HANDHELD COMPUTERS

A Feasible Alternative to Paper Forms for Field Data Collection

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Recent advances in handheld computer hardware and software may provide alternatives to paper-based data collection methods. The authors compared data collected with paper forms to data collected with handheld computer-based forms in a field observation study of alcohol purchase attempts at 47 community festivals in a large metropolitan area. Agreement between data collected with paper forms and data collected with handheld computers was greater than 95%. Computer-based forms handled branching patterns better and yielded data that were immediately available for analyses. Paper forms handled written comments better. Handheld computers are a feasible alternative to paper forms for field data collection.

Keywords: *handheld computer; data collection; data quality; PDA; palm*

Data collection and management with paper forms can be an inaccurate and labor-intensive process. Data are often key punched twice and then reviewed for missed, out-of-range, or erroneous responses—an inefficient validation process that can be time-consuming and inaccurate. As the interval between data collection and validation increases, data collectors' recall decreases and some data become unobtainable. Recent advances in small, handheld computer hardware and software allow quick and reliable data entry in the field. Data entry at the time of collection overcomes the limitations of paper forms by providing immediate validation and eliminating the need for later manual data entry of responses written on paper forms. The

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goal of the current study was to examine the efficacy of handheld computers as a data collection tool in a field observation study.

Personal digital assistants (PDA) are small, handheld computers that typically have a pen-based data entry interface. PDAs, often used as personal organizers for calendars and address books, are becoming inexpensive and ubiquitous. In addition, PDAs are increasingly used for data collection in medical, business, and academic settings, and reports describing their performance have begun to appear in the scientific literature (see, e.g., Greene 2001; Malan et al. 2000; Navarrete 1999; Schmidts 2000). In medical and clinical settings in which data can be collected on-site, experimental comparisons of paper forms and various types of pen-input-based handheld computers for data collection have yielded promising results. In a retrospective review study, medical chart data collected with a PDA were retrieved 23% faster and generated 58% fewer errors than data collected with paper forms (Lal et al. 2000). Dental patients who completed a 78-item health history questionnaire both on a paper form and a handheld computer responded positively to using a handheld computer and provided data with 93% reliability across the two data collection methods (Berthelsen and Stilley 2000).

Compared to on-site data collection, field data collection with a PDA may present additional challenges to the researcher. To be useful in the field, data entry equipment should be small and easily portable, robust enough to withstand less-than-ideal environmental conditions, and easy to use so that the data collector can function independently where technical support is not readily available and potentially complex data must be entered into multiple field types. Even in light of these challenges, handheld computers show promise for effectively collecting data in settings outside of the research laboratory. In one study, research subjects completed menstrual histories using both paper forms and a handheld computer outside of the clinic environment. Researchers found an 81% reduction in data entry and cleaning time with data from handheld computers compared to data collected with paper forms. The handheld computer also resulted in less missed data, handled skip patterns better, and was preferred by participants over paper forms (Johannes et al. 2000). Greene (2001) found handheld computers to be small enough and robust enough to use for ethnographic research in numerous remote and urban settings. Several questions remain, however, regarding the viability of PDAs for data collection in general and data collection in the field in particular. First, the quality of data collected with PDAs is unclear. Although overall reliability was high (93%) in the Berthelson and Stilley (2000) report, they also found that only 2 out of 50 participants (4%) answered all 78 questionnaire items the same on both paper and the handheld computer. The authors suggested the format of the paper form may have contributed to the

discrepancies. None of the previous studies have tested PDAs against paper across multiple forms.

Data safety is another important issue to consider when comparing paper versus PDA data collection methods, as battery failure, damage, or loss of the PDA could result in the data being lost. Johannes et al. (2000) reported that records were missed due to battery failure in the handheld computer and one subject who missed an entire day of data entry. The potential for such data loss needs to be explored further before the PDA can be considered a viable data collection option in field settings where any number of unexpected conditions may lead to missing or compromised data.

Ease of use of handheld computers is another issue that needs to be explored. In some data collection contexts, the PDA might be used by individuals with minimal computer skills, which could lead to difficulties in the field. Although most studies report a favorable user response to the PDA, some studies suggest difficulties. For example, 17% of medical residents using PDAs for documenting procedures indicated they had trouble with data entry (Garvin, Otto, and McRae 2000). Research also suggests that text entries on pen-based PDAs are challenging (Wright et al. 2000). However, none of the preceding studies elaborated on the user performance on the PDA across multiple field types.

Finally, implementation costs of using PDAs versus paper for data collection is an issue to consider. Some of the previously mentioned studies used expensive hardware or employed sophisticated programming languages for implementation of PDA data collection. The costs associated with deploying multiple field-workers with expensive handheld computer equipment may be prohibitive. Likewise, hardware and software that require advanced programming or technical knowledge to use may not be feasible when resources such as computer programmers or systems support staff are not readily available. It would be desirable to test PDAs for data collection using the most economical approaches available.

We needed a data collection technology that was reliable, inexpensive, readily available, and did not require extensive technological expertise to implement or use. As such, we evaluated PDAs for data collection in a field observational study about alcohol sales at community festivals in a large metropolitan area. The main goal of this study was to experimentally compare data collected with PDAs to data collected with paper forms in a field observation study and to examine the quality of resulting data across multiple forms with varying lengths and field types. Secondary goals of the study included evaluating practical considerations of using PDAs for data collection such as implementation costs and ease of use for field data collectors.

METHOD

PROCEDURE

The purpose of the Alcohol Sales at Community Events project was to measure the propensity of servers to illegally serve alcohol to underage or intoxicated patrons at community festivals including fairs; art, music, and food festivals; and similar community events. Fourteen field data collection staff members attended community events that had licenses to sell alcohol to the public. A team of three field staff members attended each event and collected observational data about general event characteristics (i.e., type of event, type of security at the event), as well as data describing the results of two separate alcohol purchase attempts (one pseudo-underage, one pseudo-intoxicated) made at up to five alcohol service sites within the event (e.g., Were you asked about your age? Were you sold alcohol?). For a detailed description of alcohol purchase attempt protocols, see Forster et al. (1995) and Toomey et al. (1999).

Data collection field staff members recorded all data two times, once using preprinted paper data collection forms and once using data entry forms on a PDA. Field staff members discreetly filled out their forms at the event site, using both data collection methods one immediately after the other. The order of form completion was alternated by week, with the PDA method used first one week and the paper method used first the next week. Data were collected at 47 community events over a 14-week period.

MATERIALS

Paper. We created a set of four paper data collection forms to be completed for each community event. Forms contained yes/no, numeric, multiple choice, check-all-that-apply, and text field types. Forms varied in length and complexity. The simplest form, Form 1, had 15 questions and 2 branching fields, and the most complex form, Form 4, had 31 questions and 10 branching fields.

PDA. The same data were collected using lightweight, inexpensive, pocket-sized PalmIIIe PDAs (3com, Santa Clara, CA) with 2 MB of memory. Data entry is pen based, meaning a pen-like stylus is used to tap or write on a touch screen. Data from the PDA were synchronized with a desktop PC via a cradle attachment. With more sophisticated software and hardware, data from a PDA can be synchronized remotely via wireless communication, but

due to cost and additional complexity of remote synchronization, we elected not to use wireless technology in this study. However, the issues we explore here apply whether the data are synchronized remotely (wireless) or locally (via cradle).

Using Pendragon Forms 3.1 PDA software (Pendragon Software Corporation, Libertyville, IL, http://www.pendragon-software.com), we created four data entry forms for the PDA that were nearly identical to the corresponding paper forms. The scripting feature of Pendragon Forms 3.1 allowed us to create multiple field types as well as real-time data validation for the PDA in the form of automatic branching, range limits, and mandatory fields without using any formal programming language. For the majority of field types, the field staff used the stylus to tap the appropriate response on the PDA touch screen. Text data could be entered either by tapping the stylus on a tiny on-screen keyboard or by writing with the stylus using the Palm OS Graffiti handwriting recognition system that reasonably mimics handwriting. Questions on the PDA were presented one at a time to the user. When a given question was answered, the next question was automatically displayed. Thus, the PDA automated skip patterns or branching ensuring that the user was presented with the next sequential question (see Figure 1 for sample data entry screens). Data from the PDA were synced directly into an MS Access database (Microsoft Corporation, Redmond, WA) immediately following data collection.

FIELD STAFF

Fourteen field staff members were hired specifically for the community events project based on their perceived age or acting ability. The average age of the field staff was 33.8 years, with an age range of 21 to 60 years. Staff members were hired without consideration of their computer or technical skills. Only 1 person had ever used a PDA before the start of the study. Four of the 14 field staff members reported infrequent use of computers in their work or everyday life. Field staff members were trained to use the PDA during a 45-minute group training session.

STAFF SURVEY

All field staff members completed an anonymous survey at the end of the study. They were asked how well they liked the PDA, how comfortable they were using it, how difficult it was to learn, if the training was adequate, and how difficult or easy it was to enter data into text fields and other field types.

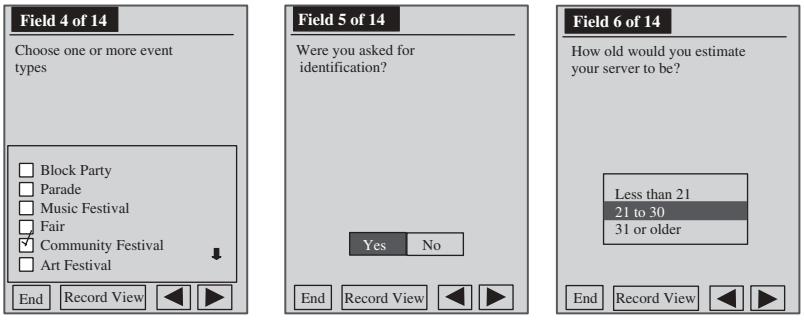

Figure 1: Sample Personal Digital Assistant Data Entry Screens

Staff members were also asked how often they needed help from other staff members when entering data on the PDA and whether they preferred using the paper forms or the PDA forms.

ANALYSIS

We examined each corresponding data point on the PDA and paper forms and assigned each to one of four categories: (a) "item agreement": data were available for both methods and matched exactly; (b) "item disagreement": data were available for both methods but did not match (we did not attempt to determine which response was correct); (c) "paper missing": data were available from the PDA but were missing from the paper forms, and (d) "PDA missing": data were available from the paper forms but were missing from the PDA. We then coded each question as a mandatory type (the item always had to be answered), a conditional type (item answered only if a pivotal question was answered a certain way), or an optional-text type (opportunity to add clarifying, text-based information) question. We assessed whether question type (mandatory, conditional, optional-text) or form (i.e., Form 1, 2, 3, 4) were possible predictors of each of these potential outcomes. Last, we assessed patterns of missing data as the study progressed to see if performance changed over time as staff members became more experienced with the data collection tools.

We conducted all analyses using SAS version 8 (SAS Institute 1999). Initial descriptive analyses included calculating percentage agreement, percentage disagreement, percentage paper missing, and percentage PDA missing.

We also calculated these separately for each form and for each question type. Differences were tested for statistical significance via a series of logistic regression models using PROC LOGISTIC. Models were estimated separately for the four outcomes (agreement, disagreement, paper missing, PDA missing) and the potential predictors, question type and form. All pairwise contrasts were estimated across the four forms and the three question types.

RESULTS

OVERALL COMPARISON

Based on 6,689 data points collected at 47 community festivals, the overall agreement between the PDA and paper forms was high at 95.5%. When all items were available for both data collection methods, the rate of disagreement was low at 1.3%. Finally, data were missing from the PDA but available from paper 1.5% of the time, and 1.7% of the time data were missing from paper but available from the PDA (see Table 1).

QUESTION TYPE COMPARISON

Question type was significantly related to agreement, χ^2 (2, n = 6,689) = 38.7, $p < .0001$. Mandatory questions showed the highest agreement (96.2%), followed by conditional questions (92.9%) and then optional-text questions (83.0%). All three were significantly different from each other (all ps < .05). Statistical comparisons indicated that there was no significant variability in disagreement across question types (see Table 1).

Question type was significantly associated with missing PDA data, χ^2(2, n = 6,689) = 43.5, $p < .0001$. Follow-up pairwise comparisons showed all question types significantly differed in rate of missing PDA data (all ps < .05), with mandatory questions showing the lowest rate (1.2%), conditional questions in the middle (2.3%), and optional-text questions having the highest rate (14.9%) of missing PDA data.

Question type was also related to missing data on paper forms, χ^2 (2, n = 6,689) = 44.8, $p < .0001$, with mandatory items having a lower rate of missing data (1.2%) than conditional items (4.1%). The rate of missing data for optional text items was not statistically significantly different from either of these (2.1%).

TABLE 1: Agreement Between Personal Digital Assistant (PDA) and Paper Forms

Data	*Total Number of Data Points*	*% Agree*	*% Disagree*	*% Missing PDA*	*% Missing Paper*
All items	6,689	95.5	1.3	1.5 (0.1)	1.7
By question type					
Mandatory	5,444	96.2	1.5	1.2 (0.4)	1.2
Conditional	1,198	92.9	0.8	2.3 (0.2)	4.1
Optional-text	47	83.0	0	14.9 (11.1)	2.1
By form					
Form 1[a] (n = 82)	1,230	99.4	0.1	0.0 (0.0)	0.5
Form 2 (n = 87)	1,740	96.6	1.8	0.1 (0.1)	1.5
Form 3 (n = 87)	2,262	94.7	1.5	1.2[b] (0.0)	2.7
Form 4 (n = 47)	1,457	92.2	1.6	4.8[c] (0.6)	1.4

NOTE: Numbers in parentheses indicate percentage missing when excluding missed records.
a. The forms are listed in ascending order of complexity.
b. One entire record missing.
c. Two entire records missing.

FORM COMPARISON

Significant variability in agreement across forms was seen, with a significant overall effect of form in the logistic regression model, $\chi^2(3, n = 6{,}689) = 66.8$, $p < .0001$. Examination of the means showed a consistent monotonic relationship between form complexity and item agreement. Form 1, the least complex of the forms, had the highest level of agreement (99.4%) between the PDA and the paper, followed by Form 2 (96.6%), Form 3 (94.7%), and Form 4 (92.2%), the most complex of the four forms. Follow-up pairwise comparisons indicated that all forms were significantly different from one another (all ps < .01) (see Table 1).

Although the overall disagreement rate was quite low (1.3%), there was significant variability across the four forms, $\chi^2(3, n = 6{,}689) = 9.85$, $p < .05$. Disagreement was about the same for Forms 2, 3, and 4 (1.84, 1.46, and 1.58, respectively) but virtually zero for Form 1 (0.1%, a single disagreement). Statistical comparisons indicated that Form 1 was significantly different from the other three forms (all ps < .01), but Forms 2, 3, and 4 were not statistically different from each other.

Three entire records (out of a total of 303) were missed on the PDA. Two of the missing records were from Form 4, which yielded a much higher rate of

PDA missing data (4.8%) than the other three forms (ranging from 0 to 1.2%). This finding, along with the findings on the effects of question type on missing data, complicates interpretation of form-level missing data comparisons. That said, the overall effect of form on missing PDA data was significant, $\chi^2(3, n = 6{,}689) = 56.3, p < .0001$. Statistical comparisons of PDA missing data between forms was complicated by the fact that Form 1 had zero missing points on the PDA. To directly statistically compare Form 1 to the other three forms, one missing data point was added to Form 1. This could affect results. Using this technique, it was found that all forms differed from each other (all ps < .01) except Forms 1 and 2.

The overall rate of missing paper varied across the different forms, $\chi^2(3, n = 6{,}689) = 21.2, p < .0001$. The rate of missing data was lowest for Form 1 (0.5%), highest for Form 3 (2.7%), and Forms 2 and 4 were in between (1.5% and 1.4%, respectively). Statistical comparisons found that all of the forms were significantly different from one another (ps < .05) except for Forms 2 and 4, which did not significantly differ.

Missing data over time. Figure 2 portrays missing data over time. Most of the missing data from the PDA were due to the three missed records. These occurred during the first half of the data collection period, with two records missed at Week 3 and one record missed at Week 10. In contrast, missing data for paper forms were distributed fairly evenly throughout the data collection period.

SURVEY RESPONSES

With few exceptions, field staff members reported positive experiences collecting data with the PDA (see Table 2). Entering text comments on the PDA appeared to be somewhat difficult for many field staff members. Four staff members reported using the Graffiti handwriting recognition system to enter text comments, and all 4 indicated they found text entry to be easy (a 4 or a 5 on a 5-point Likert-type scale). The remaining 10 staff members typed text responses using the on-screen keyboard, and only 2 of them felt that text entry was easy. There was a slight preference for the PDA, with 7 of the 14 field staff members indicating they preferred it over paper forms and 2 of the 14 field staff members saying they liked paper and the PDA equally well. Five field staff members preferred using paper forms. When asked how often they required help from other staff members when using the PDA, 3 staff members said *never*, 6 said *rarely*, 3 said *sometimes*, 1 said *often*, and 1 said *always*.

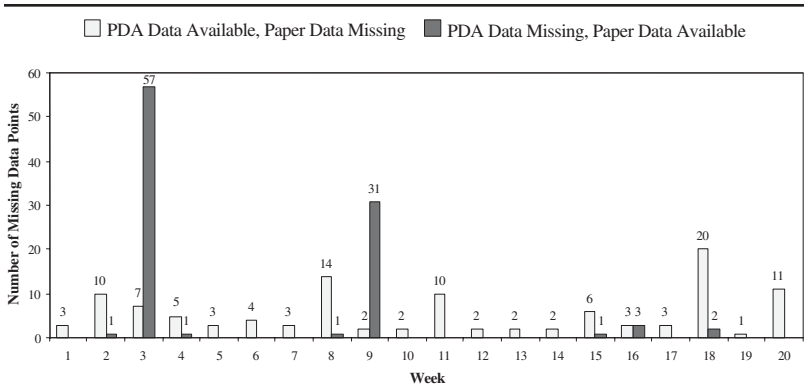

Figure 2: Missing Across Time: Personal Digital Assistant Versus Paper

COSTS

We kept track of major, out-of pocket expenses for the PDA versus paper data collection methods (not including staff time for programming the PDA or developing paper forms). We purchased two Palm IIIe PDAs at $149.99 each and software at $149.00 for the first user license and $45.00 for the additional license. The total cost with tax was $513.48. Data entry and double keying for verification was outsourced at a cost of $393.00.

DISCUSSION

PDAs can be easily adapted to meet requirements for field data collection. The overall rate of agreement between data collected with PDA and paper forms was very high (95.6%) and is consistent with previously reported results (Berthelsen and Stilley 2000). Agreement between the two data collection methods decreased as forms increased in length and had a greater number of different question types. Agreement was highest for mandatory questions and lowest for optional-text questions. Disagreement across data collection mediums was also low (1.3%) and did not appear to be related to question type but showed up only on the longer of the forms. The differences in data quality that had the most practical significance involved missing data in terms of missed records on the PDA, missed conditional questions on paper, and missed optional-text questions on the PDA.

TABLE 2: Survey of Staff Attitudes Toward Personal Digital Assistants (PDAs): Percentage Response for Each Category

Question	*Negative Anchor*	*1*	*2*	*3*	*4*	*5*	*Positive Anchor*	*Mean*
Rate your current comfort level using the PDA	Not at all comfortable	0.0	0.0	14.3	35.7	50.0	Very comfortable	4.4
Did you like using the PDA?	Very much disliked	7.1	7.1	21.4	21.4	42.9	Very much liked	3.9
Describe your learning experience with the PDA.	Very difficult	0.0	7.1	21.4	35.7	35.7	Not at all difficult	4.0
Would you have liked more training on learning to use the PDA?[a]	A lot more	7.7	0.0	23.1	23.1	46.2	Adequately trained	4.0
How difficult was it to write or type comments using the PDA?	Very difficult	0.0	50.0	7.1	21.4	21.4	Not at all difficult	3.1
How difficult was entering yes/no and multiple choice questions on the PDA?	Very difficult	0.0	7.1	7.1	28.6	57.1	Not at all difficult	4.4

a. One response missing.

Overall rates of missing data were similar across the two data collection methods (1.7% for paper vs. 1.5% for PDA); however, the patterns of missing data varied substantially across methods. Nearly all of the missing data for the PDA were due to three records that were missed entirely and to optional-text questions, whereas missed paper items were dispersed throughout the survey period but tended to show up on conditional questions. Importantly, records were not lost due to PDA malfunction but rather were never entered. This finding is similar to that reported in Johannes et al. (2000), suggesting that some reminder mechanism needs to be in place to ensure that users enter all records while collecting data in the field. Entire records were not missing with the paper forms, suggesting that blank paper may provide a helpful visual reminder to the data collector that a form needs to be completed after each observation. Although we did not lose data because of battery failure or damaged equipment, such loss is a possibility and also needs to be guarded against.

Most of the missing data for the PDA occurred during the first half of the data collection period and was due to missed records. In contrast, missing data for the paper forms appeared at roughly the same rate throughout the study. Missing data for PDAs may be more of a function of learning or comfort level with the PDA, or alternatively, could be an artifact of having to enter the data twice in this study. Missing data were least likely to occur with mandatory questions for both data collection methods. Conditional items or skip patterns were more frequently missed on paper forms than on the PDA. A significant advantage of the PDA is that skip patterns or branching is automated, forcing the data collector to answer the appropriate next question.

Other than the missing records, missing data for the PDA were found most often with the optional-text questions, which required data collectors to use either the on-screen keyboard or the Graffiti writing feature. Although the numbers are small, staff who used Graffiti for text entry, rather than the on-screen keyboard, found text entry to be less difficult. Missing data for text fields may reflect the comfort level of data collectors with using PDAs. Expanded or one-on-one training may be necessary to decrease the likelihood of missing data for text entry items. For studies that collect data with a significant amount of text entry, an optional PDA keyboard attachment may be useful (keyboards were not tested in this study).

Out-of-pocket expenses for the two methods in this small study were similar; however, our estimates did not include personnel, existing PCs, and software programs for creation of the paper forms. The relative cost of the two methods may vary by the length and type of data collection. Use of the PDA was more time intensive and costly at the beginning of the study, requiring

purchase of PDAs and software, programming time, and more intensive staff training time. After data collection, time and resources were saved in terms of data entry and data cleaning. PDA data were ready for analyses almost immediately following the data collection period. In contrast, the paper data collection method required less start-up time and resources but more time and resources at the end of the study. Most estimated costs for the paper data collection method were attributed to data-keying costs; and double keyed and cleaned data were not available for up to 3 months following the end of data collection. Once equipment and software are purchased for PDA data collection, they could be presumably used again for other studies, whereas data entry costs for the paper forms would start anew with each study.

Another advantage of the PDA is that all data can be automatically time and date stamped at the time of collection, allowing the researcher to confirm that data were entered on an appropriate schedule and providing information for workload and staffing management. In the Johannes and associates (2000) study, research subjects entered more than 61% of their data 24 or more hours late. Delays in form completion may result in invalid data due to memory/recall deficits and may be a particular problem in field studies in which data collection staff members are not directly supervised. In short, automatic date/time stamping can be a significant benefit of using PDAs for field data collection.

Overall, this study suggests that reasonably priced PDAs are viable tools for field data collection. We were able to use PDAs to collect field data within a small research budget and without sophisticated technical equipment or personnel. Using PDAs to collect data resulted in few missing data points and a data set that was ready to be analyzed almost immediately following the end of data collection. Most of the field staff members reported feeling comfortable using the PDA, and a slight majority preferred using the PDA over paper forms. More intensive, one-on-one training, however, may be needed for field staff members who do not feel at ease entering text data. This method of data collection is most promising for research studies that have adequate start-up time and those studies that require immediate access to a clean data set.

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