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TOOLS OF THE TRADE

Using Tablets to Collect Data From Young Children

Michael C. Frank , Elise Sugarman, Alexandra C. Horowitz, Molly L. Lewis,
and Daniel Yurovsky
Stanford University

Mobile, touch-screen devices are increasingly ubiquitous in children's lives. The extensive use of such devices presents an exciting opportunity for data collection. We describe a simple method for creating cross-platform, interactive tablet experiments using open Web-based resources. We illustrate this method by collecting data from 1- to 4-year-old children in a word-recognition paradigm, using 3 different techniques: tablets, eye tracking, and an in-person storybook paradigm. Both accuracy and reaction-time data from the tablet compared favorably with the other methods. Tablets should be considered as a viable method for collecting low-cost, well-controlled developmental data.

INTRODUCTION

Since Apple debuted the iPad in 2010, the ubiquity of personal tablets—interactive, touch screen-based computing devices that are typically larger than a phone but smaller than a laptop—has skyrocketed. By 2014, an estimated 71% of families with young children in the United States owned a “smart” mobile device, with 55% of households owning tablets (27% of lower-income families and 63% of higher-income families); tablets were estimated to constitute 13% of overall screen time for children aged 0 to 8 years old (Rideout, 2014). Accordingly, the market for downloadable applications targeted for children has increased dramatically. In one estimate, applications targeted toward children made up 72% of the top-selling items in the iTunes store and more than 80% in the education category (Shuler, Levine, & Ree, 2012). The explosion in popularity of touch-screen devices has created a surge of interest in the potential for using these devices as scientific tools.

Unlike in the case of traditional behavioral experiments and eye-tracking measures, there are relatively few resources to help labs implement tablet experiments. In addition, the reliability of

Correspondence should be sent to Michael C. Frank, Department of Psychology, Stanford University, Jordan Hall (Bldg. 420), 450 Serra Mall, Stanford, CA 94305, USA. E-mail: mcfrank@stanford.edu

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data gathered from tablet experiments with young children has not been tested. The goal of the current article is to address these challenges. We begin by briefly reviewing research on the use of tablets with children. We then describe a method for creating tablet-based experiments using standard, freely available Web development tools. Although this method requires some programming experience, it is significantly easier than developing tablet-native applications (e.g., apps that can be downloaded from the Apple App Store or Google Play platforms and are specific to a particular device). We report data from an experiment comparing word-recognition accuracy and reaction time (RT) across tablet, eye-tracking, and behavioral data collection. Our findings suggest that the tablet platform is an engaging method for data collection that, when used appropriately, can yield reliable estimates of accuracy and RT from young children.

PRIOR WORK ON USING TABLETS WITH CHILDREN

Although tablets are becoming increasingly common in research, relatively little published work has compared them directly to other data collection modalities. One exception to this statement, however, is the use of tablets in standardized psychological instruments. Publishers are increasingly creating tablet-specific versions of paper-and-pencil assessments; at the time of this writing, a number of instruments—including the Wechsler Adult Intelligence Scale (Wechsler, 2008), Clinical Evaluation of Language Fundamentals (CELF) (Wiig, Secord, & Semel, 2004), Peabody Picture Vocabulary Test (Dunn & Dunn, 2007), and many others—are available from commercial publishers. The tablet modality assists in standardizing instructions and facilitates response logging, both with minimal changes to the basic instrument. Thus, it seems clear that tablets can be used effectively for data collection with preschool-aged and older children in relatively straightforward and standardized paradigms.

For younger children, the primary focus of research on tablets has not been on their use as a data collection platform, but rather on the evaluation of their educational potential. The starting point for investigations of learning from tablets is the suggestion that children learn less from passive video viewing than they do from live demonstrations—a phenomenon known as the “video deficit” effect (e.g., Anderson & Pempek, 2005; DeLoache et al., 2010). The experiences offered by touch-screen devices may be distinct from passive viewing of television and computer screens, however. For example, Zack, Barr, Gerhardstein, Dickerson, and Meltzoff (2009) found that 15-month-olds were able to transfer knowledge about an object learned via a touch-screen device to a physical toy. Practice with interactive games may also benefit attention and motor control (Bavelier, Green, & Dye, 2010), and more generally, screen time with tablets can promote independence, opportunities for physical closeness, and feelings of fun and accomplishment (Rvachew, 2014). The contingent feedback and individualization offered by mobile devices may thus make them a better medium for learning and engagement than traditional view-only screens, and these advantages may also increase their utility for data acquisition.

The accuracy of young children’s motor control poses a concern about their performance using tablets. Experience likely plays a substantial role in modulating the accuracy of tablet interactions, especially for toddlers and early preschoolers, and some gestures are easier than others. Aziz, Sin, Batmaz, Stone, and Chung (2014) tested 2- to 5-year-olds in Malaysia and the United Kingdom on their ability to perform the seven most common touch gestures of iPads: tap, drag/slide, free rotate, drag and drop, pinch, spread, and flick. By age 2 years,

children mastered the tap and drag/slide gestures, and by age 3 years, they could reliably produce all but the spread gesture. By age 4 years, all children performed all of the gestures. Our experiences confirm that even 1.5- to 2-year-olds are able to learn to tap targets without too much difficulty, though more sophisticated gestures may be too complex for them.

While relatively little published research has made use of novel tablet-based tasks, there is an extensive literature that has used lab-based touch-screen paradigms with children (e.g., Friend & Keplinger, 2003; Holloway & Ansari, 2008; Sage & Baldwin, 2015). This prior literature is important for calibrating our expectations about what paradigms may be ported successfully to tablets, but if anything, it is likely to underestimate the utility of tablets. Touch-screen paradigms are often conducted with relatively specialized equipment in a lab setting, while tablets can be used anywhere. In addition, tablets are small enough for the child to hold and generally require small motor movements; in contrast, touch screens are typically on a desk or mounted on a wall and may require full arm movement (leading to fatigue during a longer testing session). Finally, the increasing comfort and proficiency of even young children with tablets may lead them to be more comfortable with experiments conducted in this medium, in turn resulting in better data.

WHY COLLECT DEVELOPMENTAL DATA WITH TABLETS?

Researchers working with young children have access to a wide variety of experimental paradigms, ranging from behavioral forced-choice to eye-tracking and looking time-based measures (Aslin, 2007; Gredebäck, Johnson, & von Hofsten, 2009). Each of these methods has its drawbacks. Behavioral methods are flexible and easy to implement, but they can be subject to experimenter biases and often require labor-intensive offline coding. In contrast, corneal-reflection eye-tracking methods are precise and unbiased, allowing for tight experimental control, but can be expensive and are difficult to implement outside of tightly controlled lab settings. In addition, eye-tracking paradigms are typically very limited in length as they tend to be noninteractive (cf. Deligianni, Senju, Gergely, & Csibra, 2011) and often result in substantial data loss due to excessive movement and calibration issues, among others.

Tablet-based experimental paradigms can supplement both of these data collection modalities by allowing researchers to create engaging, interactive paradigms that are low-cost but nevertheless offer some of the precision and experimental control of eye-tracking paradigms. In the following sections, we offer five reasons why tablets may be valuable tools for developmental research.

Diverse measures. Tablets allow for the collection of many different dependent variables, including forced-choice responding and gesture trajectories. We especially highlight the ability to measure RTs using tablets. RTs provide a continuous, informative measure of cognitive process and have proven invaluable in both developmental (e.g., Fernald, Pinto, Swingley, Weinberg, & McRoberts, 1998; Marchman & Fernald, 2008) and adult (e.g., Sternberg, 1969) studies. Behavioral paradigms that afford RT measurement for young children typically require time-consuming offline coding. In contrast, eye-tracking paradigms yield RTs but with the trade-off that the paradigms themselves typically have limited interactivity.

Engagement

Children across a wide range of ages enjoy tablets and are highly motivated to explore new tablet-based tasks, allowing researchers to collect more data from individual children. As is obvious from infants' and young children's interest, these devices are extremely engaging (for further evidence, see Couse & Chen, 2010). In addition, the use of tablet-based devices may lead children to view experiments as similar to desirable commercial apps. Behavioral paradigms with young children often require a "warm-up" period so that the child is comfortable interacting with an unfamiliar experimenter; such a period can be shorter or absent to the extent that a tablet-based paradigm requires less face-to-face interaction.

Experimental Control

Studies that involve interaction with an experimenter are the de-facto standard in cognitive development research, but such studies have major drawbacks in that it may be difficult or impossible to ensure that experimenters are blind to condition and hypothesis. Often hypotheses are simple enough that even "naïve" research assistants can infer the experimental structure or the desired response. Although there are methods for avoiding such issues, the possibility of eliminating experimenter bias via computerized stimulus presentation is attractive for situations where it is possible. And even when bias is not introduced, there are significant challenges in training a group of research assistants to implement an experimental protocol uniformly. Thus, tablet-based experiments can alleviate concerns about bias and uniformity of experimental presentation.

Inclusion of Special Populations

Tablets can be a valuable tool for working with children who have learning or physical disabilities (e.g., Bertuccio & Sanger, 2013; Cardon, 2012; Chai, Vail, & Ayres, 2015). The lack of face-to-face interaction demands makes tablets especially appealing for working with children on the autism spectrum, who may find interactions with an unfamiliar experimenter especially aversive.

Scale. Low cost and high accessibility make it possible to distribute tablets to research assistants who can collect data in a wider variety of locations (though not without concern about environmental distractions). In addition, it is in principle possible that children could contribute data to experimental studies via experiments administered by their parents or caregivers. This latter possibility might be truly revolutionary in changing the scope of developmental data collection, though there are many challenges that such a data collection effort would need to overcome.

Despite all of these advantages, there are significant technical issues related to app creation that have slowed the adoption of tablet-based methods in developmental research (as well as other limitations, which we return to below in the section "Limitations of Tablets"). On the technical side, creating tablet-native apps—those that can be accessed through an Android or iOS tablet's main menu—requires substantial programming expertise. Worse yet, this expertise is not transferrable across tablet platforms. Developing a native app for iOS requires programming in

Objective-C using Apple’s proprietary app development tools; development for Android requires programming in a Java variant. In other words, either an investigator must learn a special-purpose programming language or a programmer must be employed. This latter option is more common, but costs can easily run in the tens of thousands of dollars; in this sort of scenario, making scientifically useful changes to an app may be undesirable because of added costs.

A WEB-BASED METHOD FOR DEVELOPING TABLET EXPERIMENTS

In contrast to costly, special-purpose methods, here we describe an alternative method for prototyping and collecting data on tablets. The method relies on creating the experiment as a simple Web page and then showing this page in the tablet’s Web browser. This method still requires some programming experience but much less. In our experience, an undergraduate or graduate student with some programming practice can modify and improve an experiment written in this ecosystem by starting with the code we provide; in contrast, developing an app from scratch requires a much more substantial programming background.

Our method draws on open-source, freely available tools that are relatively easy to master compared with native app development tools. Experimental “apps” made via this method are easily shared, modified, and ported across platforms, leading to faster iteration and data collection. In addition, our method offers the ability to collect control data with adult participants on Amazon Mechanical Turk (Crump, McDonnell, & Gureckis, 2013; Paolacci, Chandler, & Ipeirotis, 2010) or using a laptop or touch-screen computer with virtually no changes to the underlying experiment. Our method has three components (see Figure 1):

1. a HyperText Markup Language (HTML)/JavaScript/Cascading Style Sheets (CSS) Web page, which is the core of the experiment;
2. a server-side PHP script to collect data in tabular format; and
3. a tablet device running a kiosk application to present the experiment.

We discuss each in the next section.¹

Web-Based Experiment

The first component of our system is a Web-based experiment created using HTML, JavaScript, and CSS. This combination is currently the most common set of tools for the creation of interactive Web sites. HTML forms the framework for the static content shown on the Web site, while CSS gives a consistent set of formatting options. JavaScript then controls the interaction functionality of the Web site. In particular, we make use of a JavaScript library called jQuery (<http://jquery.com>), which allows HTML elements like images, layouts, text, and media to be dynamically added, subtracted, and rearranged as participants interact with the resulting page.

¹Our work has used the Apple iPad as the primary tablet platform, and we provide details that are tailored for this platform. Unlike other methods, however, our method is in principle portable to a wide range of mobile devices with only very minor modifications.

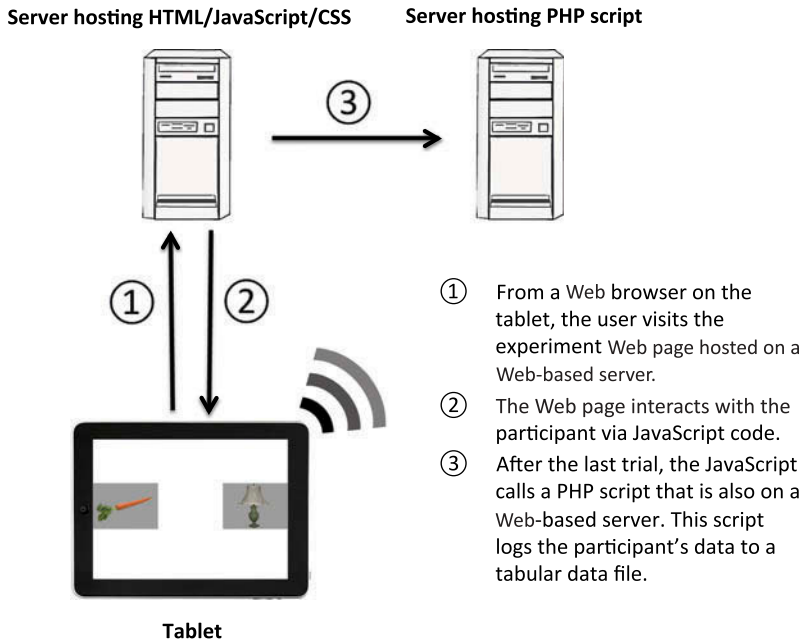


FIGURE 1 A schematic of our method of collecting tablet data using a Web-based experiment. Note that the two server functions can be executed by the same system; we have separated them here for clarity.

It is beyond the scope of this article to provide an introduction to creating JavaScript-based Web experiments, but there is a wealth of available resources on this topic. These resources include both psychology-specific tutorials and more general introductions to the general HTML/JavaScript/CSS model. A sample experiment (as well as the server-side code) is provided in the version control repository for this article at <http://github.com/langcog/tablet> and can be viewed directly at <http://langcog.stanford.edu/tablet/tabletcentered.html> (for a demo, use login ‘test’ and list 1). We note that JavaScript is what is known as a “client-side” language: It is executed in the user’s Web browser. For this reason, it can be used to collect RTs that do not depend on server latencies. For example, Crump et al. (2013) reproduced a number of classic RT effects from cognitive psychology using JavaScript-based experiments. Because our system uses a similar infrastructure, RTs gathered using our method are similarly precise and independent of connection speed.

Finally, hosting a Web-based experiment requires server space, which is often provided by universities but can also be purchased from commercial providers. We find that the requirements on such a server are typically not high, so the costs involved are minimal; our current experiment runs on our university-provided Web space at no cost.

Server-Side Data Collection

The second component of our system is a simple script that allows the experiment to save data in tabular format. Although native apps can store information on tablets, browser-based apps such

as ours cannot; thus, our method requires that the data be saved to a separate server. Every time a participant completes the experiment, their data are sent to this script. The script is written in PHP (a simple scripting language that is often used for backend Web development) and is hosted on a server with script execution capabilities. The script simply appends data from the experiment to a tabular data file. The script can be hosted on any Web-accessible server that has been configured to run executable files of this type. In practice, it will often be the same server that hosts the experiment itself, though it need not be. The researcher then retrieves the data from this server using Secure File Transfer Protocol or a similar method.

Tablet Configuration

The third component of our system is an Internet-connected tablet. The requirement for Internet connectivity is perhaps the most substantial drawback of our method, relative to native apps. The tablet must either have wireless access (e.g., from the testing location or a mobile hotspot device) or direct cellular connectivity. Once the tablet has access to the Web, the tablet's browser can simply be directed to the experiment Web site.

A major challenge of presenting experiments in the tablet's Web browser is ensuring that children cannot accidentally or intentionally navigate away from the experiment, exit the browser, or change perspective (e.g., by zooming). In practice, we use two tools that are specific for the Apple iPad for this purpose: The first tool is Guided Access, a mode that disables the hardware buttons. The second tool is Mobile Kiosk, an app that further locks the device into a particular view of a Web page. The combination ensures that the tablet presents the experiment as intended. With both of these systems in place, the "look" of the experiment is extremely similar to a native app. In future, new tools (e.g., <http://phonegap.com>) may even make it possible to compile Web pages directly into native apps.

AN EXPERIMENTAL TEST OF THE RELIABILITY OF TABLET DATA COLLECTION

To test the reliability and developmental applicability of our tablet method, we implemented a simple word-recognition paradigm based on prior eye-tracking work (Bion, Borovsky, & Fernald, 2013; Fernald, Perfors, & Marchman, 2006; Fernald et al., 1998). We compared data from this tablet paradigm to data collected via a classic "storybook" paradigm (e.g., photocopied pages in a three-ring binder) and to data collected using an Senso Motoric Instruments Inc. corneal-reflection eye tracker. We collected a cross-sectional sample of 228 1- to 4-year-old children, recruited from a local children's museum. Full methods and procedure are given in Appendix A.

Our experimental paradigm consisted of simple two-picture displays in which children were asked to match a word with one of the two pictures. The paradigm both tested children's recognition of familiar words (familiar-word trials) and asked them to make "mutual exclusivity" inferences (ME inference trials)—that a novel label refers to a novel word rather than a familiar competitor (Markman & Wachtel, 1988). We hypothesized that familiar-word recognition would be easy and fast for all but the very youngest children in our sample, while the ME inference would be both slower and more challenging. Although the psychological mechanisms underlying the ME inference are still a source of theoretical disagreement (Bion et al., 2013;

Diesendruck & Markson, 2001; Frank, Goodman, & Tenenbaum, 2009; Markman, Wasow, & Hansen, 2003), ME inferences are highly replicable, and we predicted these inferences would show developmental change across our sample. We additionally added control trials where we asked about familiar words in the context of a novel item (ME control trials).

The primary goals of our analysis were: to compare the three data collection modalities in their overall yield in terms of data quantity, to measure the pattern of accuracies across trial types for each data collection condition, to compare RT effects for eye-tracking and tablet conditions, and to measure the reliability of each condition across ages. In all four of these analyses, the tablet data appeared competitive with (and in some cases, more sensitive than) the other two modalities.

Data Yield

Children were overall enthusiastic about the experiment across data collection modalities, though anecdotally, they expressed the most enthusiasm about the tablet. Completion rates across age groups and conditions are given in Table 1. Children who began the storybook uniformly completed it, across age groups, likely due to the interactive and social nature of presentation. The tablet produced high completion rates for all groups except 1-year-olds, who mostly completed half or two thirds of the trials but not the full experiment. For the eye tracker, 1-year-olds completed a mean of 19 out of 28 trials, with many asking to stop early before the experiment completed; 2-year-olds were somewhat better, with a mean of 25 out of 28 trials but a substantial number ending significantly earlier.

Overall, the exciting and interactive experience of interacting with the tablet may have made up somewhat for the mismatch between the level of the paradigm and the competence of the youngest and oldest children, leading to higher levels of retention relative to the eye tracker. Despite these advantages for the tablet, live presentation led unambiguously to the highest completion rates, because the experimenter could customize the pace of the study to each individual child.

Accuracy Data

Word-recognition accuracies across age groups and conditions are shown in Figure 2 (see Appendix A for full details regarding this and subsequent analyses). Overall, older children (3- and 4-year-olds) were close to ceiling in all trial types; but younger children's performance varied by both trial type and data collection condition. Data for the 1-year-olds were the most variable: Children were above chance for both familiar-word and ME control trials in the tablet

TABLE 1
Proportion of children finishing all trials of the study, by age group and data collection condition

<i>Age group</i>	<i>Tablet</i>	<i>Eye tracker</i>	<i>Storybook</i>
1-year-olds	.44	.29	1.00
2-year-olds	.91	.47	1.00
3-year-olds	1.00	.88	1.00
4-year-olds	.86	.63	1.00

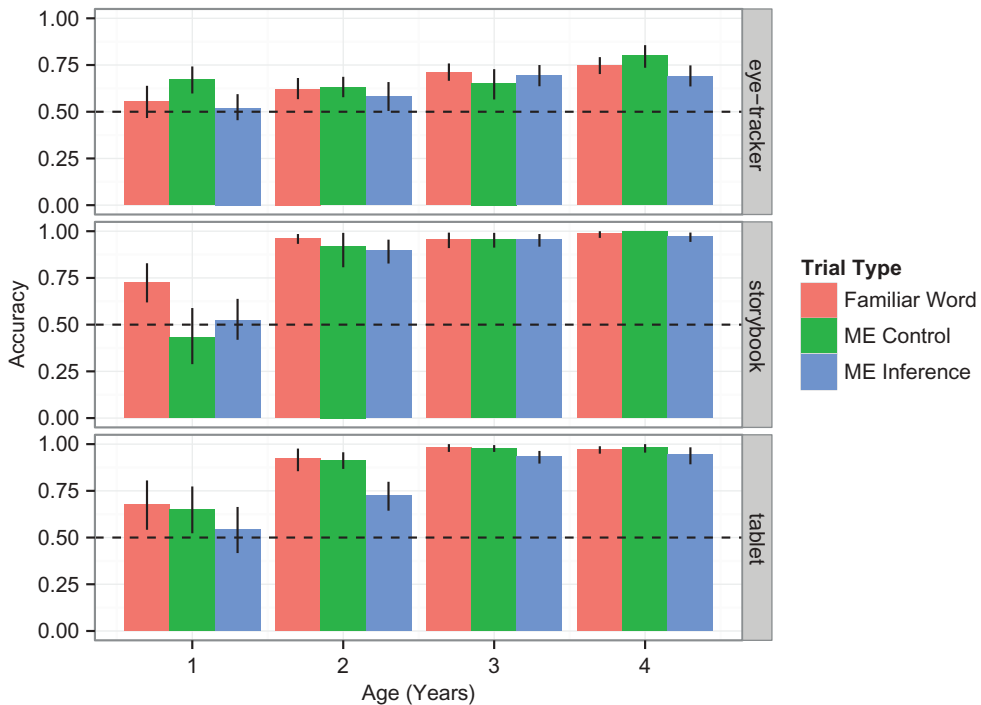


FIGURE 2 Accuracy in our word-recognition task, plotted by age group. Facets show different data collection modalities and trial types (ME = mutual exclusivity; see text for more details). Dashed line shows chance performance. Error bars show 95% confidence intervals, computed by nonparametric bootstrap.

condition, while for the eye tracker, only ME control trials were above chance and for the storybook, only familiar-word trials were above chance. The tablet also revealed lower performance in the ME inference trials for the 2-year-olds, in contrast with the other two methods. In sum, we found that accuracy data from the tablet revealed a sensible pattern of inferences—greater difficulty in ME inference trials than familiar-word trials, combined with developmental change—and the tablet had at least the sensitivity of the comparison modalities.

Reaction Time Data

RTs for the eye-tracker and tablet conditions are shown in Figure 3. While for both conditions, the primary trend was a decrease in RT for older children, several other patterns were also visible. First, RTs for the tablet were several times longer than those for the eye tracker, consistent with the more complex motor task of tapping a picture compared with making a saccade with the eyes. Second, the tablet but not the eye tracker revealed slower RTs for ME inference trials for the 2-, 3-, and 4-year-olds, a pattern that had been observed in young children in a more age-specific and substantially longer eye-tracking paradigm (Bion et al., 2013).

One potential reason for the lack of sensitivity of the eye-tracking paradigm comes from the fact that two-alternative eye-tracking paradigms only yield RTs for half of trials. No RT

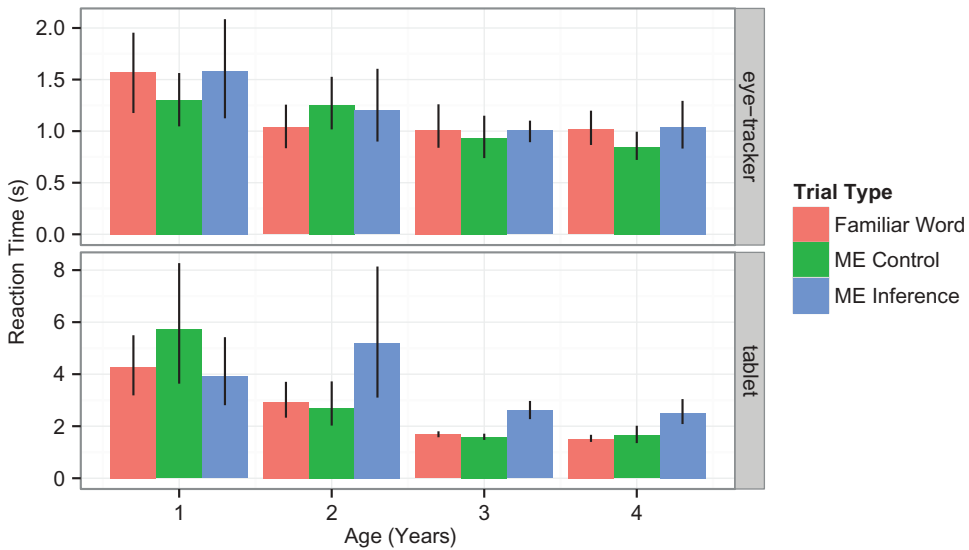


FIGURE 3 Reaction times in our word-recognition task, plotted by age group and trial type, with panels showing eye-tracker and tablet data (note different vertical scales). Error bars show 95% confidence intervals, computed by nonparametric bootstrap.

is computed on trials where the participant begins the trial looking at the target (Fernald, Zangl, Portillo, & Marchman, 2008). In contrast, every trial on a tablet yields an RT; see Table 2 for the number of RT trials for each condition and age group. In sum, in a short paradigm of this type, the tablet was more successful in reproducing a previously documented RT effect.

TABLE 2
Standardized reliability coefficients (Cronbach's α) for accuracy (acc) and reaction time (RT) by age group, along with the mean number of trials for each

Age	Condition	<i>M</i> trials (acc)	α_{acc}	<i>M</i> trials (RT)	α_{RT}
1-year-olds	Eye tracker	7.65	-.98	4.47	.88
	Storybook	13.00	.77		
	Tablet	11.78	.45	8.50	.72
2-year-olds	Eye tracker	11.61	.74	5.72	.25
	Storybook	13.00	.69		
	Tablet	16.05	.64	14.77	.69
3-year-olds	Eye tracker	12.88	.58	6.12	.60
	Storybook	13.00	.58		
	Tablet	15.83	.06	15.54	.59
4-year-olds	Eye tracker	11.25	.33	7.12	.54
	Storybook	13.00	-.11		
	Tablet	15.45	.47	15.09	.77

Reliability

Group-level developmental differences do not necessarily signal a measure with high reliability. To measure reliability differences directly, we computed Cronbach's α , a standard statistic that quantifies the reliability of a set of measurements (Santos, 1999). Our experiment contained 8 trials from each trial type, a small number of trials on which to compute reliability statistics. So as to decrease data sparsity, we selected the 16 trials containing familiar words (both familiar-word and ME control trials) and computed a reliability coefficient for each age group and condition, for both RTs and accuracies. Reliabilities are shown in Table 2.

Reliabilities were generally acceptable, with a few exceptions. First, the reliability of accuracies declined with age across conditions because of ceiling effects; 3- and 4-year-olds made essentially no errors that distinguished between individuals. Second, the eye-tracker paradigm we used yielded only a limited amount of data for the youngest children. Because of the limited number of trials, reliability numbers for 1-year-olds were noisy and we interpret them with caution. For 2-year-olds, the age group for which this paradigm was most diagnostic (e.g., there were no floor or ceiling effects), the tablet yielded the best reliabilities. In sum, though there was substantial overall variability, the tablet was competitive in reliability with both the eye-tracking and storybook methods.

LIMITATIONS OF TABLETS

The evidence presented here suggests that the tablet-based data collection replicates behavioral patterns observed in other modalities with comparable reliability for young children. There are nevertheless a number of limitations, both to our method and to the use of tablets more generally.

In our view, the specific Web-based method we presented here has three primary limitations. First, it requires Internet connectivity. For experiments in the field or in public places, this requirement may mean that other techniques are more appropriate. Second, it relies on a Web-based development ecosystem that includes server-side technologies like PHP and client-side technologies including HTML, CSS, and JavaScript. Although these open tools are well documented and relatively easy to master, setting up these experiments still requires some technical orientation. If a lab is already hiring a programmer, it might be appropriate to build a native app rather than a Web-based one. Third, there are cases where having a robust, native app might lead to better performance, especially when an experiment requires extensive media or animation, use of the tablet's camera, or large-scale data transfer. For these reasons, data collection with a native app may be better suited for some projects.

Tablets more generally also have a number of limitations that make them suitable for many but not all experiments. We consider three classes of limitations in more depth: participant variability in experience with tablets, limitations of measurement, and limitations associated with the novelty of the method.

Limitations due to children's prior experience. Performance while interacting with a tablet depends to some degree on children's prior experience with the tablet. Children who have prior experience may be better practiced at the motor skills necessary for indicating their

responses. If children have not interacted with a tablet before, care must be taken to familiarize them with the device prior to data collection. There may also be population-level differences in experience with tablets, suggesting that researchers should exercise caution in cross-population comparisons of tablet-collected data.

Limitations due to measurement issues. There are a number of limitations associated with measurement when using a tablet for data collection. RT measurements on the tablet appear reliable in the data we collected, but validation of the precision of RT recording will require more substantial technical efforts (cf. Crump et al., 2013). In particular, it is likely that the precision of RTs will vary somewhat from device to device, perhaps making tablets unsuited for paradigms that yield small time differences and that require very fast reactions. And although eye-tracking did not yield more reliable data in our comparison, it is likely that well-tailored eye-tracking experiments would eventually yield more reliable measurements, especially for younger children (Fernald et al., 2006). Regardless of modality, the more closely an experiment is tailored to the appropriate developmental population, the more likely it will be to yield interpretable data.

Limitations due to methodological novelty. Because data collection with a tablet is a relatively new method, there are several limitations associated with its novelty. One issue is that the length or sophistication of the paradigms that can be implemented on tablets is still unknown. Another issue is related to ethical concerns of electronic data collection. While storage and transmission of fully anonymized data on our Web server has been approved by our institutional review board (IRB), researchers should consult with their local IRBs to understand the issues that can arise in electronic data collection. We recommend that researchers never collect names or other identifying information on their tablet apps—instead, if such information is collected, it should be stored separately and more securely. Finally, tablet-based experiments in general require some technical expertise to implement (either as a Web-based or native app) and hence can be slower for initial piloting than traditional behavioral methods. Although these features of the tablet are limiting, they may be mitigated as tablet-based data collection becomes more widely used.

In sum, tablets are a powerful tool, but they are not suitable for every study; care should be taken to consider these limitations prior to beginning paradigm development.

CONCLUSIONS

We presented a simple method for creating tablet “apps” that allows experimenters to create basic Web sites and use these Web sites to collect data. This method is substantially easier and more flexible than tablet-native app development, which can be costly and time-consuming. In addition, our method allows for cross-platform compatibility and easy sharing for the resulting experiments. We showed in a simple word-recognition experiment that this method yields reliable RT and accuracy data for young children and compares favorably with two other standard data collection modalities. Data collection using tablets thus has the potential to supplement—and perhaps even supplant—many behavioral methods currently in use.

Mobile and tablet-based computers are becoming increasingly commonplace in children’s experience. Children play with their parents’ and their own devices, and these devices are

used for education, reading, games, and video chat with friends and relatives. Many important developmental issues are raised by this ubiquity, and more research must be done to determine how, when, and what children can learn from interactive media. Despite these issues, the opportunity posed by such devices for developmental psychologists is immense.

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ORCID

Michael C. Frank  <http://orcid.org/0000-0002-7551-4378>

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APPENDIX A: EXPERIMENTAL DETAILS

Methods

Participants. We recruited a sample of 228 1- to 4-year-old children (1;0–4;11) from the floor of the Children’s Discovery Museum of San Jose, CA. Demographics for these participants are shown in Table A1. A first group of children was recruited for the tablet condition, and then subsequently, children in the storybook and eye-tracker comparison groups were recruited and randomly assigned to one of these two conditions.

A number of additional children in the target age range were recruited but excluded from the sample for the following reasons: parent-reported English exposure less than our prespecified criterion of 75% ($n = 48$), parent interference ($n = 12$), noncompliance or difficulty with the experimental procedure ($n = 7$), experimenter error or technical issues ($n = 2$), and self-reported developmental disability ($n = 2$). Parent interference was spread evenly across data collection conditions (4 parents in each condition). Of the noncompliant children, 5 were in the storybook condition and 2 were in the tablet condition and could not complete the initial training phase.

Stimuli. Visual stimuli consisted of images of 16 familiar and 8 novel objects. All were presented as cropped images on a gray background with approximately the same resolution and detail. Audio stimuli consisted of a carrier phrase (“Can you find the [target]?”), into which we spliced recordings of the target words. All recordings featured a female speaker and were created following the procedures described in Fernald et al. (2008). We selected words from the MacArthur-Bates Communicative Development Inventory word list (Fenson et al., 1994,

TABLE A1
Demographic information for the final sample of children in each data collection condition of our experiment

Condition	Age Group	<i>N</i>	Mean Age	Prop. Male
Tablet	1	18	1.71	0.44
	2	22	2.46	0.68
	3	24	3.56	0.67
	4	22	4.51	0.59
Eye tracker	1	17	1.43	0.47
	2	19	2.48	0.58
	3	17	3.55	0.76
	4	16	4.52	0.56
Storybook	1	15	1.62	0.60
	2	19	2.49	0.32
	3	19	3.48	0.53
	4	20	4.48	0.45

2007) and chose some words that we were certain nearly all children would be very familiar with (e.g., “car,” “dog,” “bottle”) and others that were intended to be slightly more challenging (e.g., “monkey,” “shovel,” “lion”). Novel words were monosyllabic and disyllabic words that had been used in previous experiments of this type (e.g., “dax,” “pifo,” “kreeb”). We further included 4 fillers to break up the experiment (e.g., a picture of a child rowing a boat with a sentence describing it). All reaction times were computed from the onset of the target word.

Procedure. Procedures were substantively identical in the three data collection conditions. In each, experimental stimuli were presented in one of two pseudorandom lists, in which trials (pairs of pictures) were counterbalanced for order and target side. The three trial types were a) familiar-word trials, in which two familiar pictures were presented and children were asked to select the image that matched a familiar word; b) mutual exclusivity (ME) control trials, in which a familiar image and a novel image were presented and children were asked to select the image that matched a familiar word; and c) ME inference trials, in which a familiar image and a novel image were presented and children were asked to select the image that matched a novel word. The experiment had 28 trials in total (8 of each of the three trial types plus 4 fillers). On each trial, two pictures were shown side by side as the sentence was presented.

Eye-tracking data were collected using an SMI RED 120 Hz system. Children first completed a simple two-point calibration and then saw each trial presented on a static slide, accompanied by audio (played over speakers). Children were seated in a car seat mounted in an adjustable-height barber chair.

The storybook was a three-ring binder containing printouts of the slides that participants viewed in the eye-tracking condition. An experimenter read the carrier phrases and target words from a script.

For tablet data collection, the procedure was identical to the eye-tracking condition, with the exception of a pretraining phase, which consisted of a task to help children learn to tap appropriately on the iPad. To advance past this training page, children needed to tap a set of five dots in random locations; each dot transformed into an “X” when tapped. A second page showed the same game with smiley faces. We found that this fun training sequence helped children select pictures effectively during the rest of the experiment. During test trials, touches were disabled until 300 ms after the onset of the target word. After the target was touched, the participant’s choice was highlighted with a red border and further touches had no effect.

Results

Accuracy. Accuracy for the eye tracker was calculated as the proportion of total time in the trial that participants spent fixating on the target in the period starting 300 ms after the onset of the target word, divided by the summed looking time at the target and the distractor. The eye tracker showed relatively limited sensitivity to the word recognition of the youngest children; neither familiar-word recognition nor ME inference performance was above chance, $t(16) = 1.23$, $p = .24$, and $t(11) = 0.52$, $p = .62$, respectively (different degrees of freedom are due to missing data). In contrast, ME control trial performance was above chance, $t(12) = 4.49$, $p < .001$. Two-year-olds and older children were reliably above chance for all trial types, with the exception of 2-year-olds in the ME inference trials who trended toward above-chance performance, $t(17) = 1.98$, $p = .06$. Overall, our impression was that the sensitivity of our eye-tracking paradigm was limited relative to other experiments of this type (Fernald et al.,

2006), perhaps due to the necessity of designing a stimulus set that was relatively engaging for the full age range we studied.

Accuracies were higher for the storybook and tablet conditions. In both conditions, responding was above chance for 1-year-olds in familiar-word trials (smallest $t > 2.57, p < .02$) and was above chance for the tablet in the ME control trials, $t(17) = 2.23, p = .04$, but not in the other trial types.

To equate across the slightly different age distributions for the different groups and to quantify the broader pattern of differences, we fit a logistic mixed-effects model to data from the tablet and storybook conditions (Jaeger, 2008). We specified fixed effects of age (continuous), condition, and trial type (dummy-coded, with familiar-word trials as the intercept) and all interactions, and with random effects of trial type varying by participant. We found significant main effects of age ($\beta = 1.17, p < .0001$) and trial type (ME control, $\beta = -3.86, p < .0001$; ME inference, $\beta = -1.36, p = .05$). We also found significant Age \times Trial Type, Condition \times Trial Type, and Age \times Condition \times Trial Type interactions for the ME control trials, thereby capturing the pattern that these trials were relatively more difficult for younger children in the storybook condition than in the tablet condition.

Reaction Time. We did not measure reaction times (RTs) in the storybook condition; though coding these reaction times from video would in principle have been possible, timing was not tightly controlled. RTs on the tablet were defined as the time from word onset to first tap on correct trials. Eye-tracking RTs were defined as the time to switch from distractor to target on trials where the eyes were initially fixating on the distractor at the point of disambiguation (for more details, see Fernald et al., 2008). For the tablet RT data, we found a significant proportion of extreme outliers. In an exploratory analysis, we fit a Gaussian mixture model and found that the best Bayesian Information Criterion (BIC) values were produced by a two-cluster solution—featuring a large faster cluster and a small, very slow cluster, probably interpretable as children who were hesitant to respond.

We excluded RTs faster than 500 ms or slower than 4,000 ms. These values were determined post-hoc, based on visual inspection of the distribution. They correspond well both to our intuitions about the task and to our exploratory analyses (and resulted in a loss of 10.9% of values). In future work, we recommend the adoption of a-priori standards for RT exclusion; we did not do so here because exploring such standards was a goal of the current experiment. Experimenting with other RT outlier exclusion processes did not qualitatively alter the pattern of results. Nevertheless, we recommend that investigators using this method carefully examine their distribution of RTs, as averages can be heavily skewed by just a small number of very long RTs.

Overall, older children were faster in both the eye-tracker and tablet conditions. Because of the different magnitudes of RTs across the two conditions, we fit independent linear mixed-effect models to the logarithm of RT for each. A model fit to the eye-tracker data revealed only a main effect of age. A model fit to the eye-tracker data with fixed effects of age (continuous), trial type, and their interaction and random effects of trial type by participant revealed only a highly reliable main effect of age. No further patterns were visible in the eye-tracker data, perhaps due to the relatively low number of trials that were included in this analysis. (Computing RTs from two-alternative eye-tracking data requires excluding approximately half of all trials, because the participant is already fixating on the target at the point of disambiguation). In contrast, a model fit to the tablet data also showed a highly significant main effect of age ($\beta = -0.24, p < .0001$) and a significant Age \times Trial Type interaction such that ME inference trials were slower for older children ($\beta = 0.07, p = .04$).