J Ornithol (2015) 156:1125–1129
DOI 10.1007/s10336-015-1267-5

TECHNICAL NOTES

A high-accuracy, time-saving method for extracting nest watch data from video recordings

Dean R. Evans[1] · Sarah L. McArthur[1] · Jacob M. Bailey[1] · John S. Church[2] · Matthew W. Reudink[1]

Received: 2 April 2015 / Revised: 2 June 2015 / Accepted: 29 June 2015 / Published online: 11 July 2015

Abstract Understanding inter- and intraspecific variation in parental care has been an important focus in studies of avian behaviour and evolution. Unfortunately, typical methods for quantifying parental care, such as field observation and video recordings, can be extremely time-consuming. Here, we demonstrate that utilizing behavioural analysis software, such as EthoVision XT, can reduce time required for video data extraction by 37−69 %. This method is highly accurate; results and error rates did not differ from those of manual observation. We suggest this method could be beneficial and time-saving for studies analyzing large amounts of video recordings.

Keywords EthoVision · Nestling provisioning · Parental care · Mountain Bluebird · Video analysis

Zusammenfassung

Eine sehr genaue und zeitsparende Methode zur Extraktion von Nestbeobachtungsdaten aus Videoaufnahmen

Das Verständnis inter- und intraspezifischer Variation der elterlichen Brutpflege ist ein wichtiger Schwerpunkt bei der Erforschung des Verhaltens und der Evolution von Vögeln. Leider können die üblichen Methoden zur Quantifizierung elterlicher Fürsorge, beispielsweise Feldbeobachtungen und Videoaufzeichnungen, äußerst zeitaufwendig sein. Hier zeigen wir, dass der Einsatz von Verhaltensanalyse-Software, wie zum Beispiel EthoVision XT, die für die Extraktion der Videodaten notwendige Zeit um 37–69 % verringern kann. Diese Methode ist sehr genau; die Ergebnisse und Fehlerraten unterschieden sich nicht von denen bei manueller Auswertung. Wir sind der Ansicht, dass sich diese Methode bei Untersuchungen, welche die Analyse größer Mengen Videomaterials beinhalten, als vorteilhaft und zeitsparend erweisen könnte.

Communicated by F. Bairlein.

Electronic supplementary material The online version of this article (doi:10.1007/s10336-015-1267-5) contains supplementary material, which is available to authorized users.

✉ Matthew W. Reudink
mreudink@tru.ca

[1] Department of Biological Sciences, Thompson Rivers University, Kamloops, BC, Canada

[2] Department of Natural Resources, Thompson Rivers University, Kamloops, BC, Canada

Introduction

Nestling provisioning is integral to offspring growth and survival in altricial chicks, but it represents a substantial parental cost due to increased energy expenditure and risk of predation (Wright et al. 1998). As such, examining variation in nestling provisioning rates has been a major focus for understanding avian behaviour, ecology, and evolution. Much research has examined inter- and intraspecific variation in provisioning rates in relation to life history strategies (Robinson et al. 2010), predation risk (Ghalambor et al. 2013), parental condition and quality

(Germain et al. 2010; Osmond et al. 2013), as well as offspring signalling (Węgrzyn 2013).

For many species, quantifying nestling provisioning rates is straightforward, as food is foraged from the environment and delivered to the nest by the parents, and in some cases, helpers. Traditional techniques to study nestling provisioning include field observation (often requiring the use of field scopes, binoculars, and blinds) (Davies 1986; Simmons 1986; Sullivan 1988) and video surveillance of nests. Video surveillance is advantageous as it reduces time spent in the field as well as the risk of human influence on behaviour (Cox et al. 2012). However, video surveillance is limited by data storage capacity, camera battery life, and the amount of time required to analyze video recordings. The duration of recorded video can vary depending on the scale of the experiment. For example, a study by Shen et al. (2010) examining provisioning in Taiwan Yuhinas (*Yuhina brunneiceps*) analyzed 122 h of video, while Gladbach et al. (2009) analyzed 720 h of Wilson's Storm Petrel (*Oceanites oceanicus*) video. Analyzing this amount of video is arduous and also has a high potential for error due to observer fatigue. A possible solution to this problem is the implementation of automated video tracking software, which could reduce the time needed to analyze nest watch videos.

The use of video tracking software is not a new concept in the study of animal behaviour, with the first systems being introduced in the 1990s (Noldus et al. 2001). Current software, such as EthoVision XT (Noldus Information Technology, 2013), is often used in laboratory-based settings to track the movement and behaviour of rodents and other captive animals (Noldus et al. 2001; e.g., Fonio et al. 2009; Bechstein et al. 2014). To our knowledge, this software has not been employed on free-living animals, and the only work with birds has been in captive settings (e.g., Feenders and Bateson 2013; Wood 2013). One potential advantage to this software is that it can be used with pre-existing video and does not require any specialized recording equipment.

We examined the effectiveness of using EthoVision XT (Version 10.0; hereafter: EthoVision) software for aiding in the automated processing of behavioural videos of offspring provisioning in free-living birds. Using video recordings of Mountain Bluebirds (*Sialia currucoides*), we asked: (1) whether provisioning rates obtained by employing EthoVision yielded comparable results as in manual analysis, (2) whether the differences between EthoVision and manual video analysis were comparable to inter-observer variation using manual video analysis, and (3) whether using EthoVision reduced the amount of time spent generating provisioning data for analysis. Finally, we provide a best-practices guide to using EthoVision software to analyze avian nest watch videos (ESM Appendix 1).

Methods

Manual analysis

All offspring provisioning videos for this project were collected in the Knutsford area, near Kamloops, BC, Canada (50°37′N, 120°19′W) during May–July 2014 using a Sony Handycam DCR-SX45 (Sony, Tokyo, Japan), a GoPro HD Hero2, or a GoPro HD Hero3+ (GoPro, San Mateo, CA). Both male and female Mountain Bluebirds provision throughout the entire nestling period, often approaching a perch nearby the nest before proceeding to the nest entrance, looking in, and eventually fully entering the nest to provision offspring. Each video was designed to consist of a 2-h observation of a nest box capturing male and female Mountain Bluebirds entering and exiting the nest; however, some videos were cut short due to technical issues ($n = 40$ videos, 73 h total). Videos were taken once during the early nesting period (offspring 3–5 days old) and once during the late nesting period (offspring 13–15 days old), following Morrison et al. (2014). Offspring provisioning was measured by manually watching each video and recording each time the male or female provided food for their young. Manual analysis was conducted on all videos prior to EthoVision analysis and used for comparison with EthoVision provisioning results. To quantify the time required for manual analysis (minutes required per hour of video) and to examine inter-observer variation, ten videos were chosen at random and analyzed again by an experienced observer (>50 h experience watching nest watch videos) and a new observer (no prior experience watching nest watch videos). Each of the ten videos were analyzed for 1 h starting 30 min into the video clip with the time required to determine provisioning events for each 1 h video clip recorded along with provisioning data.

EthoVision analysis

Because nest watch videos were not initially recorded with the intent to be used with EthoVision, 12 videos were excluded from a total of 40 videos due to their poor video quality and bad camera position (see ESM Appendix 1). This reduction resulted in 28 useable video recordings (48.5 h) for EthoVision analysis. All recordings were in either .mp4 or .mpg format, which were then easily imported into EthoVision. Once imported, each video underwent a series of optimization steps (ESM Appendix 1), which includes arena set up (area within the clip where tracking takes place), trail control set up (duration of video that is analyzed), and detection set up (what to track). After video settings were optimized, EthoVision analyzed each video and produced time stamps of activity at the nest box. Each time stamp was then examined manually to determine whether a provisioning event had occurred and, if so, which parent provisioned offspring. For each EthoVision trial, the time required to set up each video was recorded along with the time needed to analyze the resulting time stamps. EthoVision analysis was conducted by D.R.E.; manual analyses were conducted by one experienced and one inexperienced observer. The authors declare no conflict of interest and have no affiliation with Noldus Information Technology.

Statistical analysis

All statistical analyses were performed using JMP 11 (SAS Institute 2013), and all values presented are mean ± SD. Because our data did not meet the assumption of normality, we used Wilcoxon signed rank tests to examine differences between provisioning rates obtained by EthoVision and manual analysis ($n = 28$ videos). In addition, we used Spearman's rank correlation to examine relationships between provisioning trips recorded using EthoVision and manual observation. Similarly, we used Wilcoxon signed rank tests to test whether provisioning rates were comparable between the different analysis methods (EthoVision, new observer, experienced observer, $n = 10$ videos). We also used Wilcoxon signed rank tests to test whether differences between EthoVision and manual observation were comparable to inter-observer variation using manual observation. Lastly, differences in analysis times between (1) EthoVision and a new observer, (2) EthoVision and an experienced observer, and (3) a new observer and an experienced observer were examined using Wilcoxon signed rank tests.

Results

Accuracy of EthoVision

Provisioning rates recorded using EthoVision were highly correlated with rates obtained through manual analysis (males $n = 28$, $\rho = 0.99$, $p < 0.0001$; females $n = 28$, $\rho = 0.98$, $p < 0.0001$) (ESM Fig. 1). We found no significant difference in provisioning rates as recorded by EthoVision or manual analysis for either males ($n = 28$, $W = 7.5$, $p = 0.65$; EthoVision 6.94 ± 6.19 trips/hour, Manual 7.00 ± 6.42 trips/hour) or females ($n = 28$, $W = -15.5$, $p = 0.30$; Ethovision 7.38 ± 5.50 trips/hour, Manual 7.21 ± 5.56 trips/hour) (Fig. 1). We also did not find any differences in the number of provisioning trips recorded, depending on which procedure was used (EthoVision, new observer, experienced observer) (Table 1). Differences in the number of trips recorded based on procedure used were low (males 1.33 ± 1.95 differences per video; females 1.33 ± 2.06 differences per video) and did not vary between using EthoVision software compared to manual analysis by either experienced or new observers (Table 2).

Analysis time

The use of EthoVision to aid in the analysis of nest watch videos was significantly faster than manual analysis by both the new observer ($n = 10$, $W = -27.5$, $p = 0.002$) and the experienced observer ($n = 10$, $W = -27.5$, $p = 0.002$). The time required to manually watch nest watch videos was also significantly shorter for the experienced observer than for the new observer ($n = 10$, $W = -27.5$, $p = 0.002$) (Fig. 2). The average time to set up EthoVision and analyze an hour of nest watch video was 15.93 ± 4.95 min ($n = 10$ videos) compared to an average manual analysis time of 52.20 ± 12.38 min ($n = 10$) for a new observer and 25.60 ± 3.03 min ($n = 10$) for an experienced observer.

Discussion

Offspring provisioning is an important component in understanding avian behaviour and ecology, but is complicated by the amount of time required for field observations or to manually analyze nest watch videos. Here, we present an accurate, time-saving approach for analyzing nest watch videos through the implementation of EthoVision video tracking software. Our results indicate that EthoVision can be used quickly and reliably to obtain provisioning data that is comparable to manual analysis with error rates consistent with inter-observer variation. This method has the potential to significantly reduce the amount of time required to obtain provisioning data. To put these time savings into perspective, Morrison et al. (2014) examined 178 h of Mountain Bluebird videos (the same population examined here), which would have taken approximately 154.86 ± 36.73 h for the new observer or 75.95 ± 8.99 h for the experienced observer, based on rates recorded in this study. Use of EthoVision could have reduced analysis time down to approximately 48.06 ± 14.24 h, a time savings of 37–69 %.

The primary limitation to our study was that the nest watch videos we used were not recorded with the intent to be used within EthoVision. Ideal camera setup involves positioning the camera perpendicular to the side of the nest box, the use of high definition recording devices (1080p and at least 24 frames per second), and avoiding any vegetation or obtrusions between the camera and the nest

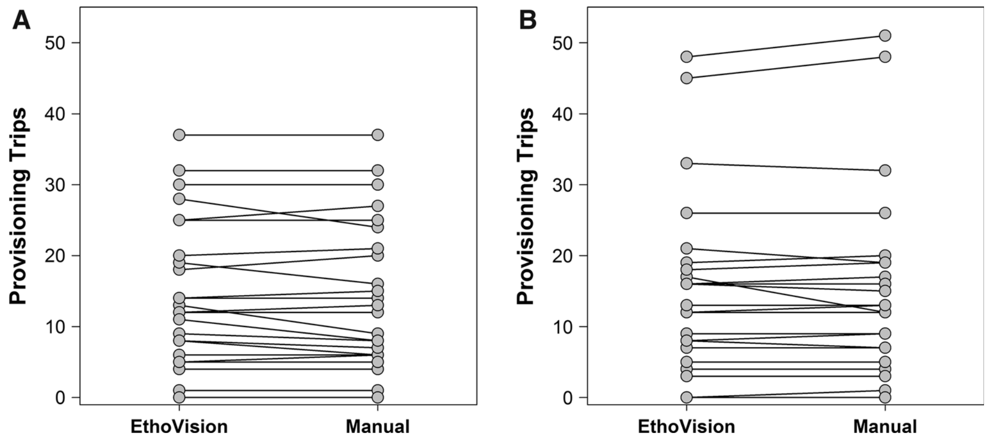


Fig. 1 Provisioning rates obtained through EthoVision and manual analysis for females (**a**) and males (**b**) ($n = 28$ videos)

Table 1 Wilcoxon signed rank tests examining differences in provisioning rates obtained by EthoVision and manual observations for males (above diagonal) and females (below diagonal) ($n = 10$ 1-h videos)

Type	EthoVision	New observer	Experienced observer
EthoVision	–	$W = -7.00$ $p = 0.19$	$W = -4.50$ $p = 0.53$
New observer	$W = 1.00$ $p = 0.94$	–	$W = 7.50$ $p = 0.13$
Experienced observer	$W = -0.50$ $p = 0.94$	$W = -0.50$ $p = 1.00$	–

Table 2 Wilcoxon signed rank tests examining inter-observer variation between EthoVision and a new observer (EV/NO), EthoVision and an experienced observer (EV/EO), and a new observer and an experienced observer (NO/EO) for males (above diagonal) and females (below diagonal) ($n = 10$ 1-h videos)

Type	EV/NO	EV/EO	NO/EO
EV/NO	–	$W = 6.00$ $p = 0.19$	$W = -4.50$ $p = 0.53$
EV/EO	$W = 0.50$ $p = 1.00$	–	$W = 0.50$ $p = 1.00$
NO/EO	$W = -2.00$ $p = 0.81$	$W = -1.50$ $p = 0.81$	–

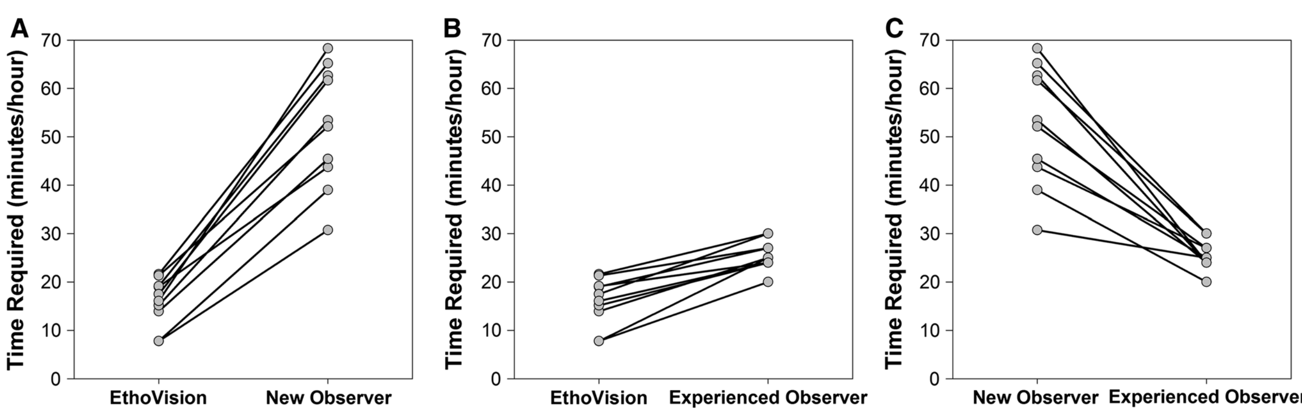


Fig. 2 The time required to analyze 1 h of video using **a** EthoVision compared to manual analysis by a new observer ($n = 10$), **b** EthoVision compared to manual analysis by an experienced observer ($n = 10$), and **c** manual analysis by an experienced observer compared to a new observer ($n = 10$)

box, which can inadvertently register false positive time stamps. The 12 videos excluded from EthoVision analysis were either recorded in low definition or located in a poor location, causing them to fail in EthoVision analysis. For future studies hoping to use this method to analyze offspring provisioning, camera positioning should be considered carefully to improve the success of this method.

There are several additional limitations for the use of behavioural analysis software, such as EthoVision. First, some studies require that the food items themselves be identified or classified based on size (e.g., Schwagmeyer and Mock 2008); however, this remains beyond the scope of EthoVision and the observer must still identify whether the bird is carrying a food item and what is that item is. Second, EthoVision's ability to determine the sex of an individual is limited to highly dichromatic species that also contrast with the background environment. Although Mountain Bluebirds exhibit sexually dichromatic plumage, the bluer male plumage can be mistaken for blue skies and the drabber female plumage can be mistaken for other colors in the environment such as clouds. Thus, for many species, an observer must still determine the sex of the provisioning parent. Given these limitations and the importance of manual verification of provisioning events, we caution against using EthoVision as a fully automated process to gather provisioning data.

Taken together, our results indicate that employing behavioural video analysis software such as EthoVision can be an accurate and time-saving technique for field researchers studying nestling provisioning in free-living birds. In addition, this technique has great potential for any studies in which stationary video recordings are utilized for data collection (e.g., carcass scavenging, nest predation, and gap crossings).

Acknowledgments We thank G. Dreger, P. and J. Gray, and the members of the Kamloops Naturalists Club for use of their bluebird routes. We thank C. Miller for the use of EthoVision software, J. Mumford for his technical advice regarding EthoVision, and D. Eye for volunteering to watch nest watch videos. Funding for this project was provided by a Natural Sciences and Engineering Research Council Discovery Grant (MWR), the Canada-British Columbia Ranching Task Force Funding Initiative as administered by the Investment Agriculture Foundation of British Columbia (JSC), and a CUEF U-REAP undergraduate research award (DRE).

References

Bechstein P, Rehbach N-J, Yuhasingham G et al (2014) The clock gene period1 regulates innate routine behaviour in mice. Proc Biol Sci 281:20140034

Cox WA, Pruett, Benson TJ et al (2012) Development of camera technology for monitoring nests. surveillance of nesting birds, 1st edn. University of California Press, Berkeley, pp 185–198

Davies NB (1986) Reproductive success of dunnocks, prunella modularis, in a variable mating system. I. Factors influencing provisioning rate, nestling weight and fledging success. J Anim Ecol 55:123–138

Feenders G, Bateson M (2013) Hand rearing affects emotional responses but not basic cognitive performance in European starlings. Anim Behav 86:127–138

Fonio E, Benjamini Y, Golani I (2009) Freedom of movement and the stability of its unfolding in free exploration of mice. Proc Natl Acad Sci 106:21335–21340

Germain RR, Reudink MW, Marra PP, Ratcliffe LM (2010) Carotenoid-based male plumage predicts parental investment in the american redstart. Wilson J Ornithol 122:318–325

Ghalambor CK, Peluc SI, Martin TE (2013) Plasticity of parental care under the risk of predation: how much should parents reduce care? Biol Lett 9:20130154

Gladbach A, Braun C, Nordt A et al (2009) Chick provisioning and nest attendance of male and female Wilson's storm petrels *Oceanites oceanicus*. Polar Biol 32:1315–1321

Morrison A, Flood NJ, Reudink MW (2014) Reproductive correlates of plumage coloration of female Mountain bluebirds. J Field Ornithol 85:168–179

Noldus LP, Spink AJ, Tegelenbosch RA (2001) EthoVision: a versatile video tracking system for automation of behavioral experiments. Behav Res Methods Instrum Comput J Psychon Soc Inc 33:398–414

Osmond MM, Reudink MW, Germain RR et al (2013) Relationships between carotenoid-based female plumage and age, reproduction, and mate colour in the American redstart (*Setophaga ruticilla*). Can J Zool 91:589–595

Robinson WD, Hau M, Klasing KC et al (2010) Diversification of life histories in new world birds. Auk 127:253–262

Schwagmeyer PL, Mock DW (2008) Parental provisioning and offspring fitness: size matters. Anim Behav 75:291–298

Shen S-F, Chen H-C, Vehrencamp SL, Yuan H-W (2010) Group provisioning limits sharing conflict among nestlings in joint-nesting Taiwan yuhinas. Biol Lett 6:318–321

Simmons R (1986) Food provisioning, nestling growth and experimental manipulation of brood size in the African Redbreasted sparrowhawk *Accipiter rufiventris*. Ornis Scand 17:31–40

Sullivan JP (1988) Effects of provisioning rates and number fledged on nestling aggression in Great blue herons. Colon Waterbirds 11:220–226

Węgrzyn E (2013) Intensity of mouth coloration in Blackcap *Sylvia atricapilla* nestlings affects food distribution among siblings but not provisioning of the whole brood. Ibis 155:156–164

Wood JN (2013) Newborn chickens generate invariant object representations at the onset of visual object experience. Proc Natl Acad Sci 110:14000–14005

Wright J, Both C, Cotton P, Bryant D (1998) Quality vs. quantity: energetic and nutritional trade-offs in parental provisioning strategies. J Anim Ecol 67:620–634

Best Practices for EthoVision Video Analysis

Brief Background on EthoVision

EthoVision (Noldus Information Technology, 2013) is behavioural analysis software that allows users to track and record the movements of animals from video recordings. The first video tracking software used in behavioural studies of animals was first introduced in the 1990s (Noldus et al. 2001). More recent programs, such as EthoVision, allow for precise identification of moving objects from the background using contrast or color, the ability to analyze live or imported video, the ability to track distances traveled, the ability to define zones in an area and record when an object enters these zones, and the ability to visualize movement tracks. While EthoVision is primarily used for studies involving rodents in laboratory settings, here we present a best practices approach for utilizing this software for the behaviour analysis of nestling provisioning in free-living birds using EthoVision XT Version 10.

Camera Set-up

1. *Camera Positioning:* Proper video camera positioning is crucial for capturing a recording that can be analyzed with EthoVision. First, the camera should be positioned to avoid any interference by vegetation or other objects between the camera and the nest box. Because vegetation may move in the wind, EthoVision can mistakenly misidentify this movement and this can lead to false positive results. Furthermore, if there are any obtrusions between the camera and nest box, the likelihood of false negatives (missing the bird enter the nest box) is increased.
2. *Video Quality:* Low quality recordings often lead to pixelization, which makes it more difficult to define the subject within the video. In our experience, the best approach for achieving high quality recordings in the field is to use a GoPro video camera (GoPro, San Mateo, CA). GoPro cameras record high quality video and have the added advantage of a weather proof case. The suggested video recording settings are 1080p at a frame rate of at least 30 frames per second.
3. *Lighting:* EthoVision uses either color or contrast of the subject against the background within the video clip to track movements, and poor lighting makes this task more prone to error. The best way to achieve proper lighting within your recordings is to face the

camera away from the sun. When there are brighter objects in the recording other than the focal point (i.e., the nest box), the focal point tends to lose detail and tracking of the subject (the bird) may be missed (Figure 1). The best position for a camera recording a nest box would be perpendicular to the side of the box with the sun behind the camera.

A B

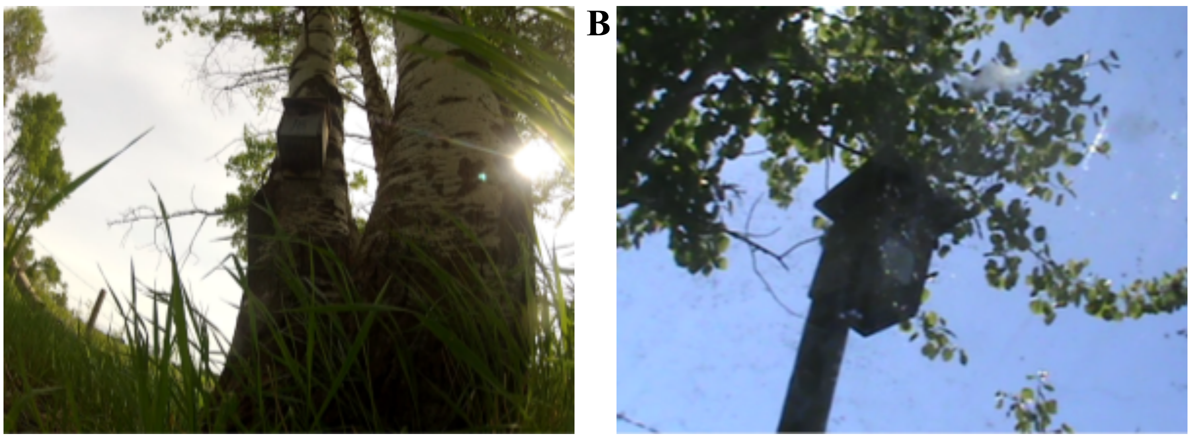


Figure 1. Examples of improper video recordings, displaying (A) poor camera position and (B) poor lighting and recording quality.

EthoVision Setup and Analysis

Experiment Settings

After all videos have been recorded, the first step to analyzing your videos with EthoVision is to set up the experiment settings. To begin, open EthoVision software and select **New Default Experiment**, name the experiment and select where to save the experiment file. You will then be brought to the EthoVision Overview window. Select **Experiment Settings** which brings you into the default Experimental Settings (Figure 2). In the "Experiment Information" field you can verify location of your experiment file as well as add a description to your experiment. We recommend that recording details about the video such as the date and time of the recording here. Next, select the source of your video files under the "Video Source" field. For nest watch videos obtained in the field, the video source will be **From video file**. For the "Tracked Features" field select **Center Point Detection**. The "Analysis Options" and "Trial Control Hardware" settings are irrelevant for the purpose of analyzing nest watch videos so these settings can be left as they are. Lastly, specify the units you would like to work with within your experiment.

For highly dichromatic birds, there is an option to color marking tracking, which enables EthoVision to determine the sex of the individual. To use this option, set the number of subjects to **2** under the "Subjects" field and label Subject 1 and Subject 2 as male and female by right clicking on Subject 1 and 2 and selecting **Rename**. Within the "Tracked Features" field choose **Color marker tracking** instead of center-point detection. All other settings remain the same.

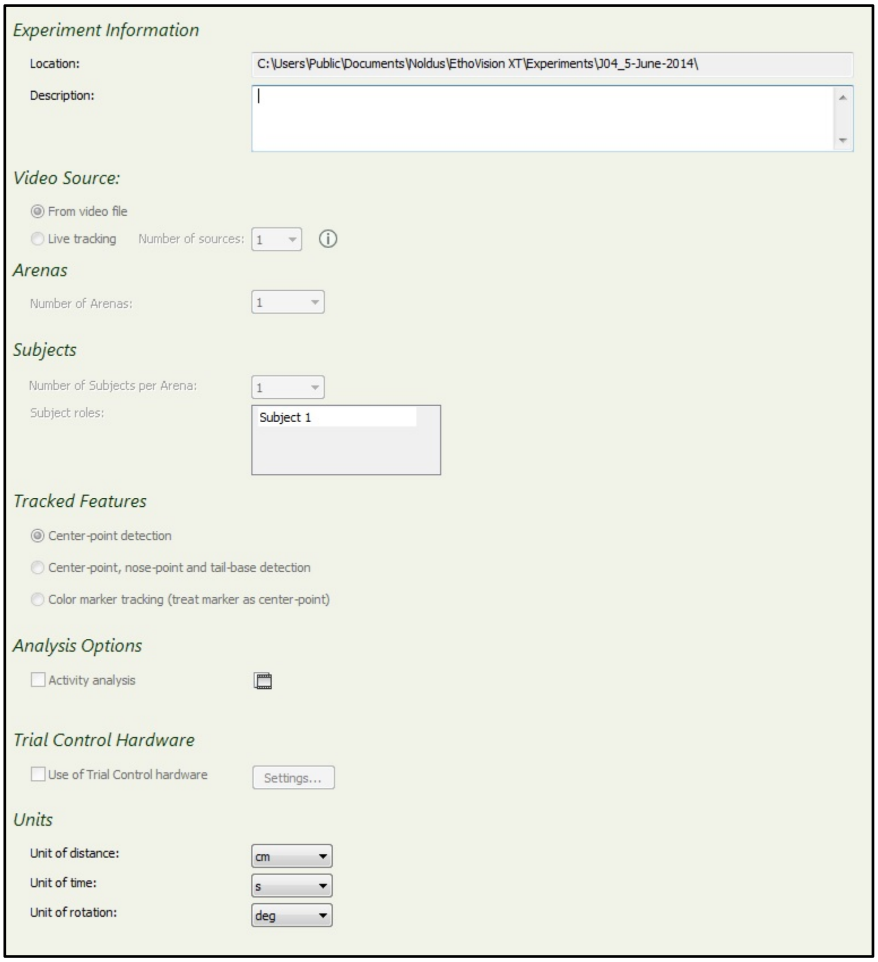


Figure 2. The default Experiment Settings window within EthoVision where initial settings for are made for the entire experiment.

Arena Settings

Arena Settings is where the areas of interest in our video clip will be defined. Tracking within a video takes place in an arena, which is a portion of the video frame defined by the experimenter. As there should only be one nest per video, you will only need to identify one arena. An arena consists of an area within the video that is large enough to track the animal and has a minimal number of artefacts that could trigger false positives, such as grass blowing in the wind (Figure 3**).** Navigate to Arena Settings use the Experiment Explorer on the left side of the screen and select **Arena Settings**. The first step for arena setup is to establish a background picture. After you navigate to Arena Settings the "Grab Background Image" window should appear. If it does not appear you can select the **Grab Background Image** button within the Arena Settings window. Select the **Browse** button and locate the video file you want to use and select **Open**. The "Video" window will open; use the slider to find a portion of your video where there are no birds within the scene and select **Grab** to use this image as a background. By default the arena will encompass the entire background image. To draw your own arena select **Arena 1** (default arena name) in the Arena Settings window (to make it active to editing) and then choose a **Drawing Object** tool within the component tool bar at the top of the window. Now create a shape that excludes any portions of the frame that could have a high number of artefacts. You will see an "Arena Label" on the screen with an arrow pointing to an area within the frame. Make sure this arrow is inside the arena you just created (see Figure 3).

Figure 3. Arena Settings within EthoVision showing arena (green diagonal lines) and zone (purple diagonal lines) set-up excluding of areas with vegetation.

After the arena has been defined, a zone will be established which is a specific area of interest within the defined arena (Noldus et al. 2001). The zone in each experiment will encompass the part of the nest box where birds enter and exit during the provisioning of their offspring. The default settings do not include a zone within the arena so a zone will have to be added. To do this select **Zone Group 1** (found under Arena 1) in the Arena Settings window. Using the **Draw Object** tools, draw a zone that covers the nest box and includes a small amount of area where the birds will be entering or exiting (see Figure 3). Make sure the zone label arrow is pointing to the created zone. To finish arena and zone setup, you must calibrate the scale, which converts two locations in the video (pixel coordinates) into real world coordinates. Proper scale calibration will allow for accurate distance and velocity measurements within the video analysis. If this is not important to your experiment, simply select a random scale. To do this select the **Calibration** button within the component toolbar at the top of the Arena Settings window and select two points within the video. The calibration window will now appear where you can specify the real world distance between those two points.

Alternatively, if the videos have been recorded using the guidelines above, the option of using hidden zones is more favourable. Hidden zones are used to classify areas within the arena where the subject will become hidden (e.g., a nest box). EthoVision can use a hidden zone to determine whether the subject is either entering or exiting that zone. To define a hidden zone, click the **Add Hidden Zone Group** button (instead of selecting Zone Group 1) within the Arena Settings window. Create a zone that covers the entire nest box using the same methods as described for a normal zone. Next, in the Arena Settings window select **Entry Zone Group** and add another zone that defines where the bird is entering and exiting. This zone must overlap slightly with the hidden nest box zone. When finished, link this entry zone to the hidden zone in the "Entry Zone" window and also select **Use this entry zone also as leaving zone**. Make sure the appropriate zone labels are pointing to the created hidden zone and entry zone.

Trial Control Settings

Trial control settings allow for the automated management of an experiment so that certain aspects can be controlled while the researcher is absent. The only component of trial control settings that may be relevant for nest watch videos is a delayed start. For each of the videos used in our study the first minute or two contained researches setting the camera up. This portion of the nest watch videos can confuse EthoVision and need to be excluded from tracking. Adding a delayed start of (n) minutes for each experiment will tell the program to not begin analysis until that time has elapsed. To start, navigate to **Trial Control Settings** using the Experiment Explorer. Next add a time condition by selecting **Time** under the "Conditions" field within the Trial Control Settings window. Set the time to the desired length of delay and click **OK**. The time condition will now be added to the Trial Control Settings window but will not be connected to the default Trial Control. The default Trial Control will contain a condition entitled "In Zone" before the Start Track action. This is condition is irrelevant and can be removed by selecting it and pressing **Delete** on the keyboard. The "Time" condition will take its place and this can be done by dragging it into the location of the deleted "In Zone" condition. To connect the newly added Time condition, click on the **Rule Begin** box followed by clicking on the **Time** condition box. This will add an arrow between the two and connect them. Following the same procedure connect the "Time" condition box to the "Start Track" action box so that your results look similar to Figure 4.

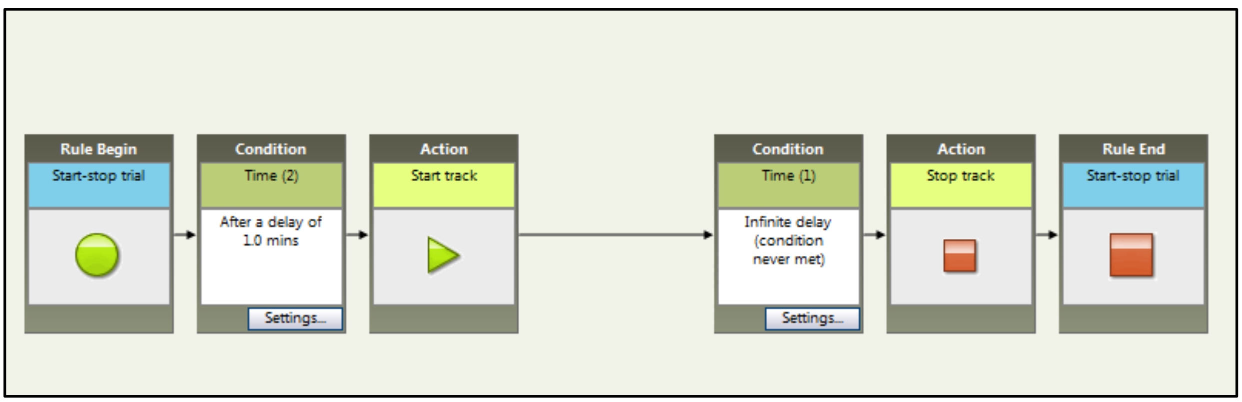


Figure 4. Configured Trial Control settings within EthoVision showing a tracking delay of 1 minute to avoid researcher interference.

Detection Settings

Detection settings are important for allowing the program to detect when a subject is moving within an arena. To begin, navigate to the **Detection Settings** window using the Experiment Explorer on the left side of EthoVision. The first and most important procedure is to use video viewer to scroll to a portion of your clip where there is an active subject. This is important because as you adjust the detection settings the video viewer will display the tracking results, which when configured properly should look like Figure 5. After getting the video clip to an appropriate frame showing a subject, change the method of detection to **Differencing** under the "Method" field of the Detection Settings Window (Figure 6). Under the "Video" field change the sample rate to approximately **15 frames per second**. By default the sample rate will be set to be the same frame rate as the video file. By reducing the frame rate, EthoVision will analyze the video at a faster pace. Under the "Detection" field, select the **Settings** button next to "Reference Image" and set it to **Dynamic** if not already selected. A dynamic reference image will update throughout the analysis and ensure any small movements in the background are not tracked (such as moving clouds). Next, depending on the colour of the bird you aim to study, tell EthoVision whether the subject is brighter or darker than the background by selecting **Brighter** or **Darker** next to "Subject is" in the "Detection" field. Play with the "Sensitivity" slider until your results begin to look similar to Figure 5. Next to "Background Changes:" use the drop down menu to select that the background changes **Very fast**. This updates the reference image more often. Within the "Subject Size" field select **Edit** to open up the subject size window (Figure 7). In some cases the tracking results in the video viewer may show that EthoVision is tracking something other than the subject, like a large cloud in the background. This is where setting the subject size becomes important. Adjust maximum and minimum size of the subject until the tracking display in the video viewer shows your subject being tracked (Figure 6). Leave the "Subject Contour" settings as is and save your changes. The detection settings are now configured and the video is ready for analysis.

If colour marking detection was selected for the identification of dichromatic birds, the "Detection Settings" appear differently (Figure 8). The only fields that are included in the Detection Settings window for color marker detection are "Identification" and "Video." The "Identification" field is where the color of each bird (the male and female) will be determined. Select either **Male** or **Female** and click on the **Identification** button within the "Subject Identification" field. Use the eyedropper tool to select the subject color from the "Marker Detection" window. Adjust the tolerance, hue, saturation, brightness, and marker size settings within the "Identification" window until the view shows the subject is successfully being tracked. Do this for both male and female using the video window to find the active subjects.

Figure 5. Tracking display within the video viewer of EthoVision's Detection Settings showing proper detection setting configuration.

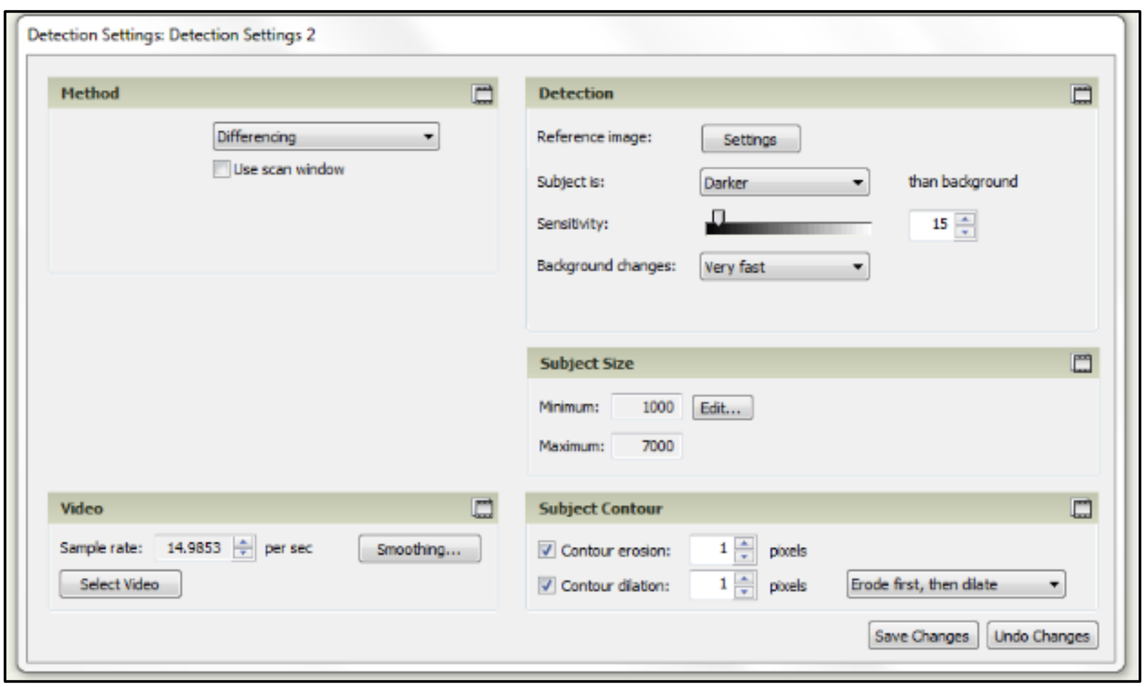


Figure 6. Detection Settings window within EthoVision displaying the different editable fields and the best settings for nest watch videos used within our study.

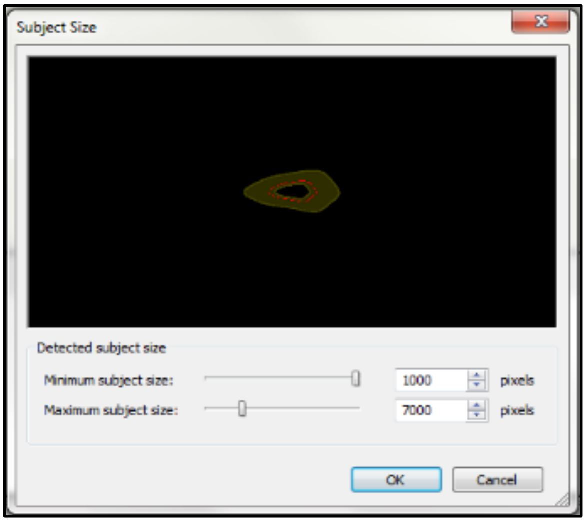


Figure 7. Subject size window within EthoVision's Detection Settings Window used to set the subjects maximum and minimum size.

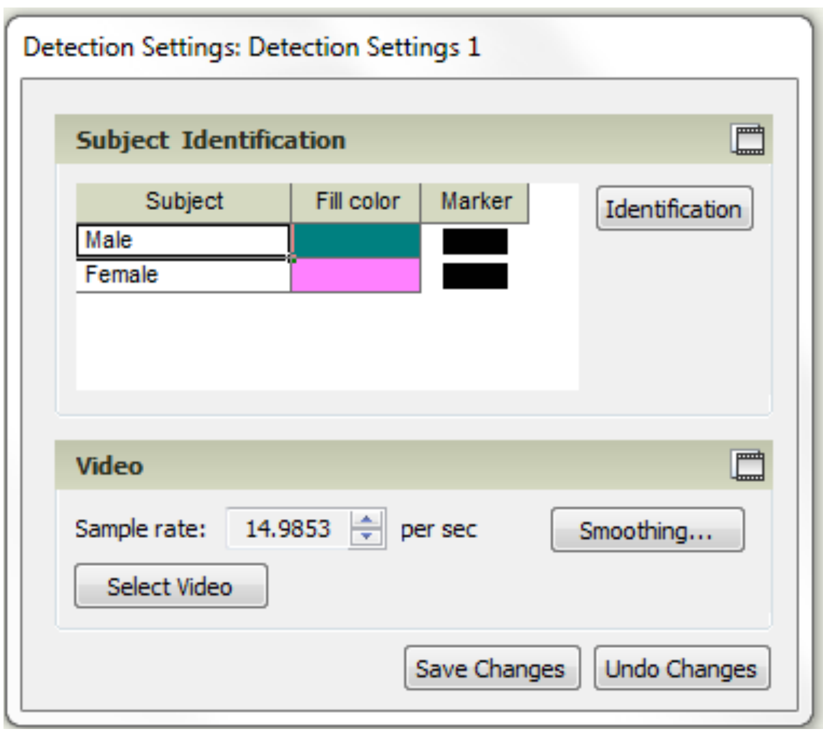


Figure 8. . Detection Settings window within EthoVision displaying the different editable fields when using color marker detection of dichromatic birds.

Data Acquisition

The video is now ready for tracking, which is done within the "Acquisition" window. Navigate to the **Acquisition** window using the Experiment Explorer. To start a new trial for acquisition, select the **Add Trial** button within the "Acquisition Control" window (Figure 9). Make sure all the correct settings are selected in the "Acquisition Settings" box (Figure 9) and begin the trial by selecting the start trial button (the green button). EthoVision will analyze the video and track the bird's behaviour. Progress of the acquisition will appear in the video viewer of the "Acquisition" window.

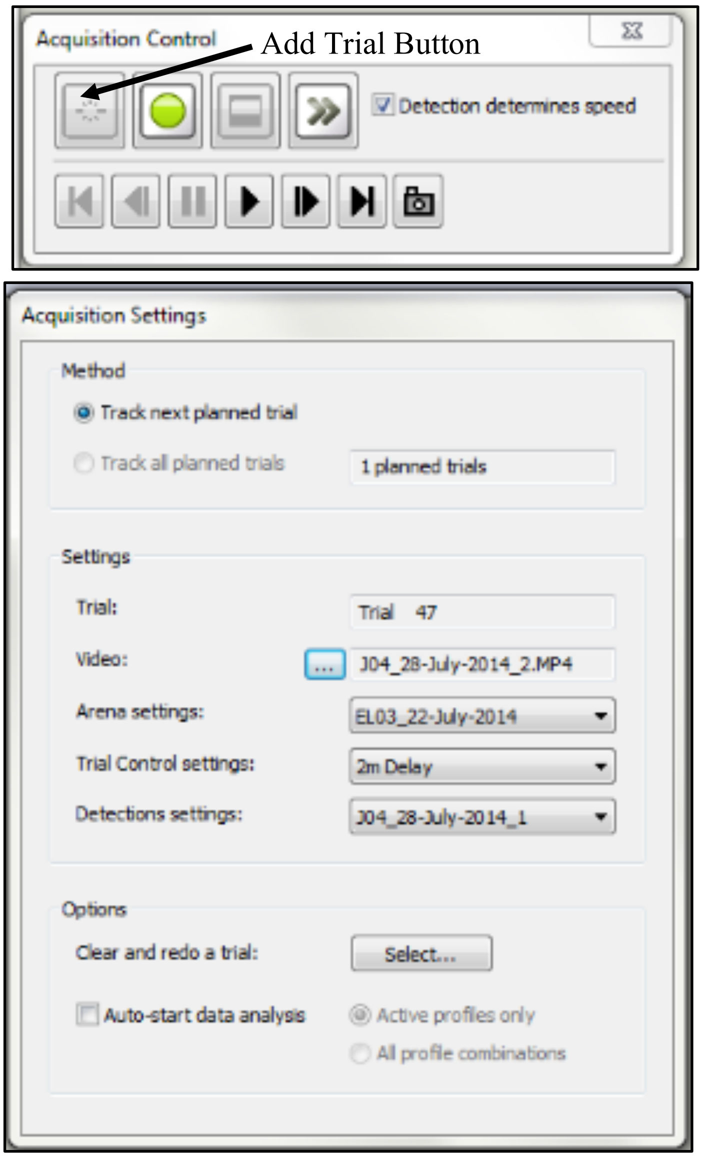


Figure 9. Acquisition Control and Acquisition Settings window within EthoVision.

Analysis Profile

The Analysis Profile in EthoVision is where the dependent variables of an experiment are defined. Dependent variables in EthoVision either quantify behaviours or indicates whether a specific event occurred. Because we are interested in when there is activity within the arena and the zones we defined earlier, these dependent variables need to be added to the analysis profile. To do this, go into the **Analysis Profile** window using the Experiment Explorer. Click on the **In zone** button and add both the arena and zone defined earlier to the analysis profile. This will now allow for the visualization of movement in these areas of the video clip.

Integrated Visualization

EthoVision provides integrated visualization of the results, which is primarily used to determine time stamps of activity within the arena and zone. The integrated visualization displays as a timeline of the video and shows activity in the arena and zone through the presence of markers at a given time. Go to the **Integrated Visualization** window using the Experiment Explorer to view a timeline along with a video viewer. You can use the plus and minus buttons to zoom in and out of the timeline. The more zoomed out of the timeline you are, the faster you can scroll through it. The arena and the nest box zone are the most important on the timeline, whenever there is activity in either of these areas, it is represented as a coloured bar (Figure 10). Starting at the beginning of the timeline, use the left and right arrow keys on the keyboard to navigate through time. Whenever bars show up in the timeline these are areas of interest that should be checked. Scroll to that position on the timeline to see what is occurring at that time stamp to determine if a provisioning event is occurring. Due to the arena and zone set-up, a trip to the nest by a bird has a unique identifier in the timeline. For a bird coming to the nest, the arena should show activity before the zone (see Figure 10) and when the bird is leaving it should display as the opposite. Sometimes there may be a lot of activity in the arena that EthoVision may track, such as moving clouds or vegetation; this is why it is important to look for activity in both areas of interest. Sometimes, if the camera was not set up properly their might be a lot of interference (which we experienced in some of our videos) which can lead to EthoVision missing the bird enter the nest box zone. If there appears to be strong interference the best way to ensure nothing is missed is to also look at the velocity display within the timeline. A bird entering a nest box is displayed as a negative slope and as a positive slope when leaving (see Figure 10). After scrolling through the timeline and examining all points of interest you should be able to get an accurate account of nestling provisioning from your video.

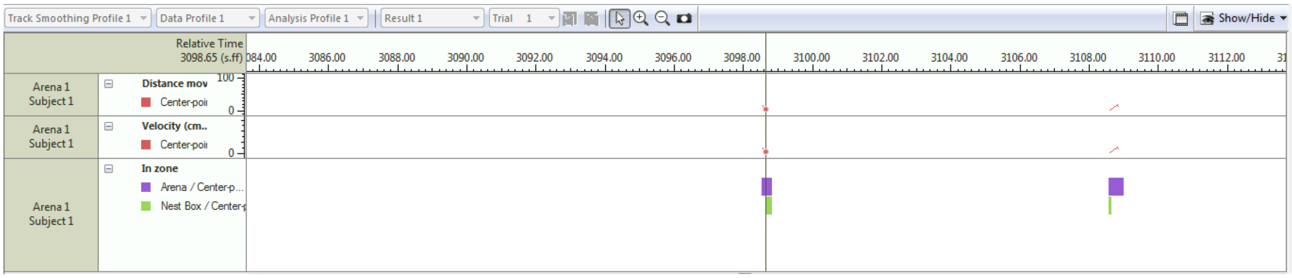
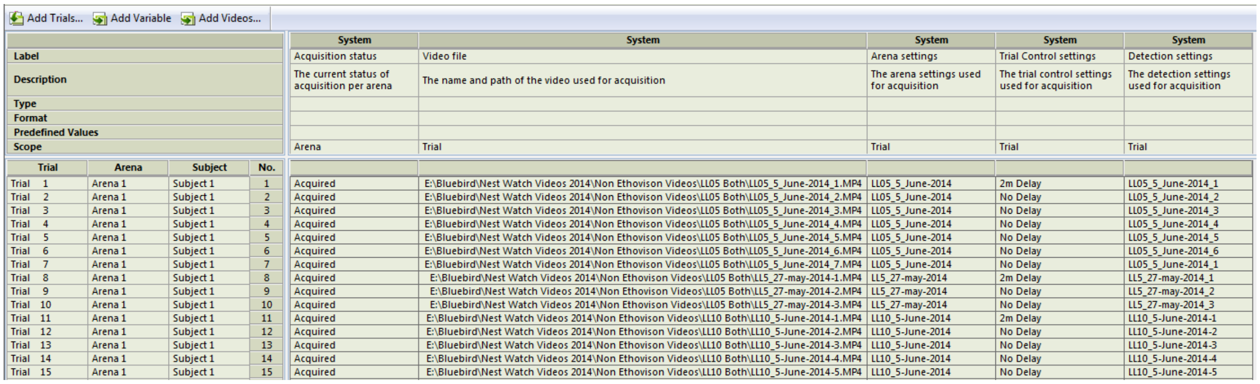


Figure 10. EthoVision's Integrated Visualization window showing the timeline results of a nestling provisioning event through activity within the arena and zone.

Running Multiple Trials

The above practices describe how to analyze one video within EthoVision; however, a more efficient approach may be to have EthoVision analyze all your videos at one time. Furthermore, depending on your recording equipment you may end up with several video files for one observation period (these can all use the same settings but will have to be treated as separate trials unless you chose to render them together). To allow EthoVision to analyze numerous trials at one time you must create a trial list, which can be done in the "Trial List" window. Before doing this you need to follow the above practices to create proper arena, trial control, and detection settings for each video you want to analyze. This will all be done within one experiment in EthoVision. To create a specific arena for each video, right click on "Arena Settings" in the Experiment Explorer (far left side within EthoVision) and select new Arena. Select the video file you want to use as a reference image and name each new arena accordingly so that you know which arena is for which video. We used arena names that were the same as the video file names to avoid confusion. The same can be done for trial control and detection settings. When optimizing, ensure the detection settings for each video use the proper video source, otherwise tracking will be unsuccessful. Once you have created settings for each video you can now make a trial list where for each trial you select the video source, arena settings, and detection settings for each trial (Figure 10). After the trial list is complete, go into the "Acquisition" window and select **Track All Planned Trials**. EthoVision will now run through each trial one at a time; this will take some time depending on the number and length of your videos. Each trial can then be viewed individually within the integrated visualization window.



Add Trials... Add Variable Add Videos...

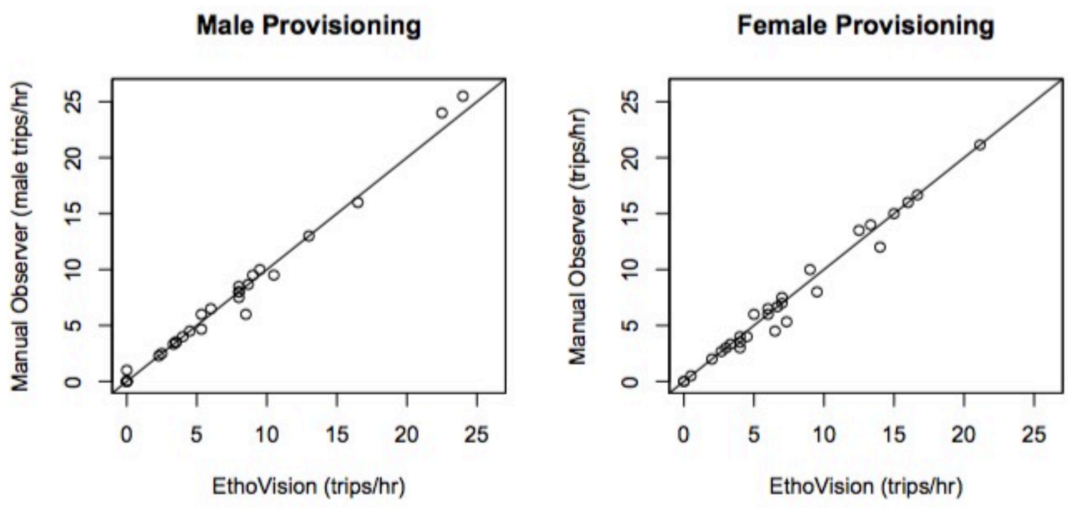
				System	System	System	System	System
Label				Acquisition status	Video file	Arena settings	Trial Control settings	Detection settings
Description				The current status of acquisition per arena	The name and path of the video used for acquisition	The arena settings used for acquisition	The trial control settings used for acquisition	The detection settings used for acquisition
Type								
Format								
Predefined Values								
Scope				Arena	Trial	Trial	Trial	Trial
Trial	Arena	Subject	No.					
Trial 1	Arena 1	Subject 1	1	Acquired	E:\Bluebird\Nest Watch Videos 2014\Non Ethovison Videos\LL05 Both\LL05_5_June-2014_1.MP4	LL05_5_June-2014	2m Delay	LL05_5_June-2014_1
Trial 2	Arena 1	Subject 1	2	Acquired	E:\Bluebird\Nest Watch Videos 2014\Non Ethovison Videos\LL05 Both\LL05_5_June-2014_2.MP4	LL05_5_June-2014	No Delay	LL05_5_June-2014_2
Trial 3	Arena 1	Subject 1	3	Acquired	E:\Bluebird\Nest Watch Videos 2014\Non Ethovison Videos\LL05 Both\LL05_5_June-2014_3.MP4	LL05_5_June-2014	No Delay	LL05_5_June-2014_3
Trial 4	Arena 1	Subject 1	4	Acquired	E:\Bluebird\Nest Watch Videos 2014\Non Ethovison Videos\LL05 Both\LL05_5_June-2014_4.MP4	LL05_5_June-2014	No Delay	LL05_5_June-2014_4
Trial 5	Arena 1	Subject 1	5	Acquired	E:\Bluebird\Nest Watch Videos 2014\Non Ethovison Videos\LL05 Both\LL05_5_June-2014_5.MP4	LL05_5_June-2014	No Delay	LL05_5_June-2014_5
Trial 6	Arena 1	Subject 1	6	Acquired	E:\Bluebird\Nest Watch Videos 2014\Non Ethovison Videos\LL05 Both\LL05_5_June-2014_6.MP4	LL05_5_June-2014	No Delay	LL05_5_June-2014_6
Trial 7	Arena 1	Subject 1	7	Acquired	E:\Bluebird\Nest Watch Videos 2014\Non Ethovison Videos\LL05 Both\LL05_5_June-2014_7.MP4	LL05_5_June-2014	No Delay	LL05_5_June-2014_1
Trial 8	Arena 1	Subject 1	8	Acquired	E:\Bluebird\Nest Watch Videos 2014\Non Ethovison Videos\LL05 Both\LL5_27-may-2014-1.MP4	LL5_27-may-2014	2m Delay	LL5_27-may-2014_1
Trial 9	Arena 1	Subject 1	9	Acquired	E:\Bluebird\Nest Watch Videos 2014\Non Ethovison Videos\LL05 Both\LL5_27-may-2014-2.MP4	LL5_27-may-2014	No Delay	LL5_27-may-2014_2
Trial 10	Arena 1	Subject 1	10	Acquired	E:\Bluebird\Nest Watch Videos 2014\Non Ethovison Videos\LL05 Both\LL5_27-may-2014-3.MP4	LL5_27-may-2014	No Delay	LL5_27-may-2014_3
Trial 11	Arena 1	Subject 1	11	Acquired	E:\Bluebird\Nest Watch Videos 2014\Non Ethovison Videos\LL10 Both\LL10_5-June-2014-1.MP4	LL10_5-June-2014	2m Delay	LL10_5-June-2014-1
Trial 12	Arena 1	Subject 1	12	Acquired	E:\Bluebird\Nest Watch Videos 2014\Non Ethovison Videos\LL10 Both\LL10_5-June-2014-2.MP4	LL10_5-June-2014	No Delay	LL10_5-June-2014-2
Trial 13	Arena 1	Subject 1	13	Acquired	E:\Bluebird\Nest Watch Videos 2014\Non Ethovison Videos\LL10 Both\LL10_5-June-2014-3.MP4	LL10_5-June-2014	No Delay	LL10_5-June-2014-3
Trial 14	Arena 1	Subject 1	14	Acquired	E:\Bluebird\Nest Watch Videos 2014\Non Ethovison Videos\LL10 Both\LL10_5-June-2014-4.MP4	LL10_5-June-2014	No Delay	LL10_5-June-2014-4
Trial 15	Arena 1	Subject 1	15	Acquired	E:\Bluebird\Nest Watch Videos 2014\Non Ethovison Videos\LL10 Both\LL10_5-June-2014-5.MP4	LL10_5-June-2014	No Delay	LL10_5-June-2014-5

Figure 10. The Trial List window within EthoVision showing trial configuration for the analysis of more than one video.

Data Acquisition

Using the Integrated Visualization timeline, data can be extracted manually and recorded onto a data sheet (similar to manual analysis). Using the time stamps generated by EthoVision, scroll through the timeline of the video from start to finish stopping at each time stamp to determine whether a provisioning event has occurred, the time at which it occurred, and the sex of the bird. This step is critical for recording which sex provisioned and ensuring false positives (e.g., moving grass, other birds) are not recorded as provisioning events. Record this information into the data sheet for an accurate account of nestling provisioning.

Data can also be exported from EthoVision in either text or excel format. There are two types of data export options that contain useful information. Raw data export will retrieve all tracking data from the acquisition including the time that an event occurred (in seconds from the beginning of the trial) and whether the subject is active in either the arena or zone. Alternatively, summary statistics can be exported which shows summary information from the trial such as the frequency of trips to the arena and the zone. To use these export features within EthoVision, navigate to either **Raw Data** or **Statistics** under "Export" in the Experiment Explorer. For raw data export make sure to select **Track & independent variables** in the "Data to Export" Field of the Export Window. Under the "Export Settings" field, select the file location and the file type you wish to export. The data can now be exported by selecting **Start Export**. For trial statistics export make sure **Trial Statistics** is selected in the "Export Statistics" window and specify the file type and location. The data can now be exported by selecting **OK**.



ESM Fig. 1 Provisioning rates recorded using EthoVision were highly correlated with rates obtained through manual analysis (males: n = 28, $\rho = 0.99$, $p < 0.0001$; females: n = 28, $\rho = 0.98$, $p < 0.0001$). Shown is the y = x line on both plots.