A comparison of common behavioral observation software applications and recommendations for use

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Abstract

1. In the field of animal behavior and behavioral ecology, many standardized methods to observe

   animal behavior were established approximately 50 years ago. While the protocols are similar,

   behavioral researchers can take advantage of technological advancements to enter observations

   directly onto a handheld computer (phone, tablet, etc.), saving precious time. However, we now

   have the choice between many different platforms for recording behavioral observations. Our

   challenge is choosing the most appropriate platform that fits a particular study question,

   research design, budget, and desired amount of preparatory time.

2. Here, we review six software applications for handheld computers that are available for real-time entry of behavioral observations: Animal Behaviour Pro, Animal Observer, BORIS, CyberTracker, Prim8, and ZooMonitor.

3. We discuss the preliminary decisions that have to be made about the study design and we assess the six applications by reviewing 1) which behavioral sampling methods are possible per platform, 2) the setup and data collection routines, 3) the data output format, and 4) how to customize certain platforms so they will work more effectively for particular study aims or sampling methods.

4. Our goal is to help researchers make calculated decisions about what behavioral observation platform is best for their study system and question.

Keywords: animal behavior, animal social networks, behavioral and ecological monitoring methods, behavioral observation software applications, sampling methods, social behavior, social interactions

Introduction

In the field of animal behavior and behavioral ecology, a very important aspect of gathering data is direct behavioral observations. Since the foundational work of Altmann (1974), clear methodologies exist for the direct collection of observations (classic behavioral and ecological monitoring methods) and many researchers follow these methods (over 16000 Google Scholar citations, accessed 2020). However, the past five decades have seen major advances in technology that have changed the ways in which researchers collect and analyze data. Prior to the widespread use of computers, researchers used pen and paper to record behavioral observations and perform analyses. Today, the availability of handheld computers in the field allows for rapid real-time data collection, which can be entered directly into electronic format and is virtually ready for analyses.

The more recent technological advancement of automated methods, such as GPS trackers and proximity loggers, provide an exciting avenue to collect behavioral and ecological data (Shizuka et al.,

2020; Smith & Pinter-Wollman, 2020). Nevertheless, traditional observation methods are necessary to validate these automated methods (Gelardi et al., 2020) and to describe and collect data on the contexts of behaviors (something most automated methods still cannot collect).

Multiple software applications (apps) have been developed to collect behavioral observations via entry onto a (handheld) computer (Animal Behaviour Pro, Animal Observer, BORIS, CyberTracker, Prim8, and ZooMonitor). These software platforms differ in how the behaviors are entered, what sampling methods are supported, what contextual variables can be entered, the output for analysis, the speed of data entry, and the cost (especially for operating system-specific apps that require Android or Apple products). We reviewed these apps for our own work on monk parakeet social structure (van der Marel, Prasher, et al., 2020) and believe that others may find a review discussing these apps helpful when setting up their own studies. Therefore, we provide a description of the advantages and disadvantages of each of these six apps, which will allow researchers to make calculated decisions about which app would work best for their study question, sampling methods, and budget. We discuss 1) the study design's initial decisions, 2) which sampling methods are available within each app, 3) workflow of app setup and data collection, 4) the data output, and 5) how to customize each app to best suit your needs.

Preliminary decisions about study design

Many initial decisions are critical to evaluate during the study planning phase. The research question will influence which sampling method should be used, which will influence app choice later. Characteristics of the study site may influence how often the data can be uploaded to the cloud or whether back-up material, such as external hard drives, are necessary. When starting with a new study system, researchers may have to develop an informative ethogram from preliminary observations or customize ethograms of closely related species to better represent their study system. Sampling decisions are made so that the recorded observational data will answer the question, and these

decisions may influence the choice of which application to use. We have written these guidelines with the assumptions that the research question is known, the study site and species are chosen, an ethogram of behaviors exists, and sampling decisions are specified.

Methodological challenges do exist when using an application on a handheld computer. All the applications discussed record observational data but differ in how they record contextual data or comments. Therefore, researchers should decide what information is necessary, only behavioral data (e.g., actor, behavior (either states or events), subject, and time) or also contextual data (e.g., habitat characteristics, weather, predominant group activity, group size and membership). How behavior is entered can drastically affect the speed of data entry, which may be crucial for accurate data collection or a personal preference. Another thing to keep in mind is the data output. Most researchers prefer to import their data into the statistical program R (R Core Team, 2020). Output that is immediately ready for import to R, such as comma-delimited (CSV) or text files, would eliminate any potential errors made during intermediate data entry steps.

Another major point to consider is the sampling method, which depends on the research question (Altmann, 1974). The primary sampling method is scan sampling, where behaviors are sampled from the whole group at preselected time points. Scan sampling is very useful to get the percentage of time individuals perform a specific behavior. All-occurrence sampling (only specified behaviors are recorded) is especially useful for behaviors that are of interest but do not occur often, such as social behaviors for certain species. Researchers can combine both scan and all-occurrence sampling to get both information on a daily activity budget and social interactions. Sometimes it is better to record as much as the observer can (i.e., ad libitum sampling), although biases in sampling may occur. Focal sampling requires an observer to focus on one individual or one group for a specified amount of time. Instead of focusing on a focal individual, the observer could also focus on a sequence of interactions. When the direction and asymmetry of interactions are of interest, observers could record the

interaction data between dyads (i.e., sociometric matrix completion). Research questions often require more and/or fine scale data, thus the method in which the data is collected is crucial for efficiently and accurately collecting data. Most behavioral observation recording applications have the option to perform scan, all-occurrence, ad libitum, and focal animal sampling. However, some of the applications only provide an opportunity to perform scan and focal animal sampling.

Finally, the features available within an app, the app's compatibility with a particular device, and the budget also warrants consideration. Some applications are only compatible with iOS, and others with Android, and some are free while others are not. Below, we provide a summary of the aforementioned considerations for the behavioral observation applications Animal Behaviour Pro, Animal Observer, BORIS, CyberTracker, Prim8 and ZooMonitor (Table 1).

Assessment of the applications

In this section, we provide descriptions of the learning curve or starting costs, workflow per observation day, data output formats, the advantages and drawbacks for each of the applications, and a case study comparison. To assess the usage of the different apps, we looked up the number of times the apps were cited (either by searching for the app name or the papers introducing the app) in Web of Science and Google Scholar. To compare the learning curve, the sampling procedure, and the data output for each of the applications, we performed focal sampling using a video of five horses from the Wild Discoveries program at the University of Florida (https://programs.ifas.ufl.edu/wild-discoveries/research-practice-materials/ accessed January 22, 2021).

Table 1. Application software and which sampling methods are possible per platform, how fast behaviors can be entered, the data output, and how to customize certain platforms so it will work for a particular study.

Application	Sampling method	Behavioral entry	Data output	Customization	Platform	Price
Animal Behaviour Pro	Focal animal, scan, all-occurrence, ad libitum	Codes as buttons on screen	CSV files		iOS	0.99£
Animal Observer	Focal animal, all-occurrence, scan, ad libitum	Swiping + drop-down	dat files → CSV files	All-occurrence possible	iOS	Free
BORIS	Focal animal, scan, all-occurrence, ad libitum	Point and click, codes as buttons, or keyboard shortcuts	Multiple options	Nearly unlimited	Desktop app, Android (alpha version)	Free
CyberTracker	Focal animal, scan, ad libitum	Customizable	Different types	Nearly unlimited	Android (iOS through CyberTracker Connect)	Free
Prim8	Focal animal, scan, all-occurrence, ad libitum	Codes on keypad	CSV files	Separate keypad	Android	Free
ZooMonitor	Focal animal, scan, all-occurrence, ad libitum	Codes as buttons on screen + map	In-app analyses, CSV files		Web-based able to use on any platform	Free for qualifying institutions, otherwise 50$/year

Animal Behaviour Pro

Animal Behaviour Pro was developed by Nicholas Newton-Fisher in 2012 and was recently updated (Newton-Fisher, 2020). The recent version has already been cited 7 times according to Google Scholar (accessed March 10, 2021). Unlike other apps, this one was not exclusively designed for recording primate behavior and can accommodate a wide range of behaviors across taxa including birds (Xie et al., 2017), humans (Dunbar et al., 2017), mammals (Roberts et al., 2016), and primates (Berthier & Semple, 2018; Boeving et al., 2020; Tórrez-Herrera et al., 2020). The app supports focal animal, scan, all-occurrence, and ad libitum sampling in a highly configurable fashion allowing it to be adaptable to

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various study systems and research questions. Multiple sampling methods can be used simultaneously. The output of the data can be exported as CSV files via email or iCloud. This app is available on iOS and is low cost (currently 0.99£).

To begin using the app, each observer must enter a unique four-digit login code which identifies the observer recording the behaviors. Then users are presented with the "Configuration" menu where they can set up "Focal Animal", "Scan", "Focal Behaviour", and "Ad Libitum" sampling. To create an ethogram, the user must select "Manage" to create a coding scheme within the app or import from the iCloud Drive. The option to create the coding schemes within the app allows for easy and convenient modification in the field. Multiple coding schemes can be created and stored. Within a particular coding scheme, a user can enter an unlimited number of subjects and codes, which appear as buttons on the screen. Observers can choose their own codes of any length (2-4 characters are recommended for visibility, but this is not required). Behaviors can be classified as a "state" or an "event", and the user can specify whether the behaviors are mutually exclusive. Additionally, users may add color tags to the type of behavior or specific subjects for easy recognition. The app also includes the option to add "modifiers" to any behavior for a more detailed description of any behavior. For example, users can add the modifiers "quickly" or "slowly" to describe the way an individual retreats from an aggressive encounter. The flexibility of the coding scheme allows for quickly recording coalition behavior. When creating a coding scheme, observers can add a button to include two individuals that make up a coalition so during sampling periods both individuals can be entered simultaneously. However, coding a single button to represent multiple individuals means those individuals will be accounted for in a single cell in the data output. In this case, the data would need to be reformatted which could be time consuming. Alternatively, users may group many subjects together and sort and cluster the buttons for actors and receivers (start group names with 1, 2, 3, etc.). Once the coding schemes have been created, users can

assign any scheme to any one or all sampling methods. Then users must set the individuals or behaviors of interest and duration of sampling after which data collection starts.

Daily data collection routines

Sampling does not start until the observer enters an observation which eliminates dead time at the beginning of a sampling period. However, this could be a potential drawback for researchers interested in comparing the timing of the first event and the beginning of the sampling period. The time of occurrence for a behavior is recorded when the first button is pressed (typically the relevant actor, or the behavior of a focal individual), but the observation is not saved until users 'OK' the entry, which provides time to fully describe the behavior (to the level of detail specified in the coding scheme). Once observers enter a subject as actor, the screen automatically and quickly updates to display the coded behaviors. Dependent on whether the behavior is an interaction with a subject or not, it either goes to the receiver subject screen or to the next observation. Once the sampling period is complete, it is saved and can be found in the "Logs" menu organized by sampling type and date of sample. Here, researchers can merge the data or select a sample to export via email or iCloud. In Supplemental Material 1.1 we provided a walkthrough on how to set up Animal Behaviour Pro for focal animal sampling.

Potential drawbacks or other considerations

Although Animal Behaviour Pro is highly customizable, some drawbacks exist. The detailed coding schemes with many behaviors or individuals could cause researchers to spend an excess amount of time scrolling for a particular behavior particularly when the screen is small (phone instead of tablet). This process may slow down the data entry and behaviors may be missed as one has to look down at the screen for longer periods of time. Another drawback is that users cannot edit behaviors once submitted. Unless specified in the "Notes" (which corresponds with a single observation), the app does not provide a way to document contextual data such as weather or quality of observation period. This app does not provide any location specific features, however, the virtually limitless coding scheme allows observers to enter a specific location as a subject and record which individuals are present at that location, or use

codes to record who is, for example, resting near or walking with whom. However, as mentioned above, this method could require adding several new codes and potentially take time away from observations. No analyses can be done within the app. Finally, this app produces a CSV file in which the output of the scan and ad libitum sampling includes all subjects with their behavior in the same row, which can complicate further analyses.

Overall summary

Animal Behaviour Pro allows for many specifications, and although useful, it can overcomplicate the initial set up of coding scheme(s) particularly when creating the scheme within the app. However, there is a YouTube tutorial available that breaks down the basics of the features available which is convenient for overcoming the initial learning curve. The app allows for a very quick data input (can input very specific behaviors -with modifiers), highly customizable coding schemes, multiple sampling methods, and multiple export options.

Animal Observer

Animal Observer was designed by Damien Caillaud and his team from the Dian Fossey Gorilla Fund International and first released in 2012. The application has been used to collect behavioral data in, for example, primates (Harrison et al., 2020; Schrock et al., 2019), humans (Dai et al., 2020), bats (Welch et al., 2020), and birds (van der Marel, Prasher, et al., 2020). The main sampling methods included in Animal Observer are focal animal and scan sampling. Ad libitum, social interactions, and individual-specific data collection can also be added. Other features include a GPS function and a map mode. Researchers can also add an unlimited amount of additional information, such as observer identity, weather, and activity level of the group. This application is freely available for iOS platforms.

Initial setup

The Animal Observer app is initialized with the Animal Observer Toolbox. This toolbox is a web application that uses R in the background, which allows researchers to customize Animal Observer.

Researchers must prepare three different protocol files in json format (behavioral protocol, group composition, and global variables or content of records file that contain all the information to be gathered). Each of the protocol files consist of mandatory and optional CSV files. The structure of the CSV files is important because if the structure is incorrect the files will not be uploaded and converted into a json file. Each of the CSV files allow the user to add many different variables with endless options to add modifiers which can appear as drop-down menus. It may take a while to optimize the exact needs but there are many options to include different variables, and it is very customizable. For example, in species where pairs are the primary social unit, pairs can be added as "IDs" which allows for entering behaviors that occur between pairs instead of individuals. Thus, researchers face a trade-off between the potentially time-consuming initial set up and optimizing the app to best suit their research question.

Daily data collection routines

The user starts by entering the session variables, such as group ID, observer, what navigation tool to use, and any other variables included in the global variables file. In the next screen, the focal variables are selected, such as which focal animal to observe, duration of the focal and scan interval, but also any other contents of record added to the focal variables file. The observer is then prompted whether a scan is required. If yes, any of the customized scan variables can be entered. In a scan, the user can move the ID from the left field to the map/navigation field, after which the ID button can be clicked upon which a drop-down menu of behaviors pops up. Once the scan is finished (NB: after the behaviors of all individuals in sight are entered, do not forget to hit 'End scan', otherwise the behaviors are not saved), the focal starts. During focal sampling, the observer can move between IDs on the map and automatically a drop-down menu appears with behavioral data. If a mistake has been made during the focal sample, the user can move to the next screen, which shows the output in table format, and correct any of the variables (time, initiator, receiver, and behavior) by clicking on it. Any additional information (notes) can be easily added using the built-in voice recorder, camera, or text editor.

At the end of the observation session, the user has the option to export the data using a cable or a sftp (Secure File Transfer Protocol) server taking care to delete data from the Ipad/Ipod once downloaded, otherwise duplicate entries in the data files will appear. The collected data can be converted to CSV files using the Animal Observer Toolbox. The data files are exported separately resulting in nine different files. The observation CSV file is immediately useable in R as each row represents one observation (Supplemental Material 2). Be aware that if any of the variables are changed throughout the field season, the order of the variables in the output CSV files may end up in different columns, making it more difficult to collate the files from different observation sessions into one file. Animal Observer does not have an option to perform in-app analyses, so all the data need to be downloaded and used in other programs.

Potential drawbacks or other considerations

A potential drawback is that this application was developed for studying primates, and in the primate literature, focal animal sampling is the main sampling method. However, in other taxa, scan and all-occurrence sampling are used more frequently. Thus, for studies where interaction data is the focus, Animal Observer may not be the first choice. However, users can customize the application to focus on all-occurrence sampling and collect scan sampling at the same time (for a detailed description of how to set up both sampling methods, see Supplemental Material 1.2). Another drawback is the amount of time it takes to import and export the datafiles (the created files need to be converted from CSV to json so it can be used in the app on the iPad and vice versa), which can be an inconvenient process.

Overall summary

The Animal Observer app has a very user-friendly interface, which allows accurate data collection of the location of individuals, but more importantly a great representation to collect behavioral data. This application is very useful for study systems where many interactions can occur in a short period of time, and when individual spatial (GPS) locations are required.

BORIS (Behavioral Observation Research Interactive Software)

BORIS is a flexible tool for recording behavioral data live or from video files designed in 2016 by Olivier Friard and Marco Gamba. The software is popular in usage as the paper introducing the software (Friard & Gamba, 2016) has been cited 424 times according to Web of Science and 725 times according to Google Scholar (accessed March 10, 2021). The software has been used in diverse animal taxa, e.g., insects (Taylor et al., 2021), fish (Wing et al., 2021), and birds (Prasher et al., 2019) and is especially well-suited to focal and scan sampling. Friard & Gamba (2016) provide an extensive review of the features of BORIS and a comparison with other applications to record data from videos. Although BORIS is typically used to score videos or direct observations of animals in captivity, an Android app is currently being developed to accommodate the recording of live observations from hand-held devices.

Initial setup

The first step when using BORIS is to make a new project, which includes making an ethogram of all the behaviors the observer wants to record (see Supplemental Material 1.3 on how to set up BORIS for focal animal sampling). Behaviors can be set as point or state events and assigned a keyboard shortcut for quicker data collection during observation sessions. Observers can also specify which behaviors are mutually exclusive, which tells BORIS to stop recording the current behavior if the key for a mutually exclusive behavior is pressed. Each behavior can be associated with two or more modifiers for an additional level of specificity. If groups of animals are being observed within the same observation period or video, a list of subjects can be added to the BORIS project and each subject can be assigned a unique key to allow for rapid switching between focal sampling of different individuals. Subjects can also be defined as pairs of individuals or groups to record behaviors occurring above the individual level. Finally, contextual data (e.g., weather, group size, observer ID, etc.) that researchers want to record at the beginning of every observation can be specified at this stage. Once an ethogram is made, it can be exported in various formats to share with other observers. Alternatively, the whole project file itself can

be shared with other observers so that everyone has the same ethogram, list of subjects, and contextual data.

Daily data collection routines

To start an observation session, the user starts a new observation within the project, name the observation, optionally add a description, specify contextual data if applicable and select the videos to be observed if it is not a live observation session. To record events, the observer can point and click on subjects and behaviors, which appear in their own widgets within the BORIS window, or use the keys associated with each subject or behavior to quickly record events without having to look away from the animals. If the "coding pad" or "subject pad" option is selected from the Tools menu, behaviors and subjects can additionally be displayed as colored boxes, which can be clicked or tapped on a touch screen. Researchers may also import a map and define different areas of it to code for particular behaviors or modifiers. During observations, the observer can then click on different areas of the behavioral coding map to record events. Once a behavior is selected, there will be a pop-up window to select a modifier if applicable and BORIS will record the subject, event, and time that the event took place. All the recorded events will be visible in the events widget. During or after an observation session, particular events can be edited (e.g., changing the behavior or adjusting the time) by right-clicking on the event within the events widget. Comments can be added to specific events, but there is no built-in way to take notes on things that fall outside of what was defined in the BORIS project (e.g., behaviors not in ethogram – although a behavior called "other" could be added to the ethogram to record any unusual activity).

The record of events from observation sessions can be exported in a variety of formats for further analysis. Within BORIS, researchers can access time budgets for each observation, which include data such as the number and duration of events per subject and inter-event intervals. If applicable, time budgets for behavioral categories defined in the ethogram will also be available. Time budgets can be

easily exported as plain text files or spreadsheets. Additionally, coded events can be plotted by time within BORIS for a quick visualization of the data. Frequency and duration of behaviors can be plotted as well, and plots can be exported in various formats.

Potential drawbacks or other considerations

The main drawback of BORIS is that the software is primarily available as desktop software. Therefore, the application would not be the best choice when observing live animal behavior in the field (although rugged field laptops do exist). However, the BORIS Android app is in development (it is currently available as an alpha version for testing). The Android version is designed for live observations and is to be used with the BORIS desktop software. After importing a BORIS project file from the desktop to the app, new observations can be made within the app. Once an observation has been started, events can be recorded by tapping on the boxes on screen, which show each behavior defined in the ethogram. Once observations are complete, they can be sent back to the BORIS desktop for further processing.

Overall summary

The BORIS software provides many features that make it a flexible tool for recording a wide range of behavioral data live or from video files. However, because of the number of features, it may take some time to get accustomed to using the program, especially when making more detailed observations. Fortunately, the user interface is easy to use, and user guides are available on the BORIS website to help researchers understand how the program works.

CyberTracker

CyberTracker was designed by the CyberTracker Conservation Organisation in 1997 (http://cybertracker.org). The software was not primarily designed to collect behavioral observation data but instead to collect GPS field data (Liebenberg et al., 2017). However, CyberTracker is very customizable and could be used for behavioral observations of different animal taxa, e.g. lizards (Carter et al., 2012), birds (Ashton et al., 2019), primates (Burgunder et al., 2017; Castles et al., 2014; Herzog et

al., 2014; Marshall et al., 2015; Martina et al., 2020) and other mammals (Marneweck et al., 2015; Rauber et al., 2019; Venter et al., 2019; Welch et al., 2018). CyberTracker is also convenient for vegetation sampling. Google Scholar returns 1500 results for the search query "CyberTracker" and 614 for "Cybertracker animal behavior". The software is freely available and functions as a tool to create and design a mobile application which suits the needs of your study. Once the application has been designed it can be migrated to a mobile device (Android or iOS) for use. Collected data can then be returned to the computer for extraction and analysis. CyberTracker is highly customizable for many types of research projects because it allows researchers to customize an app interface to best suit the researchers' needs. CyberTracker was designed to accommodate an inclusive audience: app setup requires little to no coding skills, and icon-based user interfaces to allow for participation of non-literate users.

Initial setup

To begin using CyberTracker, users can download the free desktop software (available at https://www.cybertracker.org/software/free-download) for all Microsoft Windows versions. Within the desktop software, users then create a "New Screen" from a list of screen templates, which are each suited to collect a particular type of data. For example, selecting a "User list" creates a screen with a list of users, and a "Multi-select list" will present the observer with a screen in which they can select one or more possible elements. Researchers can customize the screen template to include relevant data as well as sub-screens for more detailed data collection. Users can add different buttons on each screen to save each input, go to the home screen, go to the GPS settings, or the next screen, which the user can specify. The desktop software provides a test run option so researchers can review their design before finalizing the app interface and export it to the mobile device. We have provided a walkthrough on how to set up focal animal sampling in Supplemental Material 1.4.

Daily data collection routines

After the application set up, Android users can install the app to their mobile device. This feature is not yet available for iOS; however, the CyberTracker Connect feature is available for iOS and Android devices and is available on Google Play and the Apple Store. From their mobile device researchers can collect data in the field. Observers can edit an entry during the sampling period by going to the main screen and selecting 'all sightings' where the wrong entry can be edited. Once data collection is finished, the device can be connected to the desktop using the cable and data can be downloaded to the CyberTracker desktop software.

Potential drawbacks or other considerations

Despite its versatility, the highly customizable nature of the app can be overwhelming particularly at first encounter, and it may require a substantial amount of time to properly set up the application interface for your needs. However, the CyberTracker official website has extensive resources available for references including step-by-step instructions for setting up a basic app interface. As mentioned previously, the CyberTracker desktop software is only compatible with Android devices, but options exist to use CyberTracker on iOS devices using the CyberTracker Connect feature. This may be an inconvenience for researchers with iOS devices.

Overall summary

Overall, CyberTracker is well-suited for collecting GPS data, is highly customizable, requires little to no coding experience, is free and its customizability is inclusive for users who may need symbols to communicate. CyberTracker is useful in several fields of ecology and biology due to its versatility. However, it may require time to customize it depending on its intended purposes. One thing to keep in mind is that this app was developed in 1997 and is still actively updated and supported, therefore this app may be useful when planning for a long-term research project.

Prim8

Prim8 mobile is an application created to record behavioral observations in a flexible, customizable way by Monica McDonald and Scott Johnson in 2014 (McDonald & Johnson, 2014). The app is cited 11 times according to Web of Science and 18 times on Google Scholar (accessed March 10, 2021). This app was primarily developed to observe primate behavior (Whitehouse et al., 2017; Whitehouse & Meunier, 2020) but has also been used for studies with other mammals (Szott et al., 2019; van der Marel et al., 2019; van der Marel, Waterman, et al., 2020) and birds (Benti et al., 2019; Puehringer-Sturmayr et al., 2020; Szipl et al., 2019). The sampling methods that are supported are focal animal, scan, all-occurrence, and ad libitum sampling. Observers can add many different variables as the number of modifiers after the fixed position of actor-behavior-(recipient) is unlimited. Although, the website states that the app is also freely available on iOS, the app is currently only freely available on Android platforms.

Initial setup

This app is user-friendly. An observer can use the application immediately from an Android device, without having to connect it to a computer. Some required variables (sites, locations, coordinate system, species, groups, and behavior types) can only be added on the device itself in the settings tab. Instead of having a drop-down menu, researchers provide codes for individuals and behaviors. These codes are then used to enter the behaviors using a keyboard on an Android device. This method is more similar to the old-fashioned pen and paper method. Users can either manually add their ethogram and the individuals or use the template CSV files (available from the website www.prim8software.com). The latter method is especially useful if many behaviors and individuals need to be entered. When adding the behaviors, observers are prompted to answer whether the behavior (1) has a recipient (if so, then the mandatory code field reflects "actor-behavior-recipient" and if not, it reflects "actor-behavior" after which any modifiers can be added), (2) is a state vs an event, (3) is an all-occurrence behavior, (4) or a scan behavior.

Daily data collection routines

Once the ethogram and individuals are entered or uploaded, observers can immediately start entering data in the follows tab. A focal animal follow can be setup by clicking the 'start follow' button (see Supplemental Material 1.5 for a walkthrough). In the next screen, the user can enter the individual to follow, the focal follow duration and the scan frequency. The app will sound an alarm every time the scan is up, so the user knows when to start the scan during a focal follow. Behaviors can also be entered directly without starting a focal follow but then the alarm will not be made. Users can get the duration of state behaviors if they click on the behavior once the state has finished. Once the mandatory code fields "actor-behavior(-recipient)" are entered, the observer can add an unlimited number of modifiers, such as location of the individuals, number of individuals in proximity, etc. If a mistake is made, observers could click on the behavior instance in question (all behavior instances are visible below the data entry field after hitting enter) and retype the behavior. An observer can input notes by simply starting the note using an exclamation mark. For example, a note can be entered as "! hawk circles above".

Users can 'delete and export' the data to the memory of the Android device or SD card. If researchers only 'export' the data, the data will still be visible in the app resulting in duplicate entries. Users can connect their Android device to their computer and transfer the files. The output is readily available as nine different CSV files that include the different sampling methods and backup files. Prim8 does not have any in-app analyses, but instead the output files can be directly imported in any statistical software program reducing intermediate data entry steps (see Supplemental Material 2).

Potential drawbacks or other considerations

Although this app is customizable in how to record behaviors, some drawbacks exist. First, users must remember the codes that were set for the behaviors and individuals. Thus, the training of multiple observers may take time. However, the codes are provided in the individuals and ethogram tabs, so that users can look up codes during an observation session. Another potential drawback is the usage of

modifiers. If the same modifiers are not entered in the same sequence after the mandatory code, the modifiers may end up in different columns once the data is exported, which users will have to adjust manually later. Furthermore, the keypad provides a flexible way to record behaviors, which is helpful when many individuals or behaviors that make a drop-down menu too long and make users scroll down if there is not a large enough screen. But keypads are not always responsive or easy to use. The developers of Prim8 suggest using a phone with a physical keypad instead of a screen, but this phone may not be readily available. Alternatively, observers could use their own Android smartphone or tablet and purchase an external wireless Bluetooth keyboard. Despite these potential drawbacks, Prim8 allows for great flexibility in the coding scheme as users can make-up code for anything they want. For example, users can collect data on pairs of individuals or groups instead of individuals, which all depends on how the actor and recipients are coded. Also, every observer could make up their own code (as long as the names of the individuals and behaviors are the same across devices) because the codes are immediately translated to the names once an observation has been entered in the data entry field.

Overall summary

This application is useful when many individuals, behaviors, and locations, have to be entered, as the application is code-based. This flexibility also allows an observer to enter any other comments at the end of the fixed code positions. Thus, when users are comfortable and fast-typing on a qwerty keyboard, and do not want to spend a lot of time customizing the app, Prim8 may be the choice for them.

ZooMonitor

ZooMonitor was developed by Lincoln Park Zoo to collect data that may impact animal welfare and inform management decisions (Ross et al., 2016; Wark et al., 2019). The two papers introducing the app were cited 14 and 13 times in Google Scholar, respectively (accessed March 10, 2021). This app is freely accessible for qualifying institutions (zoos, museums, and sanctuaries) and for a small cost to non-

accredited institutions (50$ per year). Therefore, the app is used as the preferred method of research

data collection by a growing number of Association of Zoos and Aquariums (AZA) facilities. Although

ZooMonitor has primarily been used by observers at zoos, museums, and sanctuaries to pursue research

questions that aim to improve animal welfare, the app is versatile and can be used effectively to tackle a

wide array of research questions. The app itself supports focal animal, scan, all-occurrence, and ad

libitum sampling, all of which can be used simultaneously. The setup is highly customizable and can be

molded to fit a variety of study systems. ZooMonitor also allows for in app data analysis, though data

can also be exported as CSV files if preferred. The collected data is backed up daily to the cloud of

ZooMonitor.

Initial setup

The ZooMonitor system is made up of two different sections: ZooMonitor Admin and

ZooMonitor App. The function of the admin section is to set up research projects, analyse data, and

export data for analysis outside of ZooMonitor. The app section is used to collect and upload data. To

begin a research project, researchers must make use of ZooMonitor's Admin section. First, the study

species in question must be added to the species pool, followed by the focal individuals that are meant

to be included within the study. These steps are both accomplished via the "configure system" option on

the dashboard of the ZooMonitor admin page. The "configure system" option can also be used to add

admin users and observers to the project if needed.

Next, a new project can be created within admin by selecting the "Create" option on the

Behavioral observation admin page. Within the setup steps, users can specify the details of the study

(name of study, study length, focal animals, etc.) as well as the used sampling methods. These sampling

methods are treated as separate "channels" within ZooMonitor, and can all be employed

simultaneously. For each sampling method channel the users must enter each of the behaviors that fall

under that specific sampling method (e.g., aggression might be a behavior that researchers would want

to record every instance of, so it would be entered under both the all-occurrence channel and the scan sampling channel). Users will have the opportunity to add up to three modifiers per entry in the behavior details pop up window, where it is also possible to add social modifiers and a description of the behavior in question.

Users also have the option to upload a map image under the Space Use channel if needed. The user can then overlay a grid atop the map with a customizable number of grid columns and rows to best divide the map into sections that may help with space use research questions. After setup completion of all the necessary channels, users may now create additional questions that will be answered before each observation session to specify contextual data, such as weather, temperature, and crowd size. Finally, users should add observers to the project. Only observers that have been added can access the project.

Daily data collection routines

After setup is complete, observers may log into the ZooMonitor App section to begin data collection. From the dashboard, the observer first must select the "Go to Behavioral Observations" option and select a project from the project list. The user can then hit "New Session" and answer all the additional questions created during setup in admin, as well as select their focal animal(s). Once completed, the observer will be brought to the data recording screen, which displays the behaviors as buttons. Behaviors are laid out in rows and separated by sampling method channels. Within each channel, behaviors are further separated by subgroup. The map sits at the bottom of the screen to be used as reference when investigating space use. Once a session has started, a countdown will begin on screen, giving the user a few seconds to prepare before the session begins. As the session progresses, a separate set of countdown timers will appear on the top of the screen, indicating both the total time left in the observation session and the time left between intervals. At the end of the session, as well as at each interval, the screen will flash and a beep will sound. To select a behavior, the observer need only to press the behavior button(s) on the screen after each beep/flash. A separate module called the

Instantaneous Observations Module exists for recording ad libitum observations and can be accessed from the dashboard. Ad libitum observations may be recorded as open text, numbers, or via a user defined list of options that was predetermined by the user in the initial setup phase. After a session has ended, the observer will have the ability to add notes or modify any of the information previously entered in the additional questions section. Once data has been collected, it cannot be edited to fix potential mistakes. A user must instead make a note of the error and edit the data once it has been exported. The data can be uploaded to the ZooMonitor cloud for analysis or exportation in admin when in internet range. In Supplemental Material 1.6 we provide a walkthrough on how to set up ZooMonitor to collect focal animal sampling.

Potential drawbacks or other considerations

Even though ZooMonitor is highly versatile and can be used to tackle a wide variety of research questions, it does have limitations that make its use in certain situations not ideal. For starters, ZooMonitor is a web-based app. While this classification allows for users to access the app on a variety of platforms, it also means that using this app effectively in a remote research setting with little to no internet is impossible. Even in research settings with adequate internet access, it is paramount for observers to ensure that their devices are properly connected to the internet when attempting to upload data. If a researcher fails to notice that the internet connection on his or her device has dropped, they may close the app prematurely, thinking that the data had been successfully uploaded. This would result in a loss of valuable data. In addition, while ZooMonitor's streamlined nature allows for ease in mastery of the app, both on the administrative and data collection side of things, it also limits the possibilities a user might have when analysing data in-app. ZooMonitor's built in analysis tools are rigid and are not significantly customizable, only meant for a preliminary look at the data via graphs before in-depth analysis, and thus may not be useful for the observer's research question. In this case the in-app analysis tools would have to be ignored and the data can be exported for analysis elsewhere.

Finally, ZooMonitor costs significantly more than other software applications unless the users are part of an accredited institution. For some, the app's high price point may overshadow its potential uses.

Overall summary

The ZooMonitor application is highly customizable and can be tailored to fit a wide variety of research questions. ZooMonitor's ability to group behaviors, add modifiers to behaviors, upload a grided map, and use multiple sampling methods at once has contributed to the app becoming the preferred data collection platform for many accredited zoos, aquariums, and sanctuaries. These attributes allow for the app to be especially useful for tackling research questions based around the space use, activity budget, or social relationships of a small number of focal individuals, and its learning curve is relatively low, allowing for many researchers to be trained quickly.

Case study comparison

We compared the set up, the ease of use, and the output files of each app using focal animal sampling of horses of the Wild Discoveries program at the University of Florida. We found that the set up was the most straightforward and fastest using Animal Behaviour Pro and Prim8, because these apps can be used immediately without having to download files from the computer. On the other extreme was CyberTracker, which took us multiple days to set up for focal animal sampling and even then, we used an external timer to set the intervals. The sampling procedure was very easy using the Animal Behaviour Pro, Animal Observer, CyberTracker, and ZooMonitor apps. For BORIS and prim8, we had to get accustomed to the different codes, which can be harder when having to remember many different codes. All the apps' output files can be exported as CSV files, but the output is very different across platforms (Supplemental Material 2). We think the output of Animal Behaviour Pro is the least intuitive, especially because the output of the scan and ad libitum sampling includes all subjects with their behavior in the same row. We provided the setup files (ethogram and individual files) and the output for each application in a Github repository (https://github.com/annemarievdmarel/behavioral-observation-

data-entry-apps). We expect that this information will be helpful to researchers who are weighing decisions about which app to choose and will make that process easier and less time-consuming.

Overall, the choice of app best suited to a particular study question and a particular research team depends on multiple aspects. Considering the duration of the study, the learning curve, which sampling methods are used, but also personal preferences, can affect which app is the most suitable for each study (Fig. 1). First, the duration of the research may influence the app choice. For a short-term study, researchers may want to consider an app with a shorter learning curve, such as Animal Behaviour Pro, Animal Observer, Prim8, or ZooMonitor. However, for a long-term research project, researchers could invest more time in an app that will be supported over a longer period and is still actively developed, such as CyberTracker, but which has a greater starting cost.

A second consideration is the learning curve to set up and use the application (Fig. 1). Some applications, such as Animal Behaviour Pro, Prim8, and ZooMonitor are very easy to setup (for example, it is possible to use Animal Behaviour Pro and Prim8 on a device without having to use a computer), while others, such as Animal Observer, BORIS, and CyberTracker, require a bit more preparatory work before these apps can be used to collect observational data. Sometimes prior knowledge is required to use an app, such as running code in R for Animal Observer. Other apps allow users to use customized coding schemes, so that observers that are not fluent in a certain language can use their own codes (Animal Behaviour Pro, BORIS, Prim8). CyberTracker accommodates an inclusive audience: the icon-based user interface allows for participation of non-literate users. Although, CyberTracker's setup may be straightforward when used for the collection of ecological and GPS data, the setup is more difficult in the context of behavioral data collection. Of course, observers also need to be trained using the application and this training may be faster when the behaviors are presented as buttons on a screen (Animal Behaviour Pro, CyberTracker, or ZooMonitor) or as a drop-down menu (Animal Observer) compared to codes entered on a keyboard (BORIS, Prim8).

Another factor to keep in mind is what sampling methods will be used, the number of animals that will be observed and what information will be entered (Fig.1). Some applications do not provide all sampling methods (although users could go around that by customizing the system). When many individuals or groups will be observed, code-based apps may be better when device screens are small, otherwise all apps function. To record behavioral data, any app will work, but to include contextual data, CyberTracker, Animal Observer, or Prim8, are better options. If GPS locations are required, then either CyberTracker or Animal Observer work best.

Personal preferences also weigh into the equation of which app to choose (Fig. 1). If users are fluent in typing on a qwerty keyboard, Prim8 or BORIS are the desired applications. However, if users are more visually inclined, then Animal Behaviour Pro, Animal Observer, or CyberTracker may be better options. The output of the data files is also something to consider (for an example of the output files see Supplemental Material 2). When Android devices are readily available, then Prim8, CyberTracker, or BORIS (alpha version) may be the best choice. On the other hand, Animal Behaviour Pro, Animal Observer, or CyberTracker work on iOS devices and BORIS and ZooMonitor are web-based. A major advantage of these behavioral observation entry software applications is that most of them are open source or are nearly free (Animal Behaviour Pro, 0.99£). Only ZooMonitor is more expensive for non-affiliated institutions.

We provided basic introductions to several behavioral observation data software applications; however, researchers can customize one or more of these apps to best suit their needs (Supplemental material 1). Researchers could use these recommendations to choose the best application for their study design and/or requirements.

Behavioral observation software recommendations

Duration

Research duration?

Short-term: ![Animal Behaviour Pro] ![Animal Observer] ![BORIS] ![Prim8]

Long-term: ![CyberTracker]

App updates?

<5 years: ![Animal Behaviour Pro] ![Animal Observer] ![BORIS] ![CyberTracker] ← ZooMonitor

Unknown: ![Prim8]

Legend
- ![Animal Behaviour Pro] Animal Behaviour Pro
- ![Animal Observer] Animal Observer
- ![BORIS] BORIS
- ![CyberTracker] CyberTracker
- ![Prim8] Prim8
- ← ZooMonitor

Learning Curve

Software setup?

Short/easy: ![Animal Behaviour Pro] ![Prim8] ← ZooMonitor

Long/harder: ![Animal Observer] ![BORIS] ![CyberTracker]

Training period?

Shorter: ![Animal Behaviour Pro] ![Animal Observer] ![CyberTracker] ← ZooMonitor

Longer: ![Prim8] ![BORIS]

Sampling methods

Sampling methods?

Scan sampling: ![Animal Behaviour Pro] ![Animal Observer] ![BORIS] ![CyberTracker] ![Prim8] ← ZooMonitor

Focal animal: ![Animal Behaviour Pro] ![Animal Observer] ![BORIS] ![CyberTracker] ← ZooMonitor

All-occurrence: ![Animal Behaviour Pro] ![Animal Observer] ![BORIS] ← ZooMonitor

Ad libitum: ![Animal Behaviour Pro] ![Animal Observer] ![BORIS] ![CyberTracker] ← ZooMonitor

 # individuals observing?

Many: ![BORIS] ![Prim8]

Few: ![Animal Behaviour Pro] ![Animal Observer] ![BORIS] ![CyberTracker] ![Prim8] ← ZooMonitor

Data?

Only behavior: ![Animal Behaviour Pro]

Behavior + Contextual: ![Animal Observer] ![BORIS] ![CyberTracker] ![Prim8] ← ZooMonitor

GPS location: ![Animal Observer] ![CyberTracker]

Personal preferences

Preferred data entry method?

Typing in code: ![BORIS] ![Prim8]

Press buttons on screen: ![Animal Behaviour Pro] ![CyberTracker] ← ZooMonitor

Swipe + drop-down menu: ![Animal Observer]

Data output readily available for R?

Yes: ![Animal Behaviour Pro] ![BORIS] ![CyberTracker] ![Prim8] ← ZooMonitor

No: ![Animal Observer]

In-app analyses: ![BORIS] ← ZooMonitor

Available system?

Android: ![BORIS] ![CyberTracker] ![Prim8]

iOS: ![Animal Behaviour Pro] ![Animal Observer] ![Prim8] ![CyberTracker]

Desktop: ![BORIS] ← ZooMonitor

Budget?

Open source: ![Animal Observer] ![BORIS] ![CyberTracker] ![Prim8]

0.99£: ![Animal Behaviour Pro]

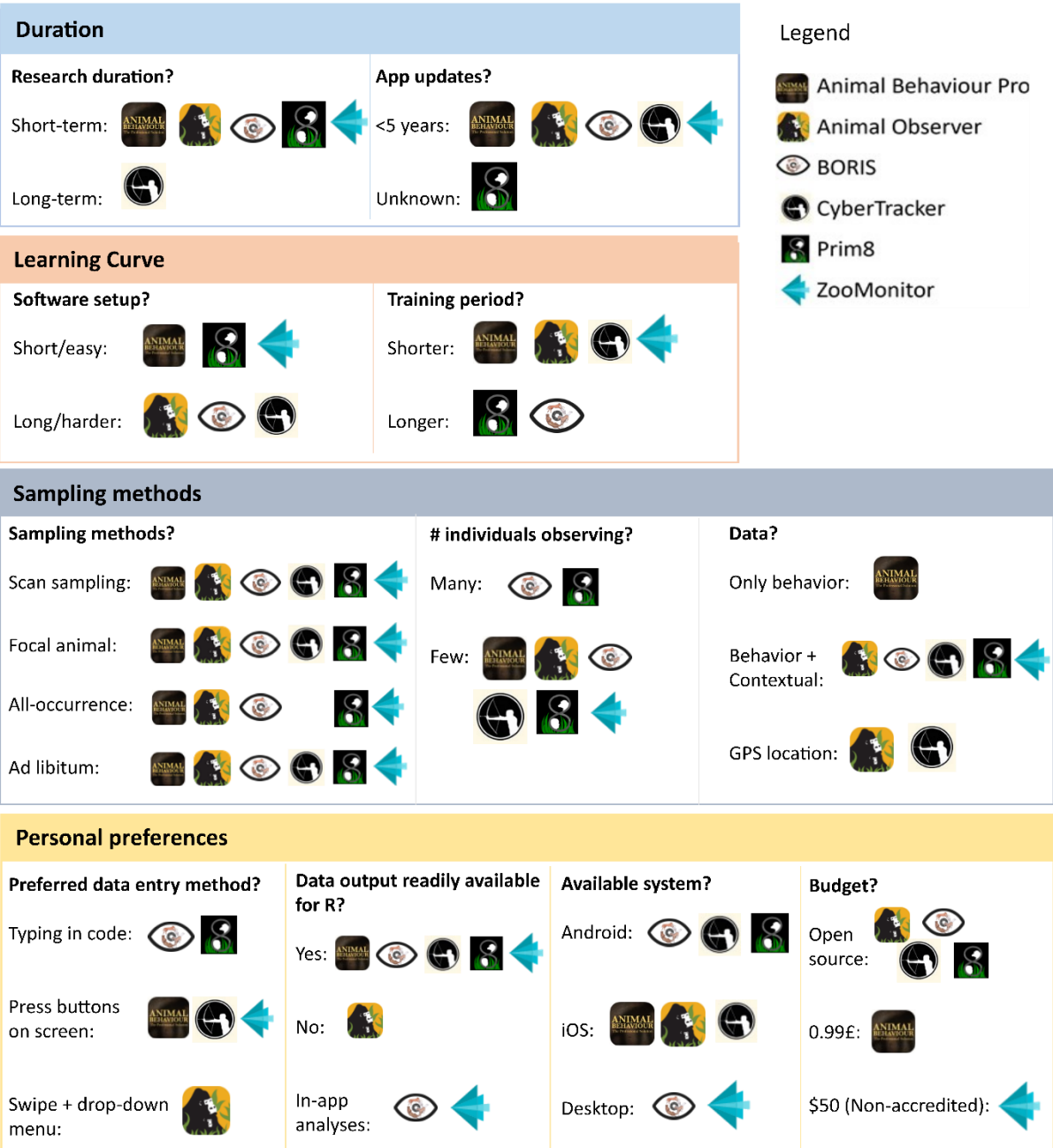$50 (Non-accredited): ← ZooMonitor

Figure 1 provides recommendations about the study duration, the learning curve, sampling methods, and preferences for which behavioral observation software application is best.

Other applications

The provided list is not exhaustive as we only show results of applications that were specifically made for the real-time collection of animal behavior observations. If the behaviors are recorded with a video camera in a captive or experimental setup (e.g., Bijleveld et al., 2014; Piquet et al., 2018), then other software applications may be more useful. A number of software programs exist to enter or 'score' behaviors from video, including The Observer XT (Noldus Information Technology BV), Jwatcher (Blumstein & Daniel, 2007), Solomon Coder (solomon.andraspeter.com), CowLog (Hänninen & Pastell, 2009; Pastell, 2016), and Datavyu (Datavyu Team, 2014). Which video software platform to use mainly depends on the budget, whether the program is actively updated, and the available support for the program. While voice and video recording reduce the delay in response time and reduces the number of missed behaviors, the main issue is still that the behaviors must be entered into a computer before the data can be used for analysis. Finally, if none of the applications work for a researcher's study system, question, or platform then they can either make their own application (Waterman, pers. comm.) or they can look at applications that are made in other research fields. Thus, the options are endless, but we hope that this review provides some guidelines for researchers studying animal behavior.

Conclusions

The major advantages of the applications over traditional pen-and-paper methods are that the transcribe time and the errors that are potentially made while transcribing the data are eliminated. Yet, a disadvantage of the applications is that users do not have a hard copy of the collected data. To promote reproducibility of data (Ihle et al., 2017), we suggest copying all the raw data files and saving them in a separate folder to make certain that no one can tamper with these raw datafiles. Another option to safeguard the raw data is to make a PDF copy of each datafile and push all the raw data to a GitHub repository (Laskowski, pers. comm.). To keep the raw datafiles unaltered, any data manipulations or data selections should be saved in another file. Another major aspect to make data

reproducible is to disclose the workflow (Ihle et al., 2017). This workflow will describe how data is extracted, selected, manipulated, analyzed, and reported.

An additional consideration to keep in mind is the number of times data should be backed up. For each of the discussed behavioral entry methods the possibility exists that data will be lost. For example, researchers may lose data if data sheets are damaged or lost in the field, and if voice recorders, video cameras, or handheld devices get damaged or stolen before the data is backed up. To prevent loss of data, we suggest backing up the data to a laptop, an external hard drive or server (we recommend having at least 2 back-ups) at the earliest convenience. Saving the files each day to a server, also provides an opportunity to document and track the sampling effort. Some applications, such as Animal Observer, have the option to use a secure file transfer protocol (sftp) server, so that the behavioral data can be uploaded automatically to a server without having to connect the device to a computer to copy the data files. Implementation of these types of functions will increase data reproducibility.

In this contribution, we compared six behavioral observation software applications. We emphasized the learning curves and starting costs for setting up each app as well as the methodological concerns involved in picking the most appropriate app for a particular study design. This approach highlights where each application excels as well as where study designs or other considerations may lead researchers to prefer one app over another. Our review and the guidelines we provide will be useful for researchers who are evaluating which behavioral observation software application may work best for their study and will make that decision easier and less time-consuming.

Authors' contributions

AM and EH designed the research; AM, CO, SP, CC, XF reviewed the different applications and performed sampling; AM led the writing of the manuscript. All authors contributed critically to the drafts and gave final approval for publication.

Data availabilty

Data, the setup files (ethogram and individual files) and the output for each application, available from the Github repository (https://github.com/annemarievdmarel/behavioral-observation-data-entry-apps)

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