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Telemetrics: Collecting Data at a Distance

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Telemetrics, the ability to collect data from a distance, is an increasingly powerful and useful research tool. As the internet has served as the primary means of conducting telemetric research to date, the impact of this research methodology is examined in detail as are many of the issues to be considered when developing new web-based research tools. The means by which other portable electronic devices, such as mobile phones, have been used in research capacities is also discussed along with the potential uses for newer self-tracking devices and software applications. Telemetrics offer many advantages relative to traditional data collection methods; the most compelling relate to sampling benefits and increased efficiency. However, these advantages are partially offset by several important concerns, including privacy and security related issues.

Central Issues

Introduction

Throughout history, technological advances have paved the way for scientific discovery. One of the most famous examples of this phenomenon is Galileo's telescope. By improving the Dutch invention that allowed visualization of distant objects as if they were nearby, Galileo laid the groundwork for modern astronomy. We call attention to the ability to observe data from afar, or *telemetrics* (derived from the Greek roots *tele* = remote and *metron* = measure), because this principle has recently been applied in the behavioral sciences with great success. Telemetric technology is exemplified by online data collection via the internet, though that is just one of the methods available for collecting data from afar. Additional examples - many of which are increasingly integrated with internet technology - include data collection via mobile phones and more recently developed self-tracking devices. These tools represent some of the greatest technological advances over the last 20 years. Telemetric technologies facilitate research because they allow instantaneous communication, quick exchange of data, and a high degree of interconnection among people (Birnbaum, 2004; M. Duffy, 2000). Furthermore, by virtue of their user-friendly interfaces, these technologies have the potential to attract large number of participants and thus revolutionize research of developmental theories.

Web-based research is by far the most popular telemetric method (and receives the most attention in this chapter as a result, though several other technologies are noted as well). Rapid increases in computer literacy over the last several years have been a primary factor contributing to the growth of web-based research. The internet is fast becoming the communication method of choice for the young and elderly alike (*Different people use the internet in different ways*, 2004). Whereas younger individuals gravitate towards social networking websites such as Facebook, MySpace, and Twitter to keep in touch with their friends, communities, and the world, older individuals are avid users of e-mail. Young and old alike use the internet daily for a wide variety of tasks including school and work-related projects, checking the news and weather, paying bills, playing games and making travel plans. The growth in general internet usage has been accom-

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panied by a boom in online research (Birnbaum, 2004). It is likely that utilization of the internet for conducting research will only continue to increase in popularity due to low cost and increasing ease of use (Barchard & Williams, 2008).

Already, millions of people have participated in online psychological research. Many web-based studies are designed to collect data from a large number of participants; exemplars of such studies have investigated personality traits (http:/www.outofservice.com/bigfive) and implicit attitudes and beliefs (https://www.implicit.harvard.edu). It seems that any psychological topic may be studied online on a large scale, as evidenced by the broad array of surveys, tests, and experiments listed on web pages devoted to advertising online psychological research (e.g., http://psych.hanover.edu/research/exponnet.html, http://www.socialpsychology.org/expts.htm/#listings). Over the past 8 years, we have collected in excess of 250,000 participants through our own web-based study at *The Personality Project* website http://personality-project.org. We can attest to the almost unfathomable ease in obtaining participants that the internet provides, which prior to the advent of online research was likely unthinkable. In contrast to studies aimed at obtaining extremely large sample sizes, the internet may also be used to conduct research on a smaller scale. This is especially evident and advantageous for studies of select groups or hard-to-reach populations. In fact, the ability to study such populations at all is one of the more compelling benefits of online research. In short, there are many reasons why online data collection has dramatically risen in prominence, as we discuss below.

Advantages over traditional methods

While we will consider the threats to validity inherent in telemetrics in a later section, here we consider their advantages. In the process of opening lines of communication on a global scale, the internet has put researchers in contact with people from all parts of the world. One obvious implication of such an extended reach is the sheer size of studies that may now be conducted. With nearly two billion users worldwide, it is safe to say that research has moved out of the realm of university undergraduate samples. Along with access to a wide variety of participants comes increases in the potential generalizability of results (Birnbaum, 2004). Results from online research may be able to avoid the routine caveat that the findings may be idiosyncratic to a small subset of the population. Researchers may also be more confident in the accuracy of their results due to the increased statistical power of using large samples. Estimates of population parameters and effect sizes can be incredibly precise when sampling from thousands of participants.

Not only has the interconnectivity of the internet increased access to large numbers of participants by casting a wide net, it has also provided access to previously hard-to-reach - and in some cases, impossible-to-reach - populations. Whereas geographic limitations may have previously restricted sample sizes of studies of special populations (e.g., individuals with developmental disabilities), space constraints do not apply to online studies. Thus, the challenges and costs of reaching such populations with face-to-face interactions can be circumvented through virtual interactions online.

The advantages that online research affords to the *process* of conducting research are just as compelling as those related to sampling (Ahern, 2005; M. E. Duffy, 2002). In particular, the costs of online research can be substantially reduced relative to other methods. Expenses associated with hiring staff are decreased as tasks typically done by human research assistants (recruiting, running studies, data entry) are automated. Beyond a computer and website domain, there are few material costs in running online studies. Participants in online studies are also routinely compensated with feedback about their responses to the study instead of monetary payments.

Data collection and entry may be completed quickly with online methods. Advertising studies is often as easy as posting a link on a web page or sending an e-mail - a method that can be used to reach many people in a short amount of time. After participants are made aware of the study, they often respond more quickly as well; for example, on average, participants respond to mail-based surveys within months, phone-based surveys within weeks, but web-based surveys within days (Granello & Wheaton, 2004). Willingness to participate in online research is boosted by potential participants' perceptions of increased anonymity. Data typically

are transmitted instantaneously and stored in a form that is easily transferable to statistical packages. The ability to stay in close contact with participants is another desirable feature of online research (Gosling, Vazire, Srivastava, & John, 2004). Web pages may contain links to more information about the study; dynamic web pages can be designed to give feedback to participants about their responses. Follow-up is easy and nearly instantaneous via e-mail.

It is important to note that the power of online research does not preclude the need for fundamentally sound research design. Due to the sheer magnitude of potential studies and the absence of face-to-face interaction, the ability to make valid comparisons across cultures may require researchers to focus more closely on issues related to the sampling of participants, the clarity of instructions given to participants from distinct cultures and the design of research instruments. On a more general note, the benefits of online research are not automatic based on the use of technology but require proper use of the tools employed and consideration of the possible impact that those tools may have (Hine, 2005).

Types of telemetric research

A wide and growing variety of telemetric tools are available for developmental research. Among these, the internet has certainly had the most meaningful impact to date as even the most traditional forms of "offline" research are often facilitated by electronic communications at some point. The internet's central role in telemetry is also likely to continue as the number of internet-enabled devices continues to grow. In fact, it is increasingly the case that the internet is being used in conjunction with other technologies which are used to record or access data.

The most ubiquitous telemetric tool is the mobile phone. While the penetration rates of mobile phones that are internet-enabled has increased dramatically over recent years (Federal Communications Commission, 2010), even less expensive mobile phones can be used in a research capacity via text-messaging technology (Wilt, Funkhouser, & Revelle, in preparation). A more unique method of telemetric research comes from the use of "electronically activated recorders" (Mehl, Vazire, Ramirez-Esparza, Slatcher, & Pennebaker, 2007; Mehl, Vazire, Holleran, & Clark, n.d.). These devices are digital voice recorders capable of collecting short audio recordings. Researchers who use this technology can record the sounds and conversations of participants at various intervals throughout the day in order to measure characteristics of their interactions. As these technologies and many more like them expand in functionality over the coming years, the breadth of variables that *can* be measured telemetrically will continue to expand rapidly.

In the meantime, there is a more-established set of methodologies employed by developmental scientists that are well-suited for use on the internet. The most common of these include the use of self-reports, informant-reports, open-response questionnaires, observational reports, ability tests, and experiments. As each of these methods can and have been adapted in various ways for use online, the remainder of this section is devoted to addressing the telemetric issues relate to each.

Self-report and informant-report. Self-report involves, quite simply, asking participants to describe themselves by responding to items or questions. Self-reports were traditionally administered as paper-and-pencil measures and now likely constitute the most popular form of online research. It is relatively straightforward to transfer self-report methodology from paper to the internet, as no specialized personnel or materials are required. Several free sites even eliminate the need to program forms to present, score, and store the items, as well as devise a method for error checking. Researchers must still consider common pitfalls including missing data and duplicate responses.

Important considerations must be made before administering self-reports online. First, it is necessary to evaluate the goals of the research and select scales for measuring the constructs of interest. Here it is essential to keep the questions and format of the items as simple as possible (Wood & Griffiths, 2007). Web pages should be easy to navigate, with instructions directing participants through each section of the self-report form. Although not commonly used, Computer Assisted Self-Interviewing (CASI) techniques may be particularly well-suited to guide partipants through an online self-report questionnaire efficiently (De Leeuw, Hox, & Kef, 2003).

In addition to self-reports, researchers may also

benefit by collecting the perspectives of others through informant-reports. These can be used either in conjunction with self-reports as a means of increasing validity, or as a substitute for self-reports when it is impossible to evaluate the subject in question. From a developmental perspective, informant-reports may be especially useful for children or elderly participants with cognitive deficits. Online research methods have made the previously difficult task of obtaining informant-reports relatively easy (Vazire, 2006). Typically this is done by asking participants to provide contact information for peers or family members that may best be able to rate the participant on a variety of characteristics. E-mail makes contacting informants easy and also allows the researcher to include instructions about the study and even links to the study web pages.

Open-response questionnaires. Open-response questionnaires - the online equivalent to face-to-face interviews - can save both time and expense over traditional methods. Participants may find online questionnaires more attractive and convenient as well. Whether responding on web pages or via e-mail, this method reduces the pressure to provide quick responses (Wood & Griffiths, 2007). Participants have time to reflect more about their answers and generate richer, more accurate data. Open-response questionnaires can also be particularly beneficial for studying sensitive issues. It is likely that participants feel more anonymous and less embarrassed when responding in this manner, thereby prompting disclosure of details they may not have chosen to reveal in a traditional interview setting (Tourangeau, 2004; Whittier, Seeley, & St. Lawrence, 2004). In contrast, e-mail and instant messaging may reduce spontaneity, which may be desired if believed to indicate more truthful or less filtered responses. Indeed, it is important to consider that asynchronous methods may change experiences of time and space and therefore have myriad substantive effects on the resultant data. Researchers aiming to simulate traditional interview settings may rely on instant-messaging programs or software allowing for video interviews (e.g., Skype). Video interviews also provide access to potentially valuable behavioral and emotional information, as facial and body movements and tone of voice may be coded to supplement the interview data.

Observational research. Observing behavior as it occurs is sometimes referred to as the gold standard of psychological methods (Funder, 2001). This makes good sense, as it is what people actually do that interests behavioral scientists. Although it may at first seem as if this method is not transferrable to online research, it is indeed possible to observe many social phenomenon or group behavior using telemetric methods. With proper permissions, video cameras may send live streaming feeds from school classrooms, business meetings, or social gatherings back to a computer that may store video and audio data. In addition to recording actual behavior, social phenomena such as group behavior occurring online may also be studied (Bruckman, 1999; Bos, Olson, Gergle, Olson, & Wright, 2002). Additionally, internet chat rooms and bulletin boards provide a rich sample of human behavior that can be mined for studies of communication. Adding to the flexibility of online methods, participants could be given expectations or goals regarding the interaction (McKenna & Bargh, 2000).

Ability tests. Ability tests are designed to measure how well individuals can perform in a given domain based on their ability to solve problems related to that domain. Well-known examples include the Scholastic Aptitude Test and the Wechsler Adult Intelligence Scale. While there is considerable potential for increasing sample sizes and reducing the cost of administering ability tests telemetrically, several challenges make it difficult to ascertain the validity of online ability tests which lack supervised administration. The most formidable of these challenges relates to the fact that most ability tests include a “speed” component - either by limiting the amount of time available or by taking the time to completion into account during scoring. Concerns related to timing are exacerbated by the inability to control the extent to which participants are using outside resources, such as other people or websites, to solve test items. Researchers can partially compensate for these difficulties through careful test design and programming, but these options remain inferior to supervised test administration. Another formidable challenge comes from the need to control the dissemination of ability items as failure to do so can compromise the validity of the item. However, with the advent of computer generated test items of known difficulties and discrim-

inations, it is possible to generate unique items for every visitor (Embretson, 2004).

In addition to following the guidelines used for designing self-report assessments, online ability tests may involve audio or visual presentation of items and thus necessitate more careful attention to browser capabilities. It is also typical for ability tests to be administered using Computerized Adaptive Testing (CAT), which is based on item-response theory and allows for more efficient testing (Embretson & Reise, 2000). CAT presents items in a response-dependent fashion and therefore may require more advanced programming capabilities. Advanced programming may be also required for researchers interested in recording information other than item responses which may serve as valid measures of ability, such as response latency, problem-solving strategies, etc. When giving participants feedback about their scores, it is important to use neutral and descriptive rather than evaluative language as people may be sensitive to negative feedback about their abilities. As in any research study, it is a good idea to write a detailed and clear debriefing in order to decrease the chances that participants misinterpret their feedback.

Experiments. Random assignment of participants to different conditions in order to conduct "true" experiments online is relatively straightforward, though these procedures are not necessarily pursued in most online assessments. In fact, most researchers using the previously described methods are looking for relationships between variables without manipulating aspects of the study between individuals. As with traditional research, correlational methods are most fruitful when combined with experimental methods (Revelle & Oehlberg, 2008) as randomization serves to break the correlation between experimentally manipulated *Independent Variables* (IVs) from non-observed but potentially *Confounding Variables* (CVs). Transfer of computer-based lab experiment to the internet generally requires relatively little difficulty though more advanced experiments may benefit from the use of specialized software applications that allow for advance graphics and more sensitive timing.

Researchers must also be aware of special circumstances that could potentially bias experimental results from online studies. It is crucial to protect against repeated participation in experimental designs (recommended safeguards are discussed in "Data quality"), and to standardize procedures and web pages as much as possible across participants. One may also record information about the computer and browser participants are using as well as asking about the environment in which they are taking the experiment as a means of measuring potential confounds. Familiarity with computers and the internet, as well as computer anxiety, may be especially relevant confounds for online experiments. Interestingly, researchers do not have to worry about the confounding effects of experimenter-participant interactions. However, this advantage comes with the limitation that participants are not able to ask for immediate clarification of instructions. A clear, simple, and thorough presentation of instructions and an easily accessible help function are therefore mandatory. Previously mentioned CASI techniques may prove useful here.

Designing an internet study

There are a plethora of programming tools to choose from when deciding how to design online studies. Presenting a comprehensive list of these options is beyond the scope of this chapter, but there are a number of articles (Barchard & Williams, 2008; Birnbaum, 2004; Cantrell & Lupinacci, 2007) and an excellent handbook (Gosling & Johnson, 2010) that contain detailed lists of resources and instructions for their proper usage. For those who do not want to do the programming themselves, there are also many commercial programs available that may be used to implement online studies of varying complexity (Crawford, 2002; Wright, 2005).

Researchers can flexibly customize their web pages to meet the specific aims of each study. Online studies may include both static pages, which present identical information to every participant, and active pages, which can differ depending on characteristics of the user, their computer, the time of day, etc. (Cantrell & Lupinacci, 2007). Items may be presented in a variety of ways: they may be ordered one after another on a single page, with subsets of questions on separate pages, or even one question per page. Items do not have to be presented in the same order to each participant. With the tremendous flexibility afforded by online methods, web-based studies will likely differ from each other greatly in terms of formatting and design. Yet there are a number of principles to which all

studies should adhere (Granello & Wheaton, 2004). All pages should use clearly delineated buttons and easy-to-read font; plain web pages without color are recommended. Forms can present special problems for persons with visual impairments, especially those using screen readers; thus, all documents should be accessible to persons with disabilities (see the Web Accessibility Initiative [WAI], 2002, for detailed instructions). Participants should also receive acknowledgment that they have finished the study shortly after completion.

Before putting the site into production, there are many steps that one should take to ensure everything runs smoothly. Some ways to do this include (i) submitting multiple entries of the data, filling in every field on the survey; (ii) downloading the data frequently to make sure it appears in the correct format; (iii) trying to find errors by purposely making the system fail, and (iv) observing a pilot group as they complete the study (Wyatt, 2000). Each of these steps decrease the chances that users will discover programming bugs after the study is active. As no study is perfect, it is likely that system maintenance will be necessary; if so, it is advised that researchers be careful when taking down active studies as it is bad form to interrupt participants while they are still in the process of completing the study.

Once the study is operational, it is time to recruit participants. Researchers can allow open access to the study or restrict participation to participants meeting certain criteria - either through the use of screening questions or by sending invitations to members of the targeted population (Nosek, Banaji, & Greenwald, 2002). Deciding where and how to advertise should be guided by the goal of obtaining a sample that accurately reflects the characteristics of the desired population. One may wish to post on websites likely to be frequented by members of the population or send out e-mails to listservs likely to contain individuals who meet the inclusion criteria. The existence of online communities (specialized or generalized) may also help one find individuals fitting each study's specific needs (Couper, 2000). Various commercial resources may be used to identify and select samples or post surveys to a nationally representative panel (e.g., http://www.surveysampling.com, http://www.knowledgenetworks.com/). Advertisements should include a short summary of the research proposal, outline how the results will be used, and provide details about how individuals can participate or obtain more information about the study.

Conceptual Principles and Statistical Assumptions

Is online research valid?

All of the advantages conferred by online research would be rendered null if it were shown that these methods had low validity. Indeed, there are still a number of potential hindrances to validity that merit consideration. Self-selection may present a large problem; for example, online intelligence tests may attract relatively intelligent individuals, and the ones who finish the test without dropping out may be even more intelligent than the average test-taker (Preckel & Thiemann, 2003). Internet users in any particular study may be rather homogenous in terms of their computer skills, their computer anxiety and their motivation to do well. The problem of self-selection may be compounded by the tendency for individuals to drop out of online studies at a higher rate than those conducted in the laboratory (Birnbaum, 2004). Lack of control over the environment may also hinder the validity of online research, especially for online experiments. Subjects can participate from nearly any location, whether from a quiet library on a desktop computer or a crowded party on an internet-enabled mobile phone. They may also consult with other people and other online resources regardless of instructions not to do so. Additionally, members of a defined population may not have equal access to the technology needed to complete the online study (Granello & Wheaton, 2004), resulting in further stratification of the obtained sample. In contrast to these potential deficits, it seems that online methods may be more valid than traditional methods in terms of obtaining representative samples and therefore more generalizable results. With its nearly unlimited reach, online research offers a way to recruit a highly diverse sample in terms of age, ethnicity, socioeconomic status, and various other demographic variables. Although the sample will likely not be as similar to the target population as it would be if representative sampling were used, it probably will be more representative than commonly used introductory psychology and high school samples.

Empirical research on the validity of online research has been accumulating steadily. In a review of nine studies, Krantz, Dalal, & Birnbaum (2000) found that results from traditional methods and online methods show a high degree of convergence. Research on the effects of computer-based testing (CBT) and computer-adaptive testing (CAT) showing similar results to paper-and-pencil tests also support the conversion of personality and ability tests to online versions (Clariana & Wallace, 2002). A recent study (Hardre, Crowson, & Xie, 2010) examined potential differences between web-based and paper-and-pencil assessments when completed in freely chosen contexts. Web-based studies showed a slightly higher percentage of data loss and lower overall time to complete relative to paper-and-pencil studies, whereas paper-and-pencil studies produce higher overall mean scores across measures, greater variability in responses, and higher positive affect for responding. Administration methods showed no difference on the internal consistency, positive-response bias, or strength of interscale correlations. A comprehensive examination of the validity of online research was conducted by Gosling et al. (2004). Online samples were found to be more diverse demographically than traditional samples. Internal consistency of measures and indicators of psychological adjustment were similar to those obtained using traditional samples and similar across different online presentation formats (e.g., radio-button vs. drop-down menus). It is clear that much more research is needed on the topic of validity; however, the results to this point are promising for online research.

Data quality

Validity depends in large part upon the quality of data that studies are able to obtain. Data quality is maximized when participants are able to understand and thus provide meaningful answers to items. Steps which increase the probability of collecting high quality data include the use of clear instructions, formats which are standardized and accessible to all participants (Nosek et al., 2002), and, if possible, web pages that are designed to guide participants through the study (De Leeuw et al., 2003). Even if most participants provide meaningful data, some will answer randomly or answer all questions with the same (or only slightly different) responses. Others may withhold effort, submit duplicate forms or lie. All of these introduce noise into the data. Researchers may take steps to reduce the chances that their data will be compromised in the face of these insidious threats. Researchers must pursue means of detecting random and duplicate data. Studies may include duplicate questions with definitive answers (e.g., When is your birthday?) to catch users who are not paying attention to the study. Detecting lies about age, location and other demographic characteristics can be difficult, though there are options for offsetting these hazards where necessary (such as requiring participants to register through an online service which can verify their information). Researchers should also consider strategies aimed at reducing the inclusion of multiple entries from the same participant, such as (1) simply asking participants whether they have previously completed the study; (2) disabling "back" or "reload" buttons; and/or (3) using "cookies", when allowable. Those concerned with the time that participants are taking on each part of the study may set timers on different parts of the test, record a time stamp, or forward participants through the survey after a predetermined time (Nosek et al., 2002).

Is online research ethical?

For any study, ethical research practices include protecting human subjects from physical and emotional risks, minimizing coercive features of the study, delivering adequate informed consent and debriefing, and ensuring confidentiality of data obtained from participants (Barchard & Williams, 2008). Online research involves little or no physical risk. Emotional risks, just as with traditional research, depend on the content of each individual study. However, there are vital differences between traditional and online methods that carry significant ethical implications.

An obvious difference is that researchers are unable to be physically present during the study. The absence of a researcher may decrease social pressure to participate or remain in a study when feeling discomfort. Therefore, online studies inherently carry less risk of coercion. Lack of researcher presence may also have the beneficial effect of increasing anonymity. Indeed, researchers may ensure participant confidentiality by deciding not to collect identifying information.

In contrast to the benefits discussed above, it's difficult - if not impossible - to capture verbal and

nonverbal cues from participants or to promptly answer their questions. These deficits may result in participants not receiving adequate informed consent or debriefing procedures. An additional threat to receiving adequate debriefing is that participants may decide to exit the study early. These problems should further motivate researchers to be especially careful in designing the statements of consent and debriefing. Including a "quit" button that directs participants to a debriefing page is thus recommended. Researchers must also be careful not to provide feedback or advice that is beyond their professional knowledge, as they have no chance to clarify such feedback.

Because researchers cannot visually verify that participants are the appropriate age to participate, they may want to institute safeguards that decrease the probability of the participation of minors: asking for participant age, advertising on sites that minors are not likely to visit, modifying the advertisement to appeal to adults, or having participants register through a service that can verify their age (Nosek et al., 2002). As no safeguard is 100% effective, researchers should also consider the potential implications should a breach of confidentiality occur for participants outside of the defined age range for the study (Barchard & Williams, 2008).

With the new and evolving risks that online technology presents for privacy in general, it should be no surprise that risks to participant confidentiality are relatively complicated. There are at least three differences between traditional and online methods with regard to privacy that merit careful consideration. The first is that the line between public and private behavior is blurred on the Internet (Kraut et al., 2008). Researchers should thus be sure to inform participants of the following issues on the statement of consent: (a) whether their responses will be identifiable or anonymous; (b) which parts of the information that they provide are being stored (as well as how it will be stored); and (c) which parts of their responses will be made public or remain private. The second difference is that data are transmitted across servers and thus may be intercepted. Some researchers may decide against collecting identifying information because programs may be able to intercept confidential info (social security numbers, credit card numbers, etc.) in transit (Kraut et al., 2008). It is important to note here that one may even elect not to record IP addresses because, although they do not directly identify the participant, they give location as well as machine information (Nosek et al., 2002). If it is necessary to collect identifying information, researchers may choose to separate the times at which they obtain participant responses and identifying information. If collecting identifying information at the same time as participant responses, encryption may be used as a means to separate content from identifying information (Nosek et al., 2002). Third, as data will likely be stored electronically (at least initially), respondents should be made aware of the risks and benefits of electronic records. The risks that hackers pose make it advisable to store data offline whenever possible as no online database can be made completely secure (Koocher, 2007). It is worth emphasizing finally that the increased risks to confidentiality necessitate that extra care should be taken when researching sensitive issues (Nosek et al., 2002).

Developmental Applications

The ease of communication provided by telemetric techniques facilitates tasks crucial to developmental research such as participant recruitment (Birnbaum, 2004) and informational interactions. Online tools allow for more effective and efficient interactions, which in turn allow researchers to attract participants more precisely, whether in terms of specific attributes or representativeness to the general population. With regards to data collection itself, there are some telemetric issues that are particularly relevant to developmental research, several of which are discussed below.

Collecting data in the natural environment

The ability to measure variables at a distance is of considerable benefit in that it allows participants to remain in their natural environment. There are a variety of circumstances where this flexibility is valuable. Especially in cases involving infants and young children, the ability to gather data outside of a laboratory can make participation significantly less intrusive in that it allows measurements to be taken in environments which are more comfortable for children and parents alike. This simultaneously reduces error and increases the flexibility to gather data at times which are conducive to the child's natural schedule. Certainly, the nature of the technol-

ogy being used to gather data affects the degree to which remote data collection will be successful. In cases where strict controls and/or specialized training are required to collect accurate measurements (as may be the case with imaging technologies for example), it may not be feasible to collect accurate data in the natural environment without supervision by a trained researcher. But in cases where the quality of data collection does not depend on specialized skills, such as with self-reports and open-response questionnaires, remote data collection can be an attractive alternative.

Longitudinal research

The appeal of remote data collection is perhaps most evident with longitudinal research. This is due to the inherent need for multiple interactions between researcher and participant. Maintaining contact with participants over time has traditionally been one of the most challenging and resource-demanding aspects of longitudinal research. By collecting some or all of the data remotely, researchers can reduce many of the costs associated with repeated measurements while simultaneously reducing the inconveniences imposed on participants. By doing so, it may be possible to include participants who would not otherwise be able or willing to participate due to physical or geographic constraints imposed by the need to visit the lab on a fixed schedule. There a number of examples of longitudinal studies which employ online research methods to great effect, including the Study of Mathematically Precocious Youth (Lubinski & Benbow, 2006) and the Dunedin longitudinal study (Moffitt, Caspi, Rutter, & Silva, 2001; Robins, Caspi, & Moffitt, 2002; Moffitt & Caspi, 2001).

This flexibility also provides longitudinal researchers the freedom to increase the reliability and frequency of assessment. Brief longitudinal studies, such as those designed to measure diurnal effects or developmental changes over critical periods, often require participants to provide information on a specific schedule. Before the advent of remote data collection technology, researchers using time-sensitive longitudinal data were dependent on participants' honest compliance. Using more recent technologies, researchers can prompt participants to provide information automatically according to a fixed or random schedule and verify when the data was collected with an electronic time stamp. As discussed earlier, technologies like the Big EAR even make it possible for researchers to collect information remotely without the participants' involvement (Mehl et al., 2007, n.d.).

Longitudinal studies for which the time-sensitivity of data collection is less relevant, such as with longevity and life outcome studies, can still benefit from remote data collection as well. One of the biggest challenges to long-term longitudinal research relates to the amount of time required to produce meaningful findings (Costa & McCrae, 1992). Researchers who conduct studies spanning several years or decades invest substantial time and funding and are therefore increasingly motivated to retain participants as the study progresses. As a result, the need to minimize attrition has been a strategic factor in the organization of many prominent longitudinal studies.

Illustration

Among the many examples of online data collection in psychological research, one which is particularly familiar to the authors and illustrative of many of the benefits and challenges is the ongoing Synthetic Aperture Personality Assessment ("SAPA") study. This procedure, which takes its name from the analogous procedure of synthetic aperture measurement in astronomy, allows researchers to capitalize on the large sample sizes which can be achieved by administering surveys on the internet. A thorough description of the SAPA technique can be found at Revelle, Wilt, & Rosenthal (2010). For the purposes of this illustration, discussion is focused on the origin of the items presented, the method by which the survey is constructed and the technology used to analyze the results.

Selecting items to be assessed

While the ability to collect data from more (and more diverse) participants is a considerable benefit of online data collection, it does not side-step the constraint that each individual participant is only willing and able to take a limited number of items. The SAPA procedure is designed to address this constraint, which is particularly relevant when a single construct can be measured in multiple ways (i.e., by distinct survey items or ability measures). For example, a greater number of survey items have been proposed to measure extraversion than could

be reasonably administered to a single participant. Each SAPA participant is given a subset of the items which relate to the construct(s) being measured (e.g. extraversion and whatever other constructs are being researched simultaneously). Through random rotation of the items across many participants, each possible pairing of items will be presented. In our example, the covariance matrix of several hundred items measuring extraversion and other constructs can be synthetically formed even though each participant is only responding to approximately 60 items. Statistical analysis of this resulting synthetic matrix allows for evaluation of the relationship between each pair of items as well as the higher level structure of multiple constructs (as if they were measured simultaneously).

Perhaps the most challenging aspect of measuring a given construct is the process of selecting the tools by which to measure it. For many of the personality constructs assessed by SAPA, this obstacle was substantially overcome by the independent development of the International Personality Item Pool ("IPIP") by Lewis R. Goldberg (Goldberg et al., 2006). Containing more than 3100 items, this pool is a repository of public-domain items for assessing a wide variety of personality constructs which we supplement with additional items to measure such constructs as cognitive ability, music preferences, Machiavellianism and hypomania, to name a few.

Survey development

Aside from selecting the appropriate measures, there are a number of important strategic considerations, including the recruitment of participants, the design of the user interface and the logistics for data handling. For internet-based surveys, it's generally necessary to provide some motivation in order to attract participants. In the case of SAPA, participants are motivated by the prospect of receiving a dynamically-generated report which describes their personality in terms of the Big 5 dimensions. The scoring for this report is based on an algorithm which compares their item responses against other participants of approximately the same age and gender. In addition to their scores and confidence intervals, participants are also given brief textual descriptions of their placement on each dimension, which are largely adapted from prior work by John Johnson (Johnson, 2005). Of course, it's difficult to overstate the importance of these reports as they represent a tacit agreement with the participant that the time spent filling out the survey will be worth their while. Participants are encouraged to share their results and/or a link to the survey and their willingness to do so is, to some extent, dictated by the accuracy and utility of their score report.

The user experience also plays an important role in the success of the survey. To that end, frequent improvements have been made to SAPA since its inception including recent updates to improve aesthetics and increase the specificity of demographic data collected from participants. In order to maintain participant confidentiality, none of the demographic data requested can be used for identification purposes and database access is password-protected. The databases themselves, which include item responses, demographic information and participant feedback, are regularly backed-up offline.

Data analysis

As is implied by the structure of SAPA, none of the participants provide responses to the full set of items and, in most cases, large samples are needed in order to evaluate the stable structure of constructs based on pairwise correlations. While these specific aspects of data collected through SAPA may be somewhat unique, it's often the case that data collected online requires powerful and flexible software for statistical analysis. The R computing environment is an excellent resource in that it offers over 2,500 specialized statistical packages and can be downloaded for free from the Comprehensive R Archive Network (CRAN) website (R Development Core Team, 2010). The *psych* package is of particular relevance for researchers who are interested in analyzing synthetic correlation matrices like those used with SAPA - as well as a variety of other psychometric functions (Revelle, 2010).

Current and Future Directions

Though well established in some respects, the adoption - and development - of online data collection techniques is still evolving rapidly. In particular, the increasing functionality and penetration of wireless technologies has led to a proliferation of portable tools which can gather data at the participant level and then transmitted them back to the

researcher via the internet. The best and most ubiquitous example of such a tool is the mobile phone.

Mobile phones themselves are not a new technology. However, there is some evidence that their increasing functionality for the transmission of data has affected the ways in which their users interact. In 2008, for example, voice usage among mobile phone users in the U.S. decreased from the prior year while the rate of data usage increased dramatically, with the bulk of the growth related to text messaging (FCC, 2010). Particularly among younger populations, penetration rates for text messaging are now quite high (FCC, 2010) and a growing number of researchers have begun adapting their methods to take advantage of this technology.

Of course, there are several ways in which text-messaging studies are distinct from "computer-based" research. Prior to the recent introduction of smartphones (which offer computer-like functionality in a mobile handheld device), text-messaging studies were distinguished by being more portable than studies which required a computer and an internet connection. While smartphone adoption has been rapid in recent years (FCC, 2010), studies that are dependent on such technology are more subject to sample biases based on the fact that they are meaningfully more expensive than traditional mobile phones with text-messaging capability.

Text-messaging studies also differ in terms of user-experience. Text messages are limited in length to 160 characters and, on phones without full keyboards, multiple button taps are required in order to input each letter. These limitations require researchers to develop questions and tasks which can be communicated briefly and which can be answered with short responses. Likert items and multiple choice items are ideal. One recent example of text-messaging-based research (Wilt et al., in preparation) relied upon the distribution of items to participants in advance. In this particular case, each participant was given a pre-printed card with items intended to measure participants' experiences in real-time at fixed intervals (every three hours) by asking about participants' moods and current activities. Researchers interacted with participants largely through the use of automated emails which were received by participants as text messages. In this way, initial instructions and automatically-generated reminders could be sent out at the precisely designated intervals. Participants sent their responses, via text message, to an email inbox for later data analysis (Wilt et al., in preparation). These data collection strategies allowed participants to quickly and discretely respond to the questionnaires in a way that was minimally disruptive to their current activities.

Text-messaging offers several advantages over more traditional methods for measuring experiential data. Relative to paper and pencil diaries, text-messaging is both more accurate and efficient. Researchers can be assured that responses are given at the designated time and the responses can be logged with considerably less effort for both the researcher and the participant. Relative to the use of PDAs and/or other specialized technologies, text-messaging is more familiar and generally less expensive (Steeh, Buskirk, & Callegaro, 2007; Wilt et al., in preparation). Unless face-to-face interaction between the researcher and participants is required, text-messaging studies also provide an effective means of interacting with participants from diverse locations. Among the challenges to consider before embarking on a text-messaging study, researchers must evaluate whether the technology is appropriate for the targeted population and how they plan to recruit cooperative participants.

Beyond text-messaging, there are a variety of emergent technologies with potential for widespread use among researchers, including several which relate to the nascent field of personal informatics. This field, also known as self-tracking, is fueled by individuals who collect - and in many cases analyze - important information about their own lives for a wide of purposes. Though the specific rationale for self-tracking varies from one person to the next, it is typically motivated by the desire to improve or maintain aspects of one's health, finances, productivity or interpersonal relations (Li, Dey, & Forlizzi, 2010). Broadly interpreted, this includes the widespread use of social networking services (such as Facebook and Twitter) where individuals can broadcast their feelings, thoughts, activities and desires in unlimited detail.

Personal informatics also includes the more precise ways in which individuals are taking measure of their own lives. In biological terms, the list of commonly self-tracked measures already includes caloric intake, body weight, the dosage and side-effects of medications, and time spent sleeping (Li et al., 2010). As it becomes more cost-

effective to collect and remotely transmit more involved biological measures (such as the presence of exogenous and endogenous substances in the skin or bloodstream), it's likely that these factors will be added to the list. In terms of behavior, a number of extant tools and services facilitate the tracking of an individual's movements (through GPS trackers and accelerometers in mobile phones), spending habits (via electronic bank statements and financial software) (Li et al., 2010), personal correspondence (by e-mail and phone records) and productivity (through the use of specialized computer software programs). Each of these tools offer the potential to measure individuals with an amazing degree of precision. While few people are motivated to analyze their own lives in such detail, the technology for doing so already exists. To the extent that people are comfortable with the complicated issue of sharing this information, the personal informatics field offers tremendous research opportunities.

More generally, the future of online data collection is likely to bring continued expansion across a broad variety of technologies. As the number and type of electronic devices connected to the internet increases, the distinction between data collected online and "offline" will decrease. While traditional paper-and-pencil measures are not yet near extinction, the need for such measures will dwindle as new technologies like touch screen computers facilitate their migration online. However, increased connectivity will not eliminate the primary obstacles to good research nor will the resultant efficiency and affordability substitute for fundamentally sound research designs. To the contrary, the likelihood that researchers will soon be capable of collecting staggeringly large amounts of data for each subject makes ethical conduct among the research community all the more imperative. It also highlights the need for ongoing development of data analytic skills and tools which facilitate the organization and interpretation of enormous data sets. Still, it seems as though the future of online data collection techniques is only limited by the innovations of those who employ them.

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