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This article reviews recent and emerging technology developments in survey research. Recent developments include computer-assisted self-interviewing (CASI) methods using audio and/or video, automated telephone interviewing systems (interactive voice response), and the World Wide Web. These developments are already having a profound effect on survey data collection. Newer technological challenges include wireless applications (mobile web) and portable digital devices. These technologies offer many opportunities to expand the way we think of survey data collection, increasing the ways we can interact with survey respondents and expanding the range of stimulus material that can be used. The implications of many of these new developments for survey data quality are yet to be fully understood. This article reviews the state of the field with regard to emerging data collection technologies, and their implications for survey research.

Keywords: automated telephone interviewing; survey research; opinion data; data collection technologies; Internet

How do we view the impact of technology on survey data collection? For some, each new wave of technological innovation brings new opportunity, offering new ways to enhance and extend survey capabilities. For others, each such innovation is viewed as a portend of the end of surveys as we know them. More often than not, the voices of the proponents of technological innovation and change drown out those of the detractors in the rush to adopt the latest technology.

To illustrate, Gordon Black (1999) proclaimed,

> Internet research is a "replacement technology"—by this I mean any breakthrough invention where the advantages of the new technology are so dramatic as to all but eliminate the traditional technologies it replaces: like the automobile did to the horse and buggy.

On the other hand, in his American Association for Public Opinion Research (AAPOR) presidential address, James Beniger (1998), noting that the "era of survey clutter" has already begun on the web, opined: "Good luck to any serious survey firms which pin much of their futures on the hope of being heard for long above the mounting background noise and confusion of the swelling tide of amateur and slapdash pseudopolls" (p. 446).

The concern about technology's effect on survey research is not new. Similar concerns and hopes have been expressed with each successive innovation, beginning with computer-assisted telephone interviewing (CATI) in the 1970s, and including computer-assisted person interviewing (CAPI) in the late 1980s and Internet surveys in the late 1990s. The rhetoric has not changed much during the years—each new technological development is hailed by some as the next big thing. For example, in 1972, Nelson, Peyton, and Bortner[2] claimed that

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CATI reduced costs, increased timeliness, and improved data quality; however, they did not provide detailed comparative data to support these claims (see Couper & Nicholls, 1998, p. 8). In summarizing the research evidence on computer assisted interviewing (CAI), Nicholls, Baker, and Martin (1997) concluded that "Although moving a survey from P&P to CAI generally improves its data quality, these improvements have not been as large, broad, or well documented as the early proponents of CAI methods anticipated" (p. 241). However, as they also noted, "None of the dire predictions made about CATI and CAPI when they were first introduced proved true after they passed from feasibility testing to production" (p. 241).

In other words, the reality is often neither as wonderful as the proponents of the technologies argue, nor as dire as the major detractors fear. Each new technology enhances and extends the range of possibilities and opportunities for survey research but also often introduces new challenges and issues for further research. Technology by itself is not inherently good or bad. It is how technology is harnessed in the survey endeavor that determines its effect. On the other hand, survey researchers are not the only ones exploiting each new technological breakthrough. To the extent that we or others misuse the technology, we cannot only harm our own survey endeavors but also make life harder for others too. One example is the rapid rise of telemarketing in the United States and elsewhere that is commonly blamed for the recent declines in telephone survey response rates.[2] A similar scenario with SPAM could have a damaging effect on the nascent web survey sector.

This article reviews several recent technological developments and their potential impact on survey data collection. This review is by no means exhaustive and is, of necessity, speculative, as many of the developments are not yet fully matured. One thing is sure in the area of computing and technology, and that is change will continue apace, making it dangerous to offer predictions beyond a few years hence.

TECHNOLOGY-RELATED TRENDS IN SURVEY RESEARCH

This review is organized around several interrelated and overlapping trends in survey research, inspired by or made possible by the introduction of new technology. These are (a) the move from interviewer-administered to self-administered surveys; (b) the move from verbal (written or spoken) inputs and outputs to visual and haptic[3] and/or sensorimotor inputs and outputs; (c) the move from fixed to mobile information and communication technology, for data collectors and for respondents; (d) the move from discrete surveys to continuous measurement; and (e) the move from data only, to data and metadata, and also to paradata. Each of these technology-driven trends is discussed in turn.

Interviewer Administration to Self-Administration

There appear to be two key drivers behind the move to self-administration for part or all of a survey. The first is the steadily increasing cost of interviewer-administered data collection, due in no small measure to the increased time interviewers need to locate, screen, persuade, and interview respondents. The second is a body of research evidence—particularly from computer assisted self-interviewing (CASI), but also from interactive voice response (IVR) or telephone audio-CASI—that self-administration improves the reporting of socially sensitive information relative to interviewer administration (e.g., Tourangeau, Steiger, & Wilson, 2002; Turner et al., 1998).[4]

Given this, we have seen the rapid adoption of technologies to facilitate the automation of self-administered surveys. Technologies such as CASI, IVR, and web surveys offer the control and complexity of CAI such as branching, edits, randomization, and so on, together with the benefits of self-administration (reduction of interviewer effects, reduced costs). This trend is well under way, and efforts are focused on further reducing the costs associated with developing and deploying such self-administered surveys, and counteracting problems of coverage and nonresponse. This is not to say that interviewer-administered surveys will fade into obscurity; however, rather that we will find more creative ways to supplement the traditional methods with self-administration.

Audio-Visual Advancements

The development of graphical user interfaces and the subsequent rise in multimedia computing have led to several major innovations in survey data collection, and this trend is also likely to continue in the near future.

Auditory communication. The use of digital sound (and, in particular, recorded voice) as output—that is, for the presentation of survey questions—has already had a marked effect on survey data collection. The first audio-CASI systems were developed on a Macintosh computer (Johnston & Walton, 1995) or using a separate sound device attached to a DOS-based laptop computer (O'Reilly, Hubbard, Lessler, Biemer, & Turner, 1994), and audio-CASI is now a well-established survey technology.

The use of digitally recorded voice for the delivery of survey questions is also widely used over the telephone, in systems variously called IVR (Tourangeau et al., 2002) or telephone audio-CASI (Cooley, Miller, Gribble, & Turner, 2000). To date, these applications have involved the recording of a live human's voice, a time-consuming and expensive undertaking, with the implication that typically a single voice is used. Recent advances in text-to-speech (TTS) systems have the potential to change this, making the production of sound files for audio-CASI or IVR much less of a drudgery. Such systems are already making major inroads in a variety of customer service applications, and customer acceptance will likely further encourage their use in surveys.

We recently explored the feasibility of TTS for survey applications, particularly IVR (Couper, Singer, & Tourangeau, 2004). We found that, while respondents can clearly distinguish between human and computer-generated voices, neither the break-off rates nor the answers to sensitive questions appear to be affected by the use of TTS instead of recorded voices. This opens the way to increased use of TTS systems for replacing the recording of interviewers.

In addition to the cost benefits of this approach, the use of TTS may allow customization of voices to match respondent characteristics—such as gender or age—were this to be useful. Furthermore, respondents could even be allowed to choose the voice of the automated interviewer, presuming, of course, that this does not reintroduce social desirability effects.

The use of voice as input for computerized surveys has lagged behind that of voice output; however, again this is an area of rapid technological advance with many promising survey applications. One of the drawbacks of large-scale surveys is their reliance on quantitative data (i.e., closed questions). In translating respondents' verbal responses into check marks on a questionnaire or having the interviewers paraphrase their comments into a fixed-length field, we may lose the rich nuances of respondents' answers. We have sacrificed this rich detail in exchange for efficiency, relegating such information to the domain of small-scale qualitative studies. There have, as always, been exceptions—notably the traditions of taping structured interviews for the purposes of behavior coding (Cannell, Lawson, & Hausser, 1975), conversational analysis (Maynard, Houtkoop-Steenstra, Schaeffer, & van der Zouwen, 2002; Suchman & Jordan, 1990) or other methodological inquiries.

The ability to digitally record a respondent's answers as a routine feature of CAI produces potential efficiency gains that may make the use of such an approach a regular part of structured interviews, whether for evaluating interviewers (Biemer, 2003; Biemer, Morton, Herget, & Sand, 2001) or for better understanding respondents' answers (Hansen, Krysan, & Couper, 2005). Digital recording offers several advantages over analog. First, there is no need for a separate device and accessories (tape recorder, cassette tapes, etc.). The sound files are recorded directly onto the hard drive of the computer being used for interviewing. Second, the system can be controlled by the interviewing software—there is no need for the interviewer to remember to switch the recording on or off. Third, the system is less obtrusive than an external tape recorder, potentially eliciting more candid answers from the respondent. Fourth, given that the system can be switched on and off at will, one can selectively record portions of an interview. Fifth, because the recordings are digital, the storage and manipulation of a large number of sound files are a much less daunting task than when the information was stored on cassette tapes. Finding and analyzing the appropriate segments becomes a trivial task. In addition, finally, speech recognition software could be used to transcribe the information, permitting the use of qualitative analysis software to code or extract themes from the information.

The capture of such verbal inputs could allow one to analyze not only the selected response to a particular question but also the certainty with which the respondent holds that view—not only from response latency measures (e.g., Bassili, 2000) but also from the verbal qualifiers used in responding, or even extracted from other nonverbal qualities of the vocal response. For example, Conrad and Schober (1999) explored the use of verbal disfluencies to detect the need for help and offer appropriate intervention in a text-based self-administered survey setting, and one can imagine this being extended to spoken input.

With the ease with which digital recording can be implemented, we are likely to see a revival and extension of techniques such as behavior coding and conversation analysis, for pretesting and for the in-depth analysis of responses in large-scale surveys, and for interviewer evaluation.

Visual communication. For the first century of their existence, surveys have primarily relied on words to elicit information from respondents. Words—whether presented visually in a mail or self-administered questionnaire, or aurally as read aloud by an interviewer—were the primary medium of survey administration. As always, there were exceptions, such as show cards for ad testing or readership surveys, pill cards, and some visual scales. However, the use of images was generally limited to specialized tasks or for only a subset of items, in part, because of the high cost of developing and reproducing the materials on paper.

With digital imaging technology, we have the wherewithal to extend survey measurement beyond the use of words to include a wide range of visual stimulus material. The use of full-color images and photographs is a technically trivial and relatively inexpensive undertaking. This is true in graphical user interfaces (GUIs) for CASI and in surveys on the Internet.

We are already seeing many examples of this in experimental research, and they are making their way into mainstream survey research. For example, a variety of scenic preference surveys have been conducted online (see, e.g., Wherrett, 2000), using unretouched photographs, digitally manipulated images, or computer-generated representations of various scenic attributes. Harris (2002) conducted a web survey to explore how people classified mixed-race persons, using a series of digital pictures that were "morphed" composites of real people. The Implicit Attitudes Test (Nosek, Banaji, & Greenwald, 2002) also uses digitally generated human faces. Digital images are already widely used in web surveys for a variety of purposes (e.g., Couper, Kenyon, & Tourangeau, 2004; Witte, Pargas, Roy, Mobley, & Hawdon, 2004).

Along with this increasing interest in the use of images and other visual materials in surveys comes the increasing appreciation of the potential effects of visual presentation on survey responses. Despite decades of survey research using self-administered questionnaires, relatively little research has focused on the nonverbal elements of the questionnaires. Redline and Dillman (2002) examined the effects of a variety of visual representations (especially for skip patterns) in paper-based surveys (see also Christian & Dillman, 2004; Jenkins & Dillman, 1997). Similar work is being done on the web (e.g., Couper, Tourangeau, Conrad, & Crawford, 2004; Heerwegh & Loosveldt, 2002; Tourangeau, Couper, & Conrad, 2004). These studies suggest that visual design is a powerful tool for facilitating the task of survey completion but can also affect the answers provided by respondents.

Audio-visual (multimedia) communication. In multimedia applications, the audio and visual modalities come together, and here again we are seeing several interesting developments. One is the use of video-CASI, or the playing of videos as stimulus material, in survey measurement. Valentino, Hutchings, and White (2000) created several versions of a television campaign commercial for a political candidate, varying the race priming across versions. These were randomly assigned to respondents for viewing in a self-administered part of a survey. Krysan and Couper (2003) explored race of interviewer effects using "virtual interviewers"—digital videos of real interviewers reading survey questions, displayed on a laptop computer screen. Video-CASI can be seen as a natural extension of audio-CASI, permitting a wide range of stimulus material to be presented to respondents in a relatively controlled manner. Use of such approaches is likely to increase in the future. As bandwidth increases, we may also see increasing use of multimedia in self-administered surveys on the web.

A related development is the increasing interactivity of self-administered surveys. Computerized survey instruments, whether on the web or a stand-alone PC, are not passive like paper-based instruments. They can react to user input. This feature is being exploited, to develop new methods of input (answering survey questions) and also in providing customized feedback to respondents. This goes beyond the presentation of visual or audio stimuli and allows the respondent to interact directly with the stimulus, for example by clicking on or manipulating the image (see the Center for Behavioral and Decision Sciences in Medicine, `www.cbdsm.org` for example Java-based tools for the web). Direct manipulation input devices also include slider bars, drag-and-drop, or other tools for indicating a response (e.g., Couper, Singer, Tourangeau, & Conrad, 2004). In addition, the interactive nature of computer administration can be used to provide visual and auditory feedback (e.g., online lookup, running totals) to aid respondents in surveys involving complex decision making or other difficult tasks. While touch interfaces are already common, full haptic interactions, permitting respondents to manipulate virtual objects, may not be far off.

Mobility

The third broad technology-related trend is the move from fixed to mobile information technology, for interviewers and respondents. Again, each of these is discussed in turn.

Mobility for interviewers or data collectors. Some dozen years after the introduction of CAPI, interviewers conducting face-to-face surveys often still lug 5-pound to 7-pound (about 2 kg to 3 kg) laptop computers around. Several researchers have explored the use of handheld computers; however, their power, storage capacity, and screen size have limited them to niche applications, such as in-store pricing surveys or short doorstep interviews (see Bosley, Conrad, & Uglow, 1998; Gravlee, 2002; Gray, 1999; Nusser, Thompson, & Delozier, 1996). Personal digital assistants (PDAs) have been used for household screening in several large-scale surveys in the United States; however, the interviewers also carry laptops for conducting the actual interviews.

Despite major advances in the field of mobile computing, the hardware used for CAPI surveys has not changed much since first introduced in the late 1980s. To be sure, we have seen major gains in computing power and storage capacity, and we have seen the evolution from DOS to Windows; however, the basic form factor (i.e., the look and feel) of the CAPI device is largely unchanged. The recent reintroduction of tablet PCs, coupled with the launch of Microsoft's Windows XP for tablet operating system, may reinvigorate interest in keyboardless machines suitable for survey interviewing in the field (see Couper & Groves, 1992, and Lyberg, 1985, for early research on the issue).

Several factors—including improvements in handwriting recognition, storage capacity (obviating the need to recognize the handwriting at the time of entry, the digital image can simply be stored for later manipulation), the development of alternative input modes for open-ended responses (e.g., digital audio recording), and the development of touch-screen audio-CASI systems (Cooley et al., 2001; Schneider & Edwards, 2000)—are all converging to point to the likely success of the new wave of tablet machines for survey interviewing applications.

Field data collectors are becoming more mobile in other respects too. With the advent of what is called *ubiquitous computing* or wearable computers, the devices that an interviewer can carry, and the kinds of data they can collect, are expanding. One example is the use of portable global positioning systems (GPS), permitting the collection of location and spatial data as part of the survey process. Nusser and colleagues (see `http://dg.statlab.iastate.edu/dg/`) are exploring a range of survey applications, including field measurement in land-use studies and more traditional survey data collection such as in-store pricing or doorstep surveys. A variety of other portable devices and add-ons to handheld computers—digital cameras (video and still), bar code readers, and so on—are further expanding the view of what constitutes survey "data."

Mobility for respondents. The most obvious of these developments is the rise of the mobile or cellular phone, and its potential impact on survey research (see Callegaro & Poggio, 2004; Kuusela & Simpanen, 2002). Mobile phones present a number of challenges with respect to sampling and coverage. One key issue is the move from the household to the person as a sampling unit. Fixed lines are more likely to be associated with a household, whereas mobile phones are mostly linked to individuals. This will remain an issue during the transition from fixed to mobile telephony and has important implications for sample design and coverage. While the worldwide number of mobile phones has overtaken that of fixed phones (Srivastava, 2005), coverage is still at a level in many countries that—for the immediate future at least—telephone surveys will be conducted with fixed and mobile phones, or even fixed only (Blumberg, Luke, & Cynamon, 2004). This will require dual-frame designs or the need for unduplication. Another coverage concern is that the definition of access or use is trickier with mobile phones (as with the Internet) than fixed lines, given the relative impermanence of mobile telephone numbers (as with e-mail addresses).[5]

On the other hand, the cost of these devices is reaching a point where coverage problems could be overcome by providing every sample person with the requisite equipment. This obviously requires some other mode for initial selection; however, for ongoing panels, this investment may pay off. Some small-scale tracking studies already provide the respondent with a mobile Internet device (e.g., Blackberry), PDA, or mobile phone for follow-up data collection (e.g., Aaron, Mancl, Turner, Sawchuk, & Klein, 2004).

The change in personal telephony has many potential implications for nonresponse too, and this may affect all types of telephone surveys. Given the increasing prevalence of screening devices (caller ID, answering machines, voice mail, etc.), along with the fact that mobile phones are not always switched on, the odds of reaching a live human being on any particular call attempt are likely to continue to decrease, thus increasing the costs of such attempts. New ways will need to be found to gain access to sample persons. While the portability of mobile phones may increase the chances of making contact relative to a fixed line, the likelihood of the contacted person being willing to do a telephone survey at that time may decrease. How respondents react when called while in transit, or in the middle of a wide variety of other activities, is an important area of research, for nonresponse and for measurement error (Fuchs, 2002).

The high variation in the cost structure of mobile phone systems presents a further challenge (Vehovar, 2002). This may affect not only the likelihood of successfully reaching a potential respondent and gaining her or his cooperation but also the efficiency of telephone surveys. On the other hand, there are potential benefits in terms of delivery of incentives—for example, electronic transfer of money, or adding minutes or money to a cell phone account in exchange for participation, especially for pay-as-you-go mobile phone plans.

Finally, a mobile phone is a very different device from a traditional landline telephone (see Srivastava, 2005). Indeed, the very notion of what constitutes a mobile phone is becoming murky. With the ability to send text messages, take and transmit photographs, connect to the Internet, and so on, the mobile phone is becoming much more than a human-to-human speech communication device. In addition, other mobile Internet devices (e.g., PDAs) are adding voice (telephone) capabilities, further blurring the line between devices. With the widespread use of text messaging (e.g., short message service or SMS), the telephone may be moving from a synchronous to asynchronous communication.[6] SMS and voice mail may have more in common with e-mail than with traditional telephone communication. Given this, SMS may be may be useful for short frequent data collection activities, or for inviting respondents to complete surveys at their convenience (Callegaro, 2002). While research on the implications of the mobile phone and mobile Internet revolution for survey research has been relatively slow to develop, we are likely to see much more in coming years.

Continuous Measurement

As already noted, many of these technological developments are related. The growth of portable Internet devices and mobile computing, like that of mobile phones, permits the development and extension of continuous measurement in surveys. In traditional interviewer-administered survey, the costs of sampling, contacting, persuading, and interviewing respondents is so high that it makes sense to maximize the opportunity to collect large amounts of data (often several hours of questions) at a single point in time, or, if a panel is used, at relatively lengthy intervals (often months or years apart). Continuous measurement using self-administered methods—beepers, mobile phones, Blackberries, and so on—changes the cost equation.

A relatively large initial investment may be required to enroll sample persons in a panel and provide them with the required equipment. Thereafter, using self-administered methods, with automated prompts, survey instruments, and reminders, small amounts of data can be collected at much more frequent intervals. This approach may reduce respondent burden, by spreading the load over a large number of shorter interactions. It may also improve data quality, by reducing the length of recall periods and collecting information much closer to the time of occurrence. These methods hold much promise for the study of relatively frequent and recurring behaviors (e.g., alcohol consumption, diet and exercise, mood, interpersonal interaction, etc.). However, these benefits may come at a cost in terms of other sources of error, including coverage, nonresponse, and panel effects. Several small-scale studies have already demonstrated the benefits of continuous measurement (e.g., Aaron et al., 2004; Broderick, Schwartz, Shiffman, Hufford, & Stone, 2003; Helzer, Badger, Rose, Mongoen, & Searles, 2002; Mundt, Bohn, King, & Hartley, 2002).

The idea of frequent or continuous measurement is not new. Diary surveys have a long history. These methods are already used in audience measurement (television and radio), often using passive detection methods to further reduce burden on respondents. Inbound IVR surveys are often used for the regular reporting of a wide range of behaviors. However, one weakness is that the initiative to call in or complete the diary usually rests with the respondent. The advent of affordable wireless Internet devices means that the machine itself can prompt the user. There is an immediate feedback loop that permits tracking respondent progress, checking compliance and completeness on a flow basis, and automatically delivering reminders, motivational messages, and even incentives as and when needed.

Another aspect of continuous measurement involves the use of transaction data. Computers are becoming less objects we interact with at certain times to complete certain tasks, and much more part of most everyday activities, producing digital traces of everyday life. Examples include all types of digital transaction, such as electronic payment (credit or debit cards), affinity cards (frequent shopper cards, frequent flyer cards), e-commerce, library card use, video rental, prescription cards, and so on. These are becoming so much part of everyday life that we are often unaware of the presence of these computing devices. Technology is thus giving us much greater access into people's lives. This offers unprecedented opportunities for research on activities that were heretofore inaccessible or prohibitively expensive to study on a large scale.

However, herein also lies the potential danger of such technology. The more we can potentially learn about people, the fewer people there may be willing to give us such access into their everyday activities. This raises a number of methodological, operational, and ethical challenges. For example, what kinds of information are people willing to share, and under what circumstances? How can data quality be assured when combining imperfect transaction-based data with the imperfect responses to survey questions? What analytic tools do we use to make sense of large volumes of dynamic data?

Data, Metadata, and Paradata

With the increase in complexity of surveys during the past few decades, largely driven by the use of technology, has come an increasing appreciation of the importance of metadata. Data are what we gather or produce, in its raw form. To make use of the raw data, that is, to turn data into information, we need data about the data. Metatada serves to describe the data, from details such as the codes associated with response options, to the description of the relevant questions and flow of the instrument, to broader descriptions of the study itself (see Bethlehem, 1997; Gillman, Appel, & LaPlant, 1996).

In 1998, I introduced the concept of paradata (Couper, 1998) to extend the notion of data about the data (i.e., metadata) to data about the process (i.e., paradata). There are many different forms of paradata, and they can be used for many different purposes (see Couper & Lyberg, 2005). For example, keystroke files or audit trails have been used not only for recovery from system failures but also for evaluating interviewers or survey questions (e.g., Couper, Hansen, & Sadosky, 1997). The time-stamp data that are routinely captured by computer-assisted software similarly have a variety of uses (e.g., Bassili, 2000; Heerwegh, 2003). At a higher level, computerized call record data or case management information are increasingly being used to better understand and manage the survey process (e.g., Groves & Couper, 1996; Groves & Heeringa, 2005)

As an automatic by-product of many computer-assisted survey data collection systems, the production of paradata is relatively cheap. The challenge has been, and remains, that of processing and analyzing the data in such a way that it is useful for methodological and operational purposes. The use of these auxiliary process data is likely to increase as we overcome these barriers to their use.

IMPLICATIONS AND RESEARCH CHALLENGES

What are the implications of the trends reviewed above for survey research? This can be viewed in two parts, first focusing on the survey process, and second on issues of data quality.

One consequence of the recent spate of technological innovations has been a proliferation of modes of survey data collection. Mixed-model designs are not only now common but also any one survey can be administered using several different modes, within and between respondents. While this has expanded the survey researcher's toolkit, it also means we need to be more precise in how we describe the methods we use to collect survey data, especially given how important these details may be more understanding the error structure of our estimates.

A related outcome of the more recent developments, particularly the Internet, has been the increasing democratization of the survey data collection process. In the early days of computerization, the cost of investing in the technology restricted its use to a few large survey organizations. The first CATI systems were run on mainframe computers. Similarly, the costs associated with equipping a large field force with laptops, along with the associated software and support systems, means that CAPI remains the domain of a few large survey organizations. The Internet, on the other hand, gives the lone researcher the power to survey large numbers of potential respondents cheaply and quickly. However, in doing so, the profession may be losing control over the quality of the work being done.

With the expanding range of measurements and the ability to collect data anywhere at any time comes an increasing concern about oversurveying or stiff competition from those using the same technologies for other purposes. Telemarketing has had a serious effect on telephone surveys, and the rapid proliferation of SPAM on the Internet similarly threatens to engulf web surveys. However, the number of surveys being conducted is also increasing. Anyone with an Internet connection can attempt to survey thousands or even millions of potential respondents at the cost of a little effort and a few dollars. Good research still takes time and effort (and, therefore, money). However, how many potential respondents know the difference between good and bad, or are willing to invest the time and effort to make the distinction? Not only is the sheer number of surveys increasing, we are also seeing increasing diversity in the quality of surveys being conducted. In this way, bad could drive out good. Now more than ever we need to educate the users of survey data, so that they understand the difference between shoddy work cheaply and quickly done and high-quality surveys that may take extra time and effort to conduct and, consequently, cost more. We need to develop better quality metrics and provide more details about the methods we use—going well beyond response rates and sampling error.

Along with the proliferation of new methods comes an increased specialization. In the early days of surveys, one person could know—and do—it all. Now many surveys (except for the simplest of ones) require a range of different specialized skills. It has become even more critical that people in each specialism communicate with each other and understand enough about the entire survey process to make such communication effective.

In a related way, the nature of survey statistics is also changing. For many decades, the basic object of analysis was one or more rectangular data files containing a set of variables for each of several cases. This is now expanding to include not only complex hierarchies (e.g., doctor visits, persons, households) but also spatial data, transaction data, and less-structured observational data. The data survey researchers have to analyze are becoming not only much richer but also correspondingly more complex. This presents new challenges and opportunities for survey analysis, and for the design and conduct of surveys.

Yet another consequence of the technological trends discussed above is that the distinction between surveys and experiments is becoming increasingly blurred. Given the ability to randomize within and across questions, to control the presentation of stimulus material, to deliver rich multimedia content, and to record a range of possible reactions (e.g., verbal responses, response latencies), experiments are increasingly being conducted using large and diverse samples of respondents (often via the web). Similarly, surveys are increasingly including experiments as an integral part of data collection. When an online experiment such as the Implicit Attitudes Test (Nosek et al., 2002) can attract more than 1.5 million participants during the course of a few years, experiments are no longer constrained to small samples of homogeneous populations (college sophomores). Whereas it is not a probability-based survey permitting generalization to a known population, the sheer size of such an undertaking has the potential to transform the research into something new and different. While we should not be blinded by the number or variety of respondents from all around the world that can be obtained via the web, we should strive to learn how these new technologies can be used to complement survey and experimental methods.

Given all of the above, the notion of what constitutes a survey—and even more important, what constitutes a good survey—is becoming increasingly important. The total survey error framework (see, e.g., Groves, 1989; Groves et al., 2004) remains a valuable tool for understanding the error properties of surveys and applies to newer technologies and approaches as well as to old.

Turning to issues of data quality, given the progression from voice and visual extensions of survey data collection to multimedia applications and even to virtual reality, it may become increasingly difficult to distinguish between human and machine. With the rise in "natural" interfaces and smart computers, the division between man and machine is breaking down—it is becoming less obvious what is human and what is computer. For example, with developments in speech systems (input and output) for telephony, it is sometimes unclear whether we are interacting with a live human or a computer. Similarly, using digital imagery, it is possible to create or morph "people" that are not real, and imbue them with rich personalities in artificial worlds or virtual reality. Given these developments, one of the challenges is figuring out which survey tasks are best for human interviewers to perform (e.g., motivating, persuading, locating, etc.), and which are best for computers (e.g., processing, calculating, standardizing, recording, transmitting, etc.). Asking questions in a standard way may be the ideal domain for computers, as the trend toward computerized self-administration (whether CASI, IVR, or web) is already showing. If we want to remove—or control for—interviewer influences on measurement, automation may be the way to go. However, we need to be careful about going too far. We also need to remember that an interviewer's task involves much more than the standardized delivery of survey questions and recording of responses. To what extent will new survey technologies replace interviewers, versus supplementing or supporting interviewers in their tasks?

Another issue arises with the increasing trend toward rich interfaces for self-administered surveys, namely the possible reintroduction of social desirability effects. As we make our automated surveys more and more human-like—using voice, visual images, video, and the like—we may run the risk of reducing the very advantage of these technologies in terms of honesty of responding (see Moon, 1998; Nass, Moon, & Carney, 1999). Our research on the web, IVR, and audio-CASI (Couper, Singer, & Tourangeau, 2003; Tourangeau, Couper, & Steiger, 2003) suggests that social presence—the addition of humanizing features to an automated survey interface—may not affect the answers people give to sensitive questions. On the other hand, using digital videos of interviewers in a video-CASI application, we have been able to replicate some race-of-interviewer effects found in surveys conducted by live interviewers (Krysan & Couper, 2003). This suggests that we need to remain vigilant that, as we move toward replacing live interviewers with rich virtual equivalents, we are not reintroducing some of the very effects we hoped to eliminate with the move to self-administration.

Another issue that will increasingly face the survey industry relates to privacy and confidentiality. Technology offers unprecedented opportunities for researching aspects of people's lives that were heretofore inaccessible or prohibitively expensive to study on a large scale. In 1998, Baker wrote, "We are about to enter an age in which the transactions of our daily lives will be entirely digital" (p. 597). Beniger (1998) further suggested that a time would come where people would willingly make such digital information based on everyday transactions available to researchers, possibly at a price. For many purposes, especially in marketing, advertising, product testing, and other fields, such self-selected samples are quite sufficient. However, there are many attitudes, behaviors, intentions, attributes, and so on, that people would be unwilling to have as a matter of public record. These are many of the things survey researchers or social scientists are interested in studying, precisely because this information is hard to obtain in indirect ways. People may be willing to put their "normal" or everyday lives on display for the researcher; however, it is the deeper, often hidden, selves that are of most interest to us—sexual behavior, drug use, other risky or illicit behaviors, prejudice, welfare cheating, purchase intentions (as opposed to past purchasing behavior), and the like. The increasing ability to pry into the intimate corners of people's lives may produce a backlash that limits such opportunity. As Rawlins (cited in Baker, 1998) noted: "Today's encryption technology could, if used widely enough, make us the last generation ever to fear for our privacy . . . if misused, it could make us the last generation with any notion of personal privacy at all" (p. 601). While we are making great strides in extending the measurement capabilities of surveys, allowing us to explore new realms of inquiry and improve the quality of existing measures, the new technologies have thus far brought few discernible benefits in terms of reducing errors of nonobservation. In terms of sampling, web surveys are at the vanguard of an apparent trend away from probability-based samples. A large number of web surveys are already based on self-selected samples or opt-in panels (see Couper, 2001b). The decision to participate is often made based on the topic or content of the survey, as revealed in the e-mail invitation. Despite the highly selective nature of such participation, researchers are making inference from estimates derived from these surveys to the Internet population, and even to the full population.

In the area of nonresponse, we may not gain much from the introduction of new technology. With some exceptions (and with certain populations, e.g., college students), mail surveys get higher response rates than equivalent web surveys (Couper, 2001a), and, when given a choice of mode, respondents overwhelmingly choose mail. The early claims that CATI and CAPI would result in improvements in response rates, or at least stem the decline, have proved unfounded. However, fortunately, so too have the fears that the introduction of these technologies would hasten the decline in willingness to participate in surveys. The evidence from CATI and CAPI suggests that the technology has played little part in declining response rates in interviewer-administered surveys. While CASI has had demonstrable effects on reducing measurement error, its impact on nonresponse has been negligible.

Given the trend toward opt-in surveys, more and more sample surveys are studies of cooperative volunteers, rather than a full cross-section of the population of interest. Poynter (2000) predicted that by 2005, 80% of research in Europe will be conducted with opt-in lists rather than probability samples, and 95% of this work will be conducted via the Internet. However, how representative are these samples? Although they may be large and diverse samples, can we assume that those who are accessible and willing to respond are identical to the balance of the population of interest on the key statistics of concern? Despite some evidence that propensity-adjusted samples of web volunteers produce some estimates that resemble those from other modes (e.g., random digit dial [RDD] telephone surveys; Taylor, Bremer, Overmeyer, Siegel, & Terhanian, 2001), there are also examples where the differences are substantial (Robinson, Neustadtl, & Kestnbaum, 2002; Schonlau et al., 2000). Similarly, while recent evidence suggests that the impact of decreasing response rates on survey estimates is not large (Keeter, Miller, Kohut, Groves, & Presser, 2000; Curtin, Presser, & Singer, 2000), this remains an area of concern—and one in need of much further research—to those using surveys for inference to broader populations.

In concluding their review of the extant literature on survey technology and data quality, Nicholls et al. (1997) noted that "computer assisted methods do not provide a panacea (or even a general palliative) for survey noncoverage, nonresponse, and measurement error" (p. 242). The same is likely true of the newer methods of survey data collection. With the countervailing forces at work, each potential gain in terms of cost reductions, timeliness, or improved measurement may be offset by possible losses with respect to sampling, coverage, or nonresponse.

With the rapid development of new technologies and the accompanying proliferation of ways to design, conduct, and analyze surveys, it is more important than ever to have an educated professional and an informed public. We must provide the information that users need to distinguish good from bad surveys and evaluate the quality of different survey products. Quality is not an absolute (see O'Muircheartaigh, 1997). Quality must be weighed against other considerations, such as costs and timeliness. Good survey design always involves trade-offs, of maximizing quality for a given level of effort. The total survey error framework is useful now more than ever in evaluating the host of new methods that are being introduced. With the increasing complexity of the survey enterprise, and increasing specialization within the profession, a common language and a common understanding of the importance of quality is vital.

Two important ways we can prepare for an increasingly technological future are through (a) education and training and (b) good theory and good research. Regarding the former, specialty skills and cross-cutting knowledge are needed. Surveys are not simply a sum of a number of disparate parts. Decisions made in one area (e.g., sample design, interviewer training) affect many other areas (e.g., analysis, nonresponse reduction, mode choice). Now more than ever, we need trained professionals designing, conducting, and evaluating surveys, and analyzing the data they produce.

With regard to theory and research, the rate of technological change is likely to outpace our ability to do sufficient research on every new method prior to adoption. We need to strike a balance between a headlong rush to adopt each new technology at once, and waiting for all the research evidence to accumulate before making the transition.

Research and practice will of necessity go hand in hand. The era of large-scale methodological inquiries may be behind us. On the other hand, every survey can be seen as an opportunity, not only to produce data of substantive relevance but also to advance our knowledge of surveys. With a solid foundation of theory and practice, research and experience, survey research is ready to face the challenges and opportunities of the technological future.

NOTES

1. Given the title of their paper, "Use of an On-Line Interactive System," they could well have been writing about Web surveys rather than CATI.

2. The introduction of the Federal Trade Commission's National Do Not Call Registry in 2003 may have halted or slowed this trend; however, the damage may already have been done.

3. Haptics refer to the sense of touch.

4. CASI and IVR methods often still involve interviewers, but in a diminished role.

5. The implementation in the United States of wireless local number portability by the Federal Communications Commission in 2003 may change this.

6. Synchronous (or real-time) communication takes place simultaneously. Examples include chat rooms, instant messaging (IM) or telephone conversations. Asynchronous (turn-based or delayed) communication takes place at different times. Examples include e-mail and SMS.

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