities but function much like analog tape recorders, requiring the user to switch them on and off manually. A few handhelds offer programmed recording capabilities plus an internal microphone. Most laptop and many handheld computers allow use of an external microphone instead of the internal one, for improved audio fidelity. However, the visible hardware calls attention to the recording process and may be more likely to affect the respondent's and interviewer's behavior.

Audio fidelity from any device depends on a number of factors. When using a laptop with internal microphone, these include

- Placement of the microphone with respect to noise-producing hardware (keyboard, fan and disk drive)
- Placement of the microphone with respect to the interviewer and respondent.
- Microphone control settings.

Some internal microphones are adequate to capture voices within 8 feet or so of the laptop when configured properly, at a quality level that allows a listener to distinguish among multiple voices and discern the spoken content.

3. Audio Recording for Quality Assurance

Although there are several advantages offered by implementing CARI, perhaps the most compelling reason is to confirm the authenticity of data for a reduced cost compared to traditional verification methods. CARI can act as a deterrent to curbstoning and as a tool for detecting questionable interviews. Interviewers who are aware that monitors may listen to parts of each interview may be less likely to falsify data, because the audio file acts as a "witness" to their actions. In this way, the simple presence of CARI can reduce cheating.

Speech patterns heard in audio files provide information to the monitors about the veracity of the interview, as indicated by the timing and phrasing of questions and responses. In a normal interchange, people pause between words, phrases or sentences, as they consider their answers or express their views (Kowal et al, 1975; O'Connell and Kowal, 1983).

Figure 2. Indicators of questionable authenticity

Silence	No voices can be heard, although room noises and key clicks are audible
Mumbling	The interviewer can be heard, but appears to be speaking to him or herself
Unnatural patterns	The respondent answers too quickly or laughs in inappropriate places
Comments	The respondent or interviewer makes comments suggesting the interview is being falsified
Same voice	The same respondent's voice is heard in multiple interviews or does not match the stated sex or age of the respondent.

For example, when an interviewer acts alone and falsifies data, there may be no voice at all in the recording or only one voice without the expected pausing, inflection or clarity of voice which would be expected in a two-way exchange. If the interviewer enlists someone to pose as the respondent, the accomplice may display inappropriate attitudes or emotions, make unexpected remarks, respond without

pausing to understand the question or pause at unnatural places while inventing an answer. CARI monitors listen to the recordings, and quickly become adept at distinguishing between recordings of normal interviewing circumstances and suspicious ones, by listening for characteristics such as those in Figure 2. (Thissen and Rodriguez, IBUC 2004)

Using CARI, a survey organization may reduce its re-contact efforts and costs. CARI monitoring may replace most telephone verification calls or field re-interview. However, it remains important to have a second means for following up a small sample of the cases since some respondents may refuse to allow audio recording, and interviewers may attempt to use that option to prevent detection of poor interviewing habits or curbstoning. The benefits of CARI plus optional re-contact are twofold: it tells the interviewing staff that they cannot avoid monitoring even if they discourage their respondents from allowing CARI, and it allows comparison of the two approaches to confirm the validity of the results.

4. Data Collection Methodology

Another benefit of CARI is that it provides a method for identifying questionnaire problems and data collection difficulties in interviewer-respondent interactions. Field staff do not always conduct interviews in an optimal manner, and it can be difficult to obtain reliable information about their performance. While personal observation can provide a wealth of information, the presence of an observer may bias the evaluation. CARI offers a unique opportunity to listen to the interview exactly as it took place, without observation effects.

During the first few weeks in the field, feedback can be an important tool for reinforcing lessons learned during training. A CARI monitor may be able to provide feedback, either praise or constructive criticism, about the way in which the interview was conducted. Improper question administration which can be detected through CARI includes

- Paraphrasing
- Improper probing
- Suggested responses
- Poor enunciation
- Improper commentary

CARI can be used to identify positive behavior such as

- Precise adherence to protocol
- Adept handling of difficult situations
- Consistency, honesty, and professional behavior

CARI can also be used to evaluate the usability of questionnaire items. The audio recording of an interviewer's presentation of an item and the subject's response provides a clear indication of whether the item succeeds in several ways:

- Readability – based on the interviewer's fluency in presenting the item
- Clarity of content – based on the respondent's ease of understanding

Survey items which evoke negative reactions or require frequent explanations are detrimental to the response rate and increase the level of burden on both interviewer and subject. Using CARI, especially during field testing of an instrument, allows the survey specialist to evaluate the success of the questionnaire items in eliciting the desired information.

5. Privacy, Security, Consent and Legalities

For CARI to be used during an interview, participants must give express consent for the interview to be recorded. Respondents are told that their participation is voluntary and that their information and responses are confidential and will only be used for statistical purposes. In two national field studies using CARI, approximately 83% of respondents in one survey on a highly sensitive topic agreed to allow the interview to be recorded, and 93% of respondents on another less sensitive survey agreed. (Wrenn-Yorker and Thissen, FedCASIC 2005). For those who do not allow recording, traditional verification methods such as telephone verification interviews are used.

All survey data, including CARI recordings, must be safeguarded. In addition to design considerations based on user needs, careful attention must be paid to security and privacy issues when dealing with human data. In the United States, laws and regulations direct the management of personal identification information, health records and other specific types of data. Computing professionals must be aware of federal, state and local requirements for confidentiality in storage, transmission and release of personal information. Institutional review boards oversee all research data on human subjects, to ensure that the studies contribute to the greater good without harming individuals. To comply with guidelines and regulations, information systems may need to include authentication mechanisms, audit histories and user records. These are regulatory rather than usability requirements but are essential components of survey information systems.

Given heightened consciousness of confidentiality and security concerns, care is required in handling audio recordings. Even though the survey may not deliberately record personally identifying information, it cannot be guaranteed to avoid it. For this reason, audio files are best treated as sensitive data, much the way response

data is handled. Encryption may be desirable for digital recordings, and special care may need to be taken in handling tapes, if the recording is by analog device.

6. Audio File Formats

Digital audio recording can take place with various levels of sound quality, and the resulting files may be stored in various electronic formats. The sound recording algorithm affects the following:

- Audio file size and storage requirements
- Required software for recording and playback
- Quality of sound on playback
- Platform requirements and CPU demands
- Cost and licensing issues.

Many audio file formats have been developed over the years, and their sheer variety may seem baffling to the new observer. Recent attention has been given to mp3 (Motion Picture Group Audio Layer 3) format, but many other file formats exist as well. A few of the common formats are listed in Figure 3.

Microsoft Windows operating systems include Sound Recorder software which writes to the wave file format, and the Windows Media Player which can play back wave files and a number of other non-proprietary formats. The PCM (pulse code modulation) digital recording algorithm is used in various encoders including Sound Recorder, and records uncompressed sound with no required licensing.

Figure 3. Common audio file formats

Name	File Extension	Use
Wave	.wav	Windows uncompressed
MP3	.mp3	Compressed audio
RealMedia	.rm	Compressed audio
RealAudio	.ra	Compressed, for streaming audio
AIFF	.aiff	Macintosh default uncompressed
CD Audio	.cda	Music CD tracks
Active Streaming Format	.asf	Streaming audio

Wave files are not especially efficient at storage, but the recording process places little demand on the computer. The size of a particular wave file depends on the recording parameters selected in its creation. For each available audio file format, there is a choice of sampling rate, bandwidth, number of channels and other parameters. For RTI's current CARI system, the standard configuration is 16 bit bandwidth, 11.25 KHz sampling rate and a single channel. Recording two channels (stereo) would require twice the storage space and provides no extra quality since a single microphone is generally used. Audio quality also is affected by sampling rate, compression and audio file format, and the settings given above are minimal for useful files.

To reduce the space for audio files, a compression technique may be used. Coder-decoder algorithms (CODECS) offer ways to store recordings in less space. They eliminate silence and mathematically map the sampled analog sound frequencies instead of preserving the actual data points. CODECS may be employed as a post-processing step after creation of the sound file or as a real-time action at the time of recording.

CODECS (compression–decompression techniques) were developed for use with audio recording, to reduce the size of sound files. It is possible for audio recording to combine the digitizing process and compression at once. For use in surveys, the system designer can choose among simple recording with no compression, simultaneous recording and compression or recording followed by compression. Section 11 discusses these approaches in a comparison of post-recording compression with simultaneous recording and compression

7. Integrating Audio Recording with Survey Software

A variety of technologies have been in use to implement survey instruments, such as Blaise (Statistics Netherlands), CASES (University of California, Berkeley) and web-based technologies like ASP.NET (Microsoft). Audio recording components have been successfully incorporated in all these environments. One of the challenges of incorporating audio recording in a survey instrument is to make the process unnoticeable to the interviewer. The recording process must not slow the system or provide any visual or audible clue as to when it starts and stops.

Audio recording can be added to Blaise instruments by using either of two programming approaches. One approach uses a Blaise procedure which in turn invokes an external application to start and stop the recorder. Using this approach requires complex programming within Blaise in every place the recording application needs to be invoked, to keep track of whether recording is already in progress or needs to be started or stopped (Thissen and Rodriguez, IBUC 2004).

The second approach uses the Blaise alien router. Starting with version 4.6, Blaise introduced the alien router as part of the Blaise component pack. The alien

router technology allows the invocation of an external component before and after every survey item. Use of the alien router externalizes the complexities of tracking the recorder state. It also opens up the possibility of maintaining a text list of items to be recorded, external to the instrument. This reduces the complexity of instrument programming and allows easy modification of the list of items to be recorded, without any need to modify the data model or recompile the instrument (Thissen and Sattaluri, 2006b).

For CASES instruments the recording can be integrated by spawning a separate application to start and stop an external recorder (Wrenn-Yorker and Thissen, 2005).

When a survey is offered in multiple modes by using a web-based instrument, field interviewing may take place through a website running on the laptop without continuous connection to the internet. In that case, the audio recording component can be achieved by installing a client side Java applet and Java scripting, similar to the way in which CARI can be implemented for internet-based surveys (Suresh, 2005)

Once a survey instrument has been enabled with CARI technology, survey information systems (Thissen, 2004) must also be expanded to handle the audio data files. From a case management and data security perspective, CARI files are no more than response data stored in a different format. Issues and concerns are the same for files containing audio response data as they are for files of textual responses. File protection on the laptop, transmission to a central site, central storage, access by authorized researchers and eventual deletion must all be planned with the same security and confidentiality used for traditional response files.

9. Transmission

There are several options for transferring audio files from the field laptop to a central management system. The files can be sent using dialup transmission, broadband, or removable media like flash drives shipped by secure delivery methods. For small surveys, it may be practical to leave audio files on the laptops until the end of data collection. With the pervasiveness of broadband access at homes through cable modem or DSL (digital subscriber line telephone service), the capacity for transmitting large files has greatly increased. Still, researchers must plan for transmission when using CARI, since audio files can be large.

The choice of transmission option may depend on the size of files being transmitted. It is found that uncompressed audio recording consumes about one megabyte of disk space for each minute of recorded dialog. (See Section 11 below for a comparison of recording parameters and file sizes.) Assuming an instrument were programmed to collect three one-minute recordings which were compressed to 100KB each, the case management system would have 300KB to transmit for every case. If the interviewer transmits one case each day, these files can be sent using a dialup connection. The use of broadband allows transmitting a larger number of files or larger size files at a faster rate.

The third option, using removable external media and shipment, can be used when entire interviews or lengthy sections are recorded. However, security concerns, the effort of handling external media and the possibility of loss make this approach less desirable than automatic transmission via dialup or broadband. Still, it may prove useful when recording interviews in their entirety or when other forms of file transfer are not available.

Audio recordings may contain personal identifying information, whether by intention or by accident, and so it is important to protect these files by using encryption tools while they reside in any location accessible to unauthorized individuals. In addition, if files are transferred over the internet, secure socket layer (SSL) certification can be used, which provides a way to encrypt the data stream during transmission.

10. CARI Monitoring

After audio files are received at a central location, the monitoring process may be as simple as opening up the files using a free player tool like Windows Media Player or Real Player. However, since manual case management is impractical for all but the smallest of surveys, it is best to build a system that provides an interface for reviewing the files and a database for recording evaluations.

The monitoring system might be a client-server application or a browser-based application located on an internal or external network. Client-server applications restrict access to an organization's internal network and locally-located users, due to poor performance of database connections over long distance. A web-based approach has advantage of being available from any workstation which has access to the network, supporting organizations with review staff distributed nationally or even internationally (Thissen and Sattaluri, 2006a).

Regardless of the implementation, it should provide role-based access to protect the security of the information stored in the audio files. For example, three levels of access might be designed into the system:

- CARI monitoring staff, who listen to and evaluate audio files

- Supervisory staff, who designate monitors, manage caseloads and track review-completion status
- System administrators who configure new surveys and create new logins and passwords.

For large surveys, the system may also include an algorithm to select a specified percentage of files to be reviewed per interviewer. Ideally, it would offer the flexibility to adjust review rates for any field interviewer for any active survey, so that quality assurance personnel can increase monitoring of any interviewer who has been suspected of improper data collection practices. (Hartman et al, 2006)

11. Audio and Operational Results

In this section, we present some results of RTI's experience with CARI technology. The data given below were obtained by lab test, field test and production survey use of CARI processes.

A comparison of recording alternatives is shown in Figure 4, with an indication of the resulting playback sound quality. The column labeled "MB Per Min" lists the number of megabytes of storage required for one minute of sound when using the uncompressed wave file format. Similar patterns of relative file size can be found for other file formats.

Figure 4. Recording parameters

Band-width	Sampling	Chan-nels	Sound Quality	MB Per Min
8 bit	11.25 KHz	1	Low	0.66
16 bit	11.25 KHz	1	Medium	1.31
8 bit	22.5 KHz	1	Medium	1.79
16 bit	22.5 KHz	1	High	1.19
16 bit	44.1 KHz	1	Very High	5.25
16 bit	44.1 KHz	2	Very High	12.3

We have looked at alternative processes for compressing existing audio files. A wave file was compressed as a separate step after recording, using a specific CODEC and selected recording parameters. In terms of a CARI system, this process might be performed by the case management system after the interview was completed but prior to transmission. Using this approach, compression ratios ranged from a factor of 2 to 75. In general, if the recording was of very high fidelity stereo, the original file would be very large and compress greatly. Lowering the recording quality produces a smaller file originally but proportionally less compression.

At RTI, files are recorded with the Windows native Sound Recorder software called from Blaise or CASES, resulting in file sizes of about one MB/minute uncompressed. Use of the LAME (The LAME Project) open source compression algorithm and appropriate parameters yields an average compression ratio of approximately 11:1 without loss of audio quality, resulting in about 100KB files for one minute of audio.

Figure 5. File sizes obtained by concurrent recording and compression

CODEC	Input Sound Quality	Number Of Files Tested	Average MB/Min
MPEGRec	Low	4	0.98
MPEGRec	Mod	3	1.68
MPEGRec	V.High, Mono	2	0.96
MPEGRec	V.High, Stereo	1	1.80
RealMedia	Low	24	0.34
RealMedia	Mod	3	0.51
RealMedia	V.High, Mono	2	0.34
RealMedia	V.High, Stereo	1	0.47

In another experiment, we recorded sound directly to a compressed format, without intervening storage as a wave file. In a CARI system, this requires the instrument to call a specific recording application and CODEC, such as MPEGRec (mp3), producing a compact file that is ready to encrypt and transmit. The simplicity of this approach was attractive because compression was immediate and effective, as shown in Figure 5. On the down side, simultaneous compression and recording tax the computer's processing power. This reduces system performance, produces lag and visible indication of recording processes, and limits its usefulness.

Figure 6. Loudness Effect on File Size

File Format	Sound Level	Averaged Over # of Files	MB Per Minute
Wave	Silent	6	1.30
Wave	Quiet voice	9	1.31
Wave	Voice	6	1.32
MP3	Silent	6	0.97
MP3	Quiet voice	8	0.96
MP3	Voice	6	0.97
RM	Silent	6	0.34
RM	Quiet voice	8	0.34
RM	Voice	6	0.34

We tested whether loudness had any effect on the size of the recorded output file by looking at the level of sound in audio files compared to file size, for CARI files which where all recorded under identical configuration settings on the same laptop. Figure 6 shows the results of the comparison, demonstrating that there was no apparent effect of loudness on audio file size.

The quality of the sound files from the field is of interest, as an indicator of the feasibility of gathering information for large numbers of interviews. Figure 7 shows results from reviewing a sample of 11% of the first 1500 completed interviews from a survey. The asterisk (*) indicates that the default rating was chosen, as opposed to an explicitly-defined score. Rating the file quality rating was optional through the monitoring interface if the quality was acceptable for review (Hartman et al, 2006).

Figure 7. CARI sound file quality distribution

Sound Quality	Number of Interviews
1 – Poor	4
2 – Passable	5
3 – Adequate	21
* – Acceptable	48
4 – Good	49
5 – Excellent	37

Problems noted with audio files included background noise, static, faintness of voices, key tapping, hum and other recording problems which interfered with detection of vocal content. Audio files were considered adequate if voices could be plainly heard and understood, regardless of other noises. This definition of quality differs from any commonly used to rate the quality of audio recording for other purposes, such as musical entertainment, but it is appropriate for survey evaluation purposes.

Figure 8. Field performance problems detected through CARI

Count	% of Cases	Problem Definition
13	0.2	Authenticity Questionable
217	3.9	Reading - Minor Deviation
72	1.3	Reading - Major Deviation
73	1.3	Recording Errors
44	0.8	Unprofessional Behavior
86	1.5	Inappropriate Probing
79	1.4	Feedback not Neutral
1	0.01	Incorrect Incentive Provided

We have also gathered operational information on field staff performance from production use of CARI. Figure 8 shows the distribution of field performance problems found in one study after review of approximately 5600 interviews. A single case might be assigned multiple problem codes, and so the problem count total is greater than the number of affected cases (Wrenn-Yorker and Thissen, FedCASIC, 2005).

In general, field interviewers and respondents have been accepting of the technology. In a feedback study, 82% of interviewers felt neutral or positive about use of CARI and a post-interview survey of 283 respondents found that 70% of the respondents reported they had no reaction one way or the other, 15% reported liking the idea, while 13% disliked the idea (Herget et al, 2005). As noted above, assent to CARI by respondents ranged from around 83% in one survey to 93% in another. This assent was independent of consent to conduct the interview (Wrenn-Yorker and Thissen, 2005).

A small experiment was conducted to determine the minimum number of CARI audio files required for making consistent monitoring evaluations, that is, how many audio files were required before reaching a point where listening to additional audio files for an interview had no effect on the determinations. This work suggested that three audio files each of 30-second duration may be adequate for verification purposes. After review of three files, CARI monitors reached 97% agreement with the ratings found by review of five files, indicating that three files provide sufficient information for evaluation purposes.

It is difficult to compare costs precisely between CARI operations and more traditional re-interview or verification processes, because the traditional systems tend to be well established while CARI systems are still evolving. A theoretical cost-analysis model was created to compare the expected costs of operating both systems at the same “steady state” in which all systems had been implemented. Analysis of that model suggests that the steady-state cost of verification is less with CARI than for the traditional approach, but actual data were not available for that comparison.

12. Visions of the Future

Looking forward, we see expanded use of CARI in field surveys, for monitoring survey quality and also as an integral part of data collection. Advances in digital signal processing may support automation of activities now being done by CARI monitors or coders.

With regard to data quality monitoring, it may be possible one day to screen a large portion of the audio files automatically for evidence of falsification. For example, software may be able to distinguish between

audio files with and without voices and to identify the number of differing voices within a single recording. This technology could be employed for a population census or large survey that requires many interviews to be screened very quickly for falsification. Audio processing software may be able to determine respondent qualities such as whether a voice is male or female, or to match spoken interviewer words with the predefined question text, for evaluation of how well the interviewer followed protocol.

CARI can also be used as a data collection tool. A number of surveys tape record respondent responses that are subsequently coded, and CARI offers a convenient, unobtrusive alternative for collecting these recordings. Matching audio responses to a dictionary of expected words might allow automated coding of open-ended items or of an "other-specify" option of multiple-choice items.

Farther in the future, recordings may be transcribed automatically to text with can be parsed and analyzed. Current commercial software often requires "training" the package to recognize the user's voice, which limits usefulness in the field. However, research is underway on speech-to-text conversion tools in uncontrolled or "noisy" surroundings (Ming, et al, 2006), which may broaden its applicability to include home environments.

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