Optimizing Behavioural Observations: A Comparative Approach to Simulated Sampling Methods James Edward Brereton1, Jonathan Tuke2 and Eduardo J Fernandez3

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Original Research paper

**Running title:** Comparison of behavioural recording methods

**Abstract:**

*Keywords:* continuous recording, pinpoint sampling, one-zero sampling, interval recording, behavioural measurement, sampling methods

**INTRODUCTION**

The measurement of behaviour is important for those involved in the scientific study of animal behaviour. Behavioural studies are used as a tool to measure captive animal welfare and are used more often than other welfare indicators such as glucocorticoid analysis (Fraser, 2009; Sands & Creel, 2004). For captive animals, behavioural research may also be used to investigate the prevalence of positive behaviours, such as foraging, or negative behaviours, such as stereotypies (Carlstead, Baldwin, & Seidensticker, 1991; Fernandez & Timberlake, 2008; Ward, Sherwen & Clark, 2018). Studies of behaviour are also frequently conducted for wild animal populations and to better understand natural history or investigate the impact of human disturbance (Lehner, 1998; Sand & Creel, 2004). Research on animal behaviour is now so well recognised that there are numerous journals dedicated to its study, for instance: *Animal Behaviour,* *Applied Animal Behaviour Science, and Ethology.*

The methods used in animal behavior research can be traced back to human studies. Scientists during the mid-twentieth Century often used a mixture of both human and animal models to answer questions in the field of behavioral psychology (Domjan, 2014; Pierce & Cheney, 2013). Based on the range of different techniques that were generated by earlier studies, Altmann (1974) summarised the behavioural research methods available. This paper became fundamentally important to those interested in behavioural research, and remains a keystone paper for researchers, with at least 16,100 citations, according to a search on Google Scholar (2020). Whilst other authors, such as Martin and Bateson (2007) further refined the behavioural methods and their definitions, Altmann’s work is still regularly cited.

Since this initial review of behavioural methods, some behavioural sampling techniques became increasingly popular in animal literature, whereas others are rarely used. Several behaviour measurement techniques have received criticism in terms of their repeatability (Bernstein, 1991). For example, ad libitum (qualitative) sampling may be useful for developing ethograms and for pilot studies but has methodological flaws with regards to its lack of standardisation (Martin & Bateson, 2007; Rhine & Ender, 1983). However*, ad libitum* sampling is still used in animal behaviour literature, with a review by Mann (1999) identifying that between 53% and 59% of cetacean studies published in *Marine Mammal Science* used this sampling technique.

Continuous recording, or focal sampling, is considered the gold standard for behavioural sampling, as this method records all occurrences of behaviour and their durations (Hämäläinen et al., 2016). In the past, this made continuous recording challenging for researchers, as an active animal that rapidly changed behaviour would have been difficult to observe and record (Tyler, 1979). Similarly, measurement of multiple animals using a continuous method would have been incredibly challenging to document accurately, hence why the method is considered synonymous with focal sampling of one individual (Altmann, 1974; Martin & Bateson, 2007). Use of modern technology has in part ameliorated some of these issues by allowing behaviour to be recorded and analysed later (Amato *et al.*, 2013). However, continuous recording may remain a challenge, even with camera availability. As a result, several sampling methods have been developed to measure multiple animals at one time (scan sampling), as well in a non-continuous fashion.

The use of pinpoint sampling, also referred to as instantaneous or momentary time sampling, is a commonly used method for observational study (Fernandez, Kinley & Timberlake, 2019; Lehner, 1998; Stevens *et al.*, 2013). With pinpoint sampling, one or more responses are recorded at preselected moments in time (e.g., every 15 s for an hour). The benefits of pinpoint sampling are that it is less intensive than continuous sampling, and therefore may be more feasible for researchers to conduct (Grenier *et al.*, 1999; Martin & Bateson, 2007; Gilby, Pokempner, & Wrangham, 2010). The methods are also more versatile, allowing researchers to make decisions as to how long intervals should be spaced. For example, some researchers might choose to use 15-second intervals, particularly when studying an active animal or when conducting observations of a key time period, such as when enrichment is provided (Fernandez & Timberlake, 2019). On the other hand, observers might choose to use much longer intervals, such as one-, two- or five-minute intervals when their subjects are inactive or if they are observing for long time periods (Shora, Myhill & Brereton, 2020; Teixeira et al., 2017). It has been noted by some authors that shorter intervals tend to result in behavioural values that match more closely the continuous behaviour scores (Pullins *et al.*, 2017).

One-zero or interval sampling involves choosing specific intervals of time, like pinpoint sampling, but instead recording whether one or more responses occur (or conversely, do not occur) within that interval of time (Bailey & Burch, 2017; Bakeman & Quera, 2012; Lehner, 1998). While popular with both human and non-human primate research, one-zero sampling seems to receive less representation than pinpoint sampling in most animal behavior studies and has been criticised by previous researchers (Altmann, 1974; Rhine & Flanigon, 1978). However, one-zero sampling has some of the same benefits of instantaneous sampling in that interval length can be tailored in line with the requirements of the study. Additionally, one-zero sampling has the potential to collect more behaviours during a stated period, as multiple behaviours can be recorded during each interval (Altmann, 1974). Leger (1977) identified good agreement with continuous behaviour measures when using one-zero sampling at 15-second intervals for chimpanzees (*Pan troglodytes)*. Likewise, Rhine and Flanigon (1978) found similar levels of occurrence when comparing continuous, pinpoint, and one-zero sampling methods with a colony group of stumptail macaques (*Macaca arctoides*). As noted above, one-zero (interval) sampling is also frequently used in studies on human behaviour, for example in the classroom (Dunkerton, 1981; Omark et al., 1976).

Both pinpoint and one-zero sampling overcome some of the issues associated with continuous recording by reducing the amount of input required by the researcher, while still aiming to keep the sample representative of the animal’s behavioural repertoire (Mitlöhner *et al.*, 2001; Simpson & Simpson, 1977). However, one key question is how closely these techniques correlate with continuous recording? Pinpoint sampling is reported to lose information in terms of behaviour duration and is potentially less likely to pick up any behaviours of short duration (events) (Martin & Bateson, 2007; Xiao *et al.*, 2005). By contrast, one-zero sampling is better at recording all observable behaviours, but both behavioural frequency and duration could be easily misrepresented: there is no way to identify whether a behaviour recorded as present for one interval was seen once or thirty times during that time period (Saibaba *et al.*, 1996).

The following study proposes to compare simulated occurrence of both low, medium, and high frequency/duration behaviours, as well as similar observation periods for pinpoint and one-zero sampling methods. We hypothesized two results: (1) one-zero sampling would be better suited for detecting the occurrence of low frequency (event) behaviours, particularly when comparing less frequent pinpoint and one-zero observation methods (e.g., 500 second observation periods), and (2) pinpoint sampling would provide a more accurate representation of percentages of occurrence for both low, medium, and high duration (state) behaviours than one-zero sampling.

**METHODS**

For all simulations, continuous recording methods were generated for both frequency of occurrence and percentage of occurrence, with two different non-continuous sampling methods directly compared: pinpoint (instantaneous) and one-zero (interval) sampling. Independent variables were split into two categories: Response frequency (to measure the ability of both behaviour methods to detect short, event behaviours) and response duration (to measure the ability of the methods in assessing long-term, state behaviours). Three levels for response frequency and response duration were determined, based on an arbitrarily level of occurrence: 3 s, 30 s, and 300 s. The interval lengths for both pinpoint and one-zero sampling were set at 5 s, 50 s, and 500 s, in order to compare the effect of interval length on test accuracy.

***Simulations***

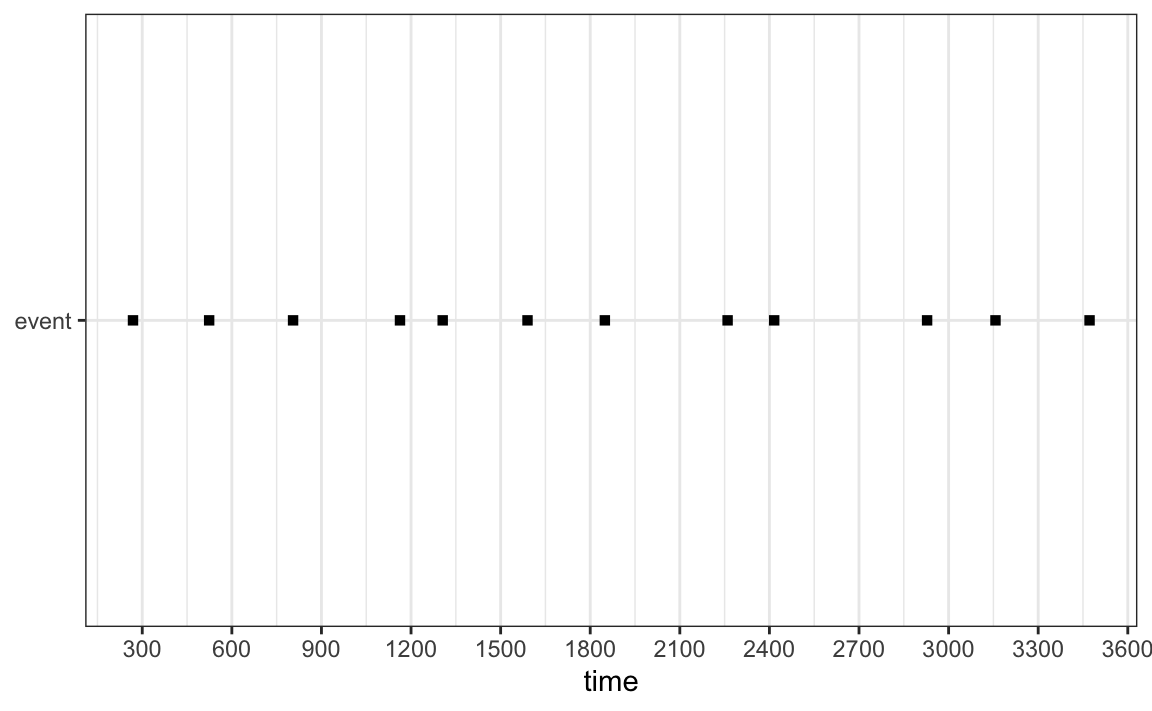
All of the simulations were done in the R computing language using the GUI RStudio. For the response frequency simulations, for a frequency of every k seconds, we split the entire time period into b blocks of length k seconds. We then randomly selected one second within each block using a discrete uniform distribution and designated that as the time the event occurred. An example of a simulation with k = 300 is given in Figure XXX.

For the response duration simulations, of duration d, we split the entire time period into 6 blocks, each of length 600 seconds. For each block, we then chose random number using a discrete uniform on the numbers from 1 to (600 – d), this was then designated as the start time of the event in the block, and the end time of the event was this time plus d. Each block had its own random starting time. An example of a simulation with d = 300 is given in Figure XXX.

All code is available at https://github.com/jonotuke/animal\_simulation\_2020

***Response frequency***

This simulation focused on the recording of event behaviours: behaviours of very short duration (Martin & Bateson, 2007). For the purpose of the simulation, the duration of all event behaviours was set to exactly one second. Next, three different frequencies of event behaviour were selected: high (3 s), medium (30 s) and low (300 s) frequency of occurrence. Simulated data sets for the observation period for all three behavioural frequencies. The observation period was 1 hour in length (3600 seconds). A total of 100 simulated data sets were generated for each of the three response frequencies. The exact time that each event occurred within the 3, 30 or 300 second period was randomised (e.g. Figure XXX).



***Figure XXX.*** *Example of simulated data set to show how each event was presented. This figure shows the location of each event when events were set to low frequency (occurs once per 300 seconds). The exact location of each event within its 300 second window was selected at random.*

The real (continuous) occurrence of each simulated response frequency was determined by calculating the number of seconds of each event that were possible in a simulated hour of data (observation period divided by frequency of occurrence; high frequency = 1200 s; medium frequency = 120 s; and low frequency = 12 s). The event behaviour seconds were then transformed into a percentage of total time (as is often shown in behaviour studies in the form of an activity budget), as well as frequency of occurrence.

To compare against this real (continuous) measurement, one-zero and pinpoint sampling were used on the simulated data sets. Three interval lengths (5 s, 50 s, and 500 s) were used for both pinpoint and one-zero sampling. This resulted in nine-hundred data sets (nine combinations of simulation parameters and sampling parameters, each combination simulated 100 times) being developed.

The data generated from the pinpoint and one-zero sampling was then converted into percentages to compare against the continuous data. The error rates for one-zero and pinpoint sampling were calculated for each of their three interval lengths.

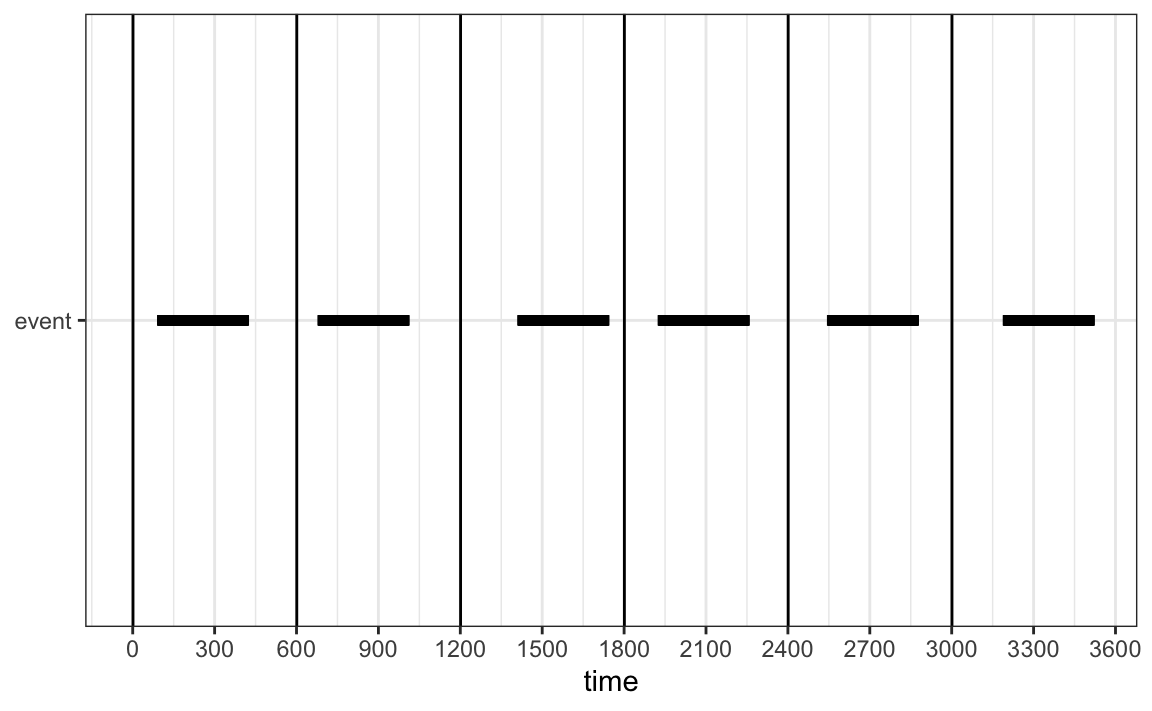
***Response duration***

This simulation was developed for long-duration or state behaviours. In the literature, state behaviours can be of variable length, lasting anywhere from seconds to minutes or hours. In order to accommodate this, three levels of behavioural duration were selected. These durations were set as short (3 s), medium (30 s) and long (300 s) durations of occurrence. Each of these states were treated separately (only short, medium or long behaviours occurred in each simulation).

As per the *Response frequency* investigation, the observation period was set to one hour in length (3600 seconds). Each behavioural duration simulation was repeated 100 times.

The chosen behaviour occurred once per 600 s period. The exact time that each behaviour occurred within its respective 600s period was selected at random (though the behaviour was not allowed to slip into the next period of 600 s). Continuous data sets were developed by using the raw, simulated data and transforming this into percentages. This meant that each behaviour occurred six times during each hour simulation, with the long duration occurring 50% of the hour, the medium state occurring 5%, and the short state occurring 0.5% of the time.

Each of the three behaviour durations (short, medium and long) were measured using one-zero and pinpoint sampling. Three interval lengths, again consisting of 5 s, 50 s and 500 s, as had been selected for the *Response frequency* investigations (Figure XXX). These interval lengths were used for both the one-zero and the pinpoint sampling. Once complete, the results were then transformed into percentages and compared to the continuous data to determine the level of error.



***Figure XXX.*** *Example of simulated data for the response duration for long (300 s states). The location of each state was selected at random within its 600 s period. This results in the state occurring for exactly 50% of the hour simulation.*

***Statistical Analysis***

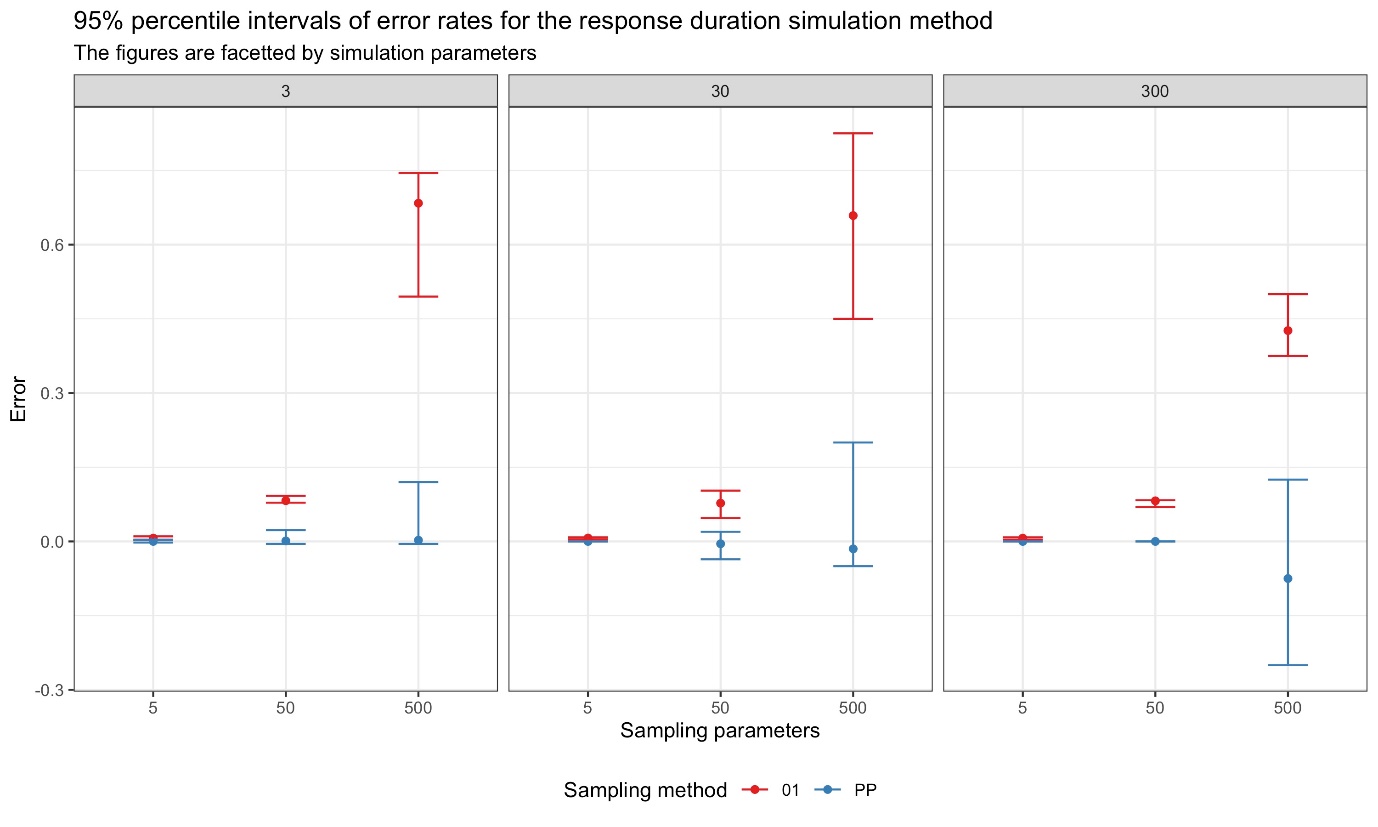
Statistical analyses were conducted on the mean error scores for the one-zero and pinpoint sampling at each respective interval length. The Friedman test was used to investigate whether there was a statistically significant effect of sampling method on the estimation error. The sampling / simulation combination was used as a blocking factor. The non-parametric Friedman test was used due to the non-normality of the errors and the observed heteroscedascity.

All code is available at https://github.com/jonotuke/animal\_simulation\_2020

**RESULTS**

***Response frequency***

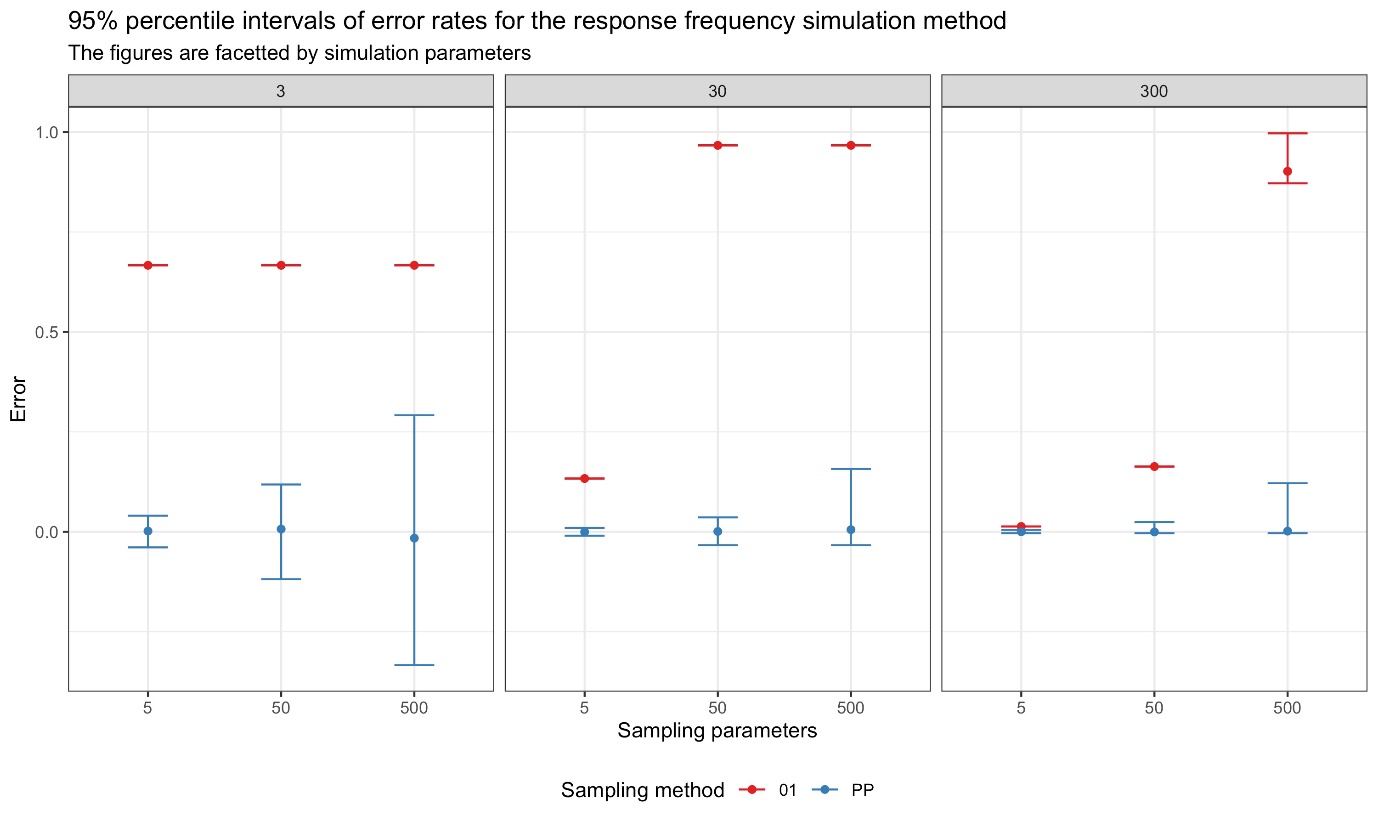
The accuracy of both one-zero and pinpoint sampling was calculated for each interval length and each of the three behavioural frequencies (Figure XXX, Table XXX). Overall, mean error rates were consistently lower for the pinpoint sampling method in comparison to the one-zero sampling method. (we’ll give p-values here, as well as confidence intervals). For both behavioural sampling methods, error rates increased as the interval length increased, with the 500 s interval showing the largest error rates and variation for both one-zero and pinpoint sampling.



***Figure XXX.*** *Mean error rates for pinpoint and one-zero sampling methods at the 5s, 50 s and 500 s intervals. Error rates were higher for the longer interval periods and were consistently higher for the one-zero sampling method. PP: Pinpoint sampling, 01: One-zero sampling.*

***Response duration***

The accuracy of both one-zero and pinpoint sampling was calculated for each interval length and all three behavioural durations (short, medium and long) (Figure XXX, Table XXX). For the short duration behaviours, one-zero sampling had a consistently high error rate. One-zero sampling was in fact accurate only when interval length was short (5 s) and the behavioural duration was medium or long. Pinpoint sampling error rates were generally lower than those from one-zero sampling, though variation in scores tended to increase as interval lengths became longer.



***Figure XXX.*** *Mean error rates for both one-zero and pinpoint sampling for the 5 s, 50 s and 500 s intervals. There was more variation in error rates for the pinpoint sampling as interval length grew longer, but average mean error rates were still small. However, error rates for one-zero sampling increased as interval length increased. PP: Pinpoint sampling, 01: One-zero sampling.*

***Table 1.*** *Mean error rates for each sampling method under 5 s, 50 s and 500 interval lengths for response frequency.*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Simulation parameters | Sampling parameters | Proportion of time event occurs | Mean error | Lower 95% percentile of error | Upper 95% percentile of error |
| **One-zero** |  |  |  |  |  |
| 3 | 5 | 0.333 | 0.667 | 0.667 | 0.667 |
| 3 | 50 | 0.333 | 0.667 | 0.667 | 0.667 |
| 3 | 500 | 0.333 | 0.667 | 0.667 | 0.667 |
| 30 | 5 | 0.033 | 0.133 | 0.133 | 0.133 |
| 30 | 50 | 0.033 | 0.967 | 0.967 | 0.967 |
| 30 | 500 | 0.033 | 0.967 | 0.967 | 0.967 |
| 300 | 5 | 0.003 | 0.013 | 0.0133 | 0.013 |
| 300 | 50 | 0.003 | 0.163 | 0.163 | 0.163 |
| 300 | 500 | 0.003 | 0.902 | 0.872 | 0.997 |
| **Pinpoint** |  |  |  |  |  |
| 3 | 5 | 0.333 | 0.002 | -0.039 | 0.0403 |
| 3 | 50 | 0.333 | 0.007 | -0.118 | 0.118 |
| 3 | 500 | 0.333 | -0.0158 | -0.003 | 0.292 |
| 30 | 5 | 0.033 | -0.0004 | -0.010 | 0.010 |
| 30 | 50 | 0.033 | 0.0010 | --0.003 | 0.0361 |
| 30 | 500 | 0.033 | 0.005 | -0.003 | 0.157 |

***Table 2.*** *Mean error rates for each sampling method under 5 s, 50 s and 500 interval lengths for response duration.*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Simulation parameters | Sampling parameters | Proportion of time event occurs | Mean error | Lower 95% percentile of error | Upper 95% percentile of error |
| **One-zero** |  |  |  |  |  |
| 3 | 5 | 0.005 | 0.006 | 0.003 | 0.010 |
| 3 | 50 | 0.005 | 0.082 | 0.078 | 0.092 |
| 3 | 500 | 0.005 | 0.684 | 0.495 | 0.745 |
| 30 | 5 | 0.050 | 0.007 | 0.004 | 0.008 |
| 30 | 50 | 0.050 | 0.008 | 0.047 | 0.103 |
| 30 | 500 | 0.050 | 0.659 | 0.450 | 0.825 |
| 300 | 5 | 0.500 | 0.007 | 0.003 | 0.008 |
| 300 | 50 | 0.500 | 0.082 | 0.069 | 0.083 |
| 300 | 500 | 0.500 | 0.426 | 0.375 | 0.500 |
| **Pinpoint** |  |  |  |  |  |
| 3 | 5 | 0.005 | <0.001 | -0.002 | 0.003 |
| 3 | 50 | 0.005 | 0.001 | -0.005 | 0.023 |
| 3 | 500 | 0.005 | 0.002 | -0.005 | 0.120 |
| 30 | 5 | 0.050 | <0.001 | <0.001 | <0.001 |
| 30 | 50 | 0.050 | -0.004 | -0.036 | 0.0194 |
| 30 | 500 | 0.050 | -0.015 | -0.050 | 0.200 |
| 300 | 5 | 0.500 | <0.001 | <0.001 | <0.001 |
| 300 | 50 | 0.500 | <0.001 | <0.001 | <0.001 |
| 300 | 500 | 0.500 | -0.075 | -0.250 | 0.125 |

**DISCUSSION**

**-Summarize the results of our simulation in terms of (a) response frequency (event), and (b) response duration (state). (hypothesis 1 not confirmed, hypothesis 2 confirmed; pinpoint sampling just outperformed one-zero sampling for both frequency and duration).**

**-Previous studies (sub-heading)**

**Prior to this study, researchers have compared differences between pinpoint and one-zero sampling methods. Early simulations lacked the precision and/or ability to run extensive repetitions of their simulations to accurately assess sampling method differences (Griffin & Adams, 1983; Harrop & Daniels, 1986; Repp, Roberts, Slack, Repp, & Berkler, 1976). Other researchers have attempted to make similar methodological comparisons via the data collection of actual behavioral occurrences (Gardenier, MacDonald, & Green, 2004; Leger, 1977; Murphy & Harrop, 1994; Rhine & Flanigon, 1978). While the results of differences in sampling methods for real occurrences of behavior varied, caution should be used in making determinations of the validity of any result based on specific examples, as exceptions to any rule can and do occur.**

**(second paragraph covers the last 6 previous simulations).**

**-Why do we use one method over the other? (sub-heading)**

**-Pinpoint sampling has not been recommended for measuring frequency (event) responses, particularly those of low occurrence (Altmann, 1974; Lehner, 1998). However, our simulation was accurately able to detect low occurrence (<1%) frequencies. Therefore, the use of pinpoint sampling to measure any event responses, regardless of their frequency of occurrence, appears to be a viable option. Similarly, one-zero sampling methods are often preferred as an observational method because of the ease with which behaviours can be observed, recorded, and assessed for Interobserver Agreement (IOA; Poling, Methot, & LeSage, 1995). The same can also be said for pinpoint sampling, which provides an equally user-friendly research method when compared to continuous (focal) recordings.**

**(not sure we need a section here on different types of interval recording; partial, whole, occurrence, nonoccurrence. Really, it would produce the same thing, so I think we can ignore this issue, as it’s only behavior analysts that really get this detailed because of how invested they are in interval recording methods).**

**An added benefit of using either pinpoint or one-zero sampling methods is they negate the difficulty in comparing frequency (event) verse duration (state) behaviours. For instance, if a researcher were assessing the impact of pacing on the welfare of some animal, how would we compare 10 instances of 6-second paces to one instance of a 60-second pace? Pinpoint and one-zero sampling methods simply record whether the response occurred during some observation period, regardless of the frequency or duration of the recorded response.**

**Historically, a major factor in determining behavioural observation methodology has been the prevalence of that sampling method within some field/observational species. Mann (1999) found that over half of all cetacean studies used *ad lib* sampling, even though such sampling methods are recognized to be both less quantitative and systematic. Likewise, one-zero sampling methods are typically used by primatologists and behavior analysts for the study of human and non-human primate behavior (need references here). The concept of using methodology passed down from previous studies and labs has been referred to as “laboratory lore” and is an asset to the cultural transmission of scientific knowledge (Buskist & Johnston, 1988; Johnston & Pennypacker, 2010). Nonetheless, the selection of behavioral observation methods, like all aspects of scientific research, should be based on the efficacy of the methodology used. In the case of selecting between pinpoint or one-zero sampling methods to estimate behavioral occurrences, our study indicates that pinpoint sampling outperforms one-zero sampling on all frequency and duration measures simulated. Thus, laboratory lore aside, pinpoint sampling seems to be the better option for behavioural researchers choosing between the two observation methods.**

**CONCLUSIONS**

**Acknowledgements**

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