BEHAVIOURAL ANALYSIS OF MEADOW JUMPING MICE; *ZAPUS HUDSONIUS*

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BEHAVIOURAL ANALYSIS OF MEADOW JUMPING MICE; *ZAPUS HUDSONIUS* IN NORTHERN ONTARIO

By

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An Undergraduate Thesis Submitted in

Partial Fulfillment of the Requirements for the

Degree of Honours Bachelor of Environmental Management

Faculty of Natural Resources Management

Lakehead University

May 2020

Major Advisor Second Reader

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ABSTRACT

Palmer, S. 2020. Behavioural Analysis of Meadow Jumping Mice: *Zapus Hudsonius.* 20pp

Temperament studies of animals can provide unique insight on how behaviour, genetics and environmental factors interact to influence the evolution and dynamics of populations. This, in turn, can be used to predict how individuals may respond in a variety of situations such as manipulations to habitat and resources, as well as increased predation risks, all of which are likely to be modified by future climate change. This thesis explored the behaviours of meadow jumping mice (*Zapus hudsonius*) from a sample of animals captured in Northwestern Ontario. The data were collected using open-field tests that quantified-sniffing, scanning, walking, running, rearing, jumping, grooming, stillness and inspecting objects within the arena. A single Principal Component described a cline of behaviour ranging from motionless 'frightful' animals at one end to highly active and agitated individuals at the other. The interpretation is consistent with the description of anti-predator adaptations used by jumping mice.

Keywords: Behaviour, Behavioural Syndromes Temperament, Open-Field Test, Personality, Personality Traits, Zapus

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ACKNOWLEDGEMENTS

I would like to thank my thesis supervisor, Dr. Douglas Morris, for guiding me through this project and allowing me to use data collected at work. I would also like to thank my parents Wendy and Graydon for supporting me through school and life, helping me get to where I am today. Special thanks to everyone who is not previously mentioned whom I have spoken with and helped me regarding my thesis and data collection, including my co-worker Alex Martin who helped collect this data.

INTRODUCTION AND OBJECTIVES

Animals typically show consistent variances in their reactions to different stimuli across a wide range of contexts and situations within populations (Dingmanse and Réale 2005; Biro and Stamps 2008). These individual differences commonly represent correlated traits, for example, animals observed to be more aggressive to conspecifics are also noted to be bolder in novel situations, commonly known as behavioural syndromes or personality traits (Dingmanse and Réale 2005; Dall *et al.* 2004; Biro and Stamps 2008). Five recognized categories of temperament, shyness-boldness, exploration-avoidance, activity, aggressiveness and sociability, have received the most attention from behavioural ecologists (Réale *et al.* 2007).

Behavioural syndromes underly multiple ecological processes such as dispersal, territory quality, survival, reproduction, offspring recruitment and physiological response to social stress (Réale *et al.* 2007). Plasticity of personality types or categories of temperament can be the optimal strategy when coping with a variety of situations, displaying greater resilience to change (Réale *et al.* 2010; Dall *et al.* 2004). Non-random dispersal, predation and the potential to acquire parasites can all be related to an individual's personality in time and space (Réale *et al.* 2010, Kortet *et. al.* 2010).

I thus explore correlations among behavioural metrics collected on a sample of meadow jumping mice, *Zapus hudsonius* in northern Ontario. There is a shortcoming of studies on jumping-mouse personalities, many of the studies are conducted with other rodents (i.e. voles, mice and rats). Jumping mice are excellent candidates for behaviour studies as they are essentially bipedal, excellent hibernators, and are novel to the study of behaviour. I describe the open-field tests that I used to quantify jumping-mouse behaviour and summarize those variables with a Principal Components Analysis. I then explain the context of the behaviours within an evolutionary and ecological perspective, focusing on how behavioural clines relate to the individual's natural functions in the environment.

LITERATURE REVIEW/CONCEPTUAL CONTEXT

BEHAVIOUR, TEMPERAMENT, PERSONALITY

There are two main definitions of personality among behavioural ecologists: 1. personality simply corresponds to consistent behavioural differences among individuals, 2. personality represents consistent individual differences in specific sets of behaviours usually in the context of a novel or challenging environment (Réale *et al.* 2010). The first definition is more in the broad-sense and has the advantage of applying an evolutionary and ecological framework to any behaviour, allowing one to identify and understand patterns in behaviour within an adaptive context, it is also known as a behavioural syndrome (Réale *et al.* 2010). The second definition is similar to the one used in psychology known as coping styles. Because of its narrower focus, it can be used to infer links between behavioural expression and emotionality (Réale *et al.* 2010). The research of personality within an ecological and evolutionary framework regardless of the approach improves our understanding of behavioural differences within and among populations; the continued development and improvement of this framework is imperative to advancing our research and understanding of personality (Réale *et al.* 2010).

The study of animal personalities using genetic concepts provides insight into the evolution of personality in metapopulations, the study of correlational selection, and indirect genetic effects (Réale *et al.* 2010). These evolutionary-based explanations can be used to determine the existence of, and co-adaptation between, correlated traits and predict the correlations among physiological, hormonal and behavioural reactions (Réale *et al.* 2010).

Temperament studies look at particular phenotypes because these traits tend to be distinguishable and strongly expressed in behaviour types such as aggressiveness, exploration, sociality, anti-predator behaviour and many more, as well as the fact that they are indicators of fitness (Réale *et al.* 2007, Powell and Banks 2003, Krebs *et al.* 2019). Temperament phenotypes have the potential to be an axis for selection. This depends on the environmental variation in the geographic area of the population. Phenotypes have the potential to affect population dynamics and genetic compositions, landscape distribution, community interactions, invasibility and speciation (Réale *et al.* 2007).

Behavioural traits are plastic and are continually being modified to suit the immediate environment. Life history influencing trade-offs in behavioural traits results in consistent individual differences in growth and fecundity, or other measures of fitness, likely contribute to the consistent individual differences in behavioural traits (Biro and Stamps 2008). Due to the non-random manner in which inter-individual variation is exhibited, and its consistent consequences for ecology and evolution, it is likely to be a focus for selection (Dall *et al.* 2004). When personality traits evolve alongside morphology and life-history they can facilitate speciation through adaptative changes which affect the ability of a population to respond to and persist in altered environments (Dall *et al.* 2004).

The effects of personality variation range from life history and demography (Biro and Stamps 2008), population density, fitness, distribution within habitats (Dall *et al.* 2004), social evolution, speed of evolution, the persistence of populations and speciation (Dall *et al.* 2004), to entire communities' structures and ecosystem processes (Wolf and Weissing 2012). Non-random dispersal caused by personality types can cause differences in the proportions of behavioural types being affected by predation, diseases, parasites, etc. (Dall *et al.* 2004, Réale *et al.* 2010, Kortet *et al.* 2010). Personality traits also promote variation in physiological, life-history, and neurobiological traits which can influence speciation and transmission of diseases and population stability (Dall *et al.* 2004, Wolf and Weissing 2012). Many studies have found that personality traits such as activity, boldness and aggressiveness are all positively related to intake of food, other studies also found a positive relationship between personality traits or behavioural syndromes and growth or fecundity further demonstrating the relationship between life-history productivity and personalities (Biro and Stamps 2008).

Behavioural plasticity is often thought to be the driving force of increased fitness in different environments; however, most individuals show very limited behavioural plasticity but differ consistently when exposed to the same or similar environmental conditions (Dingemanse and Réale 2005). Two different approaches to understanding behavioural variation; the mechanistic approach explores how phenotypes are affected by underlying genetic and environmental factors include; the functional approach explores the fitness consequences of the interaction of phenotypes with the environment (Dingemanse and Réale 2005). Although functional and mechanistic approaches can be used separately to understand personality, a combination of the two approaches will produce the most wholistic, informed evaluation (Dingemanse and Réale 2005).

QUANTIFYING BEHAVIOUR THROUGH OPEN-FIELD TESTS

Open-field tests (OFT) have been the most common way behavioural ecologists or animal psychologists quantify behaviours for over 70 years (Walsh and Cummins 1976, Perals *et al.* 2017). The method consists of placing an animal into a basin or enclosure, known as an arena, which is typically video recorded to capture the behaviours of an animal in a fixed setting (Walsh and Cummins 1976). The arena may be either empty or containing chosen stimuli, some common items are nuts, bolts, lights, music playing on speakers, other animals, food or paintings (Walsh and Cummins 1976). Originally designed by Calvin Hall in 1932 (Walsh and Cummins1976), OFTs were used to measure locomotor activity and wiliness to explore in rodents, but are now used to measure exploration, emotionality, fear, boldness and gregariousness (Perals *et al.* 2017, Powell and Banks 2003, Powell and Gartner 2011).

The different components in open-field tests make the situation multifactorial, therefore the extent of any behaviour will be a function of the different components (Walsh and Cummins 1976). This multifactorial characteristic requires that the biological meanings of the metrics be derived and interpreted properly for the test to be as accurate as possible (Walsh and Cummins 1976, Perals *et al.* 2017). The best way to interpret behavioural results from OFTs is to use factor analysis techniques such as

Principal Components Analysis, paired with a biological understanding of natural behaviours (Walsh and Cummins 1976).

BACKGROUND INFORMATION OF *ZAPUS HUDSONIUS*

Zapus hudsonisus (meadow jumping mouse) is a small (~20g) rodent that uses its large hind feet and a long tail to hop through its preferred moist and open grass and sedge-meadow habitats (Quimby 1951, Whitaker 1972). Females produce only one litter annually (in southern Ontario; Hoyle and Boonstra 1986) composed of 5-6 offspring following an 18-20-day gestation (Quimby 1951, Whitaker 1972). Females produce two litters in more southern populations (Quimby 1951, Whitaker 1972). Jumping mice are likely solitary, however, regardless of sex, age class, or the number of animals in cages, groups of mice were generally accepting of new additions (Quimby 1951). Aggression may occur between territorial males at the beginning of the breeding season (Quimby 1951). *Zapus hudsonius* remains in hibernation longer than most mammals (Whitaker 1972). Dates of emergence vary by two weeks with males emerging in late April or early May, and females emerging in late May. Males enter hibernation in late August to early September, while females can remain active from mid-September to as late as mid-October in Southern Ontario (Hoyle and Boonstra 1986). Young females are typically the last animal to be caught in the fall (Hoyle and Boonstra 1986). Predators of the meadow jumping mouse include; red-tailed hawks, barn owls, long-eared owls, as well as other opportunistic species like the red fox, the striped skunk, raccoons and cats (Whitaker 1972, Smith *et. al.* 2004).

MATERIALS AND METHODS

Our team video recorded individual jumping mice in a modified open-field test using a sample population of 25 mice caught in and around the Lakehead University Habitron Property located in Northwestern Ontario, Latitude 48°19'48.9"N, Longitude. 89°47'24.5"W. Animals were caught in May 2019 using galvanized metal or aluminum Sherman traps, baited with oats, a peanut-butter flour pastes and a piece of potato with cotton added for insulation. Traps were set at 5:30 pm and retrieved at 6:00-6:30 am. Animals were returned to traps after being weighed, measured, sexed, aged and marked with a unique metal ear tag (Monel 1005-1, National Band & Tag Company, Newport, KY). Animals were retained in the traps for no longer than 3 hours. We placed individual animals into one corner of the modified open-field arenas. The arena was a polyethylene 100-gallon watering tank (See Figure 1.). The arena was set up with different stimuli, 2 covers, 1 side hole and lines taped to the floor (See Figure 1). The animals' behaviour was recorded for 10 minutes. During this time the recorder would quietly stand back away from the arena, out of sight from the animal. Consistency was upheld by using the same stimuli within the arena and modifying the natural light by using a LED light overhead, the arena was always placed near the open door in a metal storage shed to in order to receive normal daylight while minimizing disturbance. Animals were video recorded using a GoPro Hero 3 camera attached above the arena. All recorded videos were processed using BORIS software (Version 7.7, Friard and Gamba 2016). The beginning 5 minutes were separated into the first minute and the final four minutes within BORIS; this was to observe whether the animals were acting significantly different between the two time periods. The first minute and final 4 were combined for this study, as there were no substantial differences between the two time periods. These first 5 minutes observed their general behaviours as timed state events such as sniffing, scanning, walking, running, rearing, jumping, grooming, stillness and inspecting objects within the arena (Appendix, Table A1). Within the first 5 minutes, we also recorded discrete events including, the number of times that the individual jumped, inspected the side hole, crossed grid lines, went into the cover, went under the top of the cover and dipped its head into the covers. In the remaining 5 minutes, we placed a novel object (expelled shot-gun shell) into the arena to record the time before first contact and number of encounters with the object. This allows data to be collected on habituation to novelty as well as bold/shy type behaviours. The behaviours exhibited in reaction to a novel object show insight into reactions in similar stressful situations such as dispersal and territoriality (Martin and Réale 2006). 8 out of the 25 samples were animals that had been video recorded in the arena for a second time. Two videos of a single animal are needed to create a personality profile, this was not explored in this thesis due to a lack of time.

All data were analyzed using IBM SPSS (Version 25, IBM Corp. 2017) and R with RStudio (R Core Team 2019). I used a correlation matrix to determine a set of highly correlated variables appropriate for Principal Components Analysis (PCA) (Jolliffe and Cadima 2016, Peres-Neto *et al.* 2005, Raîche *et al.* 2013). I used the analysis to reveal any underlying axis of temperament. I examined a scree plot of the eigenvalues to determine how many components should be retained for interpretation

(Jolliffe and Cadima 2016, Peres-Neto *et.al.* 2005, Raîche *et al*. 2013). I rotated the data using the varimax rotation feature of IBM SPSS (Version 25, IBM Corp. 2017), however, because I chose to only keep one variable, rotation was not necessary.

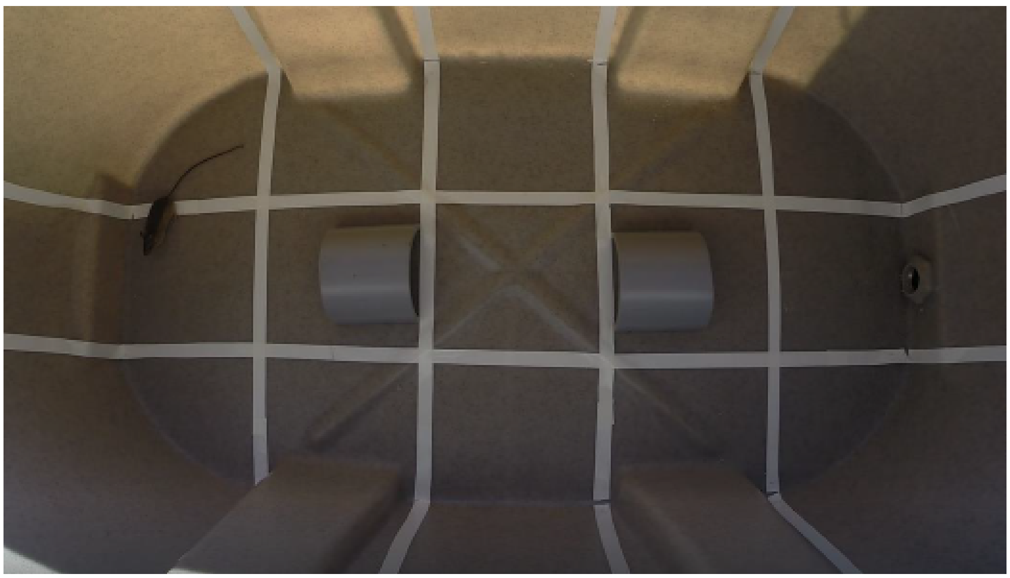

Figure 1. Image of arena setup, containing a meadow jumping mouse from recording

Table 1. Variable Names and Definitions

Variable Name	Definition
Movement	Time in seconds spent in motion = sum of walking & running
Exploration	Time in seconds spent exploring = sum of scanning, sniffing & inspecting covers & the exit hole
Jumps	Number of jumps
Rearing	Time in seconds spent rearing
Stillness	Time in seconds spent being still = sum of stillness & grooming
Cover	Time in seconds spent in and on covers
Total Lines	Number of lines crossed

RESULTS

One Principal Component (PC) accounted for 40.5% of the common variation in the seven variables retained for the PCA (Figure 2.). One Principal Component was kept according to the Cattell's scree test, which states that the location where a large change in slopes of adjacent line segments is obvious that is the number of PC's to keep (Raîche *et al.* 2013, Peres-Neto 2005). The PC loadings defined an anti-predator axis ranging from individuals frozen to those that were franticly moving (Table 1.).

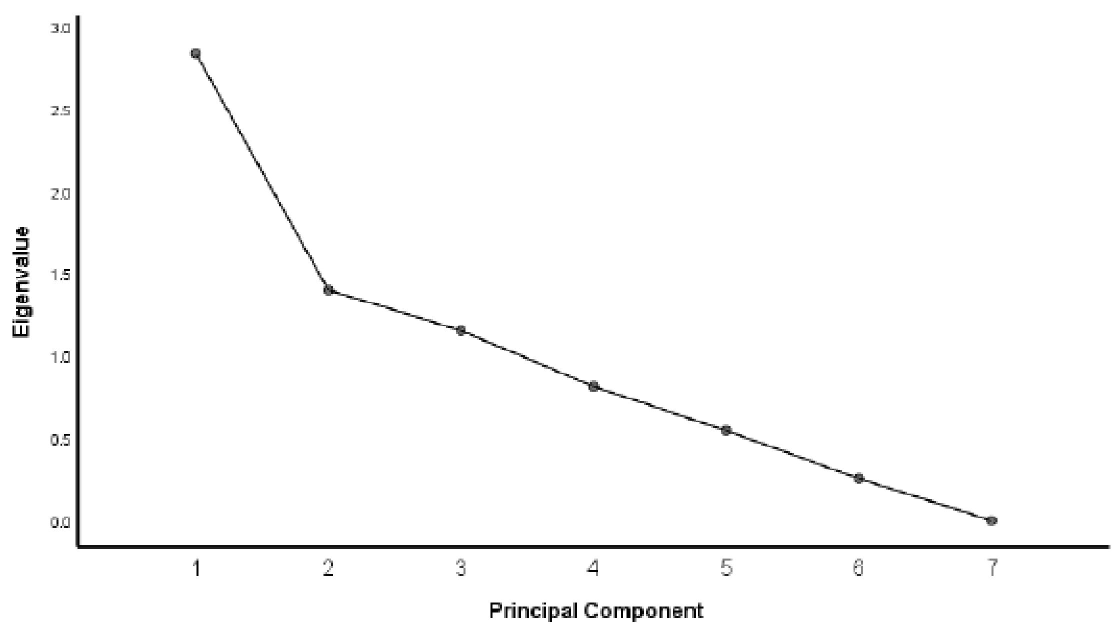

Figure 2. A scree plot of the seven Principal Components emerging from an analysis of behavioural syndromes in jumping mice (*Zapus hudsonius*) in northern Ontario Canada.

Table 2. Loadings from Principal Component 1 for each variable, including the total variance accounted for by PC 1. Bold values were used in the interpretation of PC 1.

Variables	Loadings
Movement	**0.82**
Exploration	0.06
Jumps	**0.56**
Rearing	**0.56**
Stillness	**-0.88**
Cover	0.18
Total lines	**0.83**
Total Variance	40.5%

DISCUSSION

An animal's temperament impacts its life history, population dynamics and fitness (Ives and Dobson 1987, Krebs *et. al.* 2019, Powell and Gartner 2011, Kotler *et al.* 1994). This includes any behaviours associated with its temperament including aggressiveness, exploration, sociality and anti-predator behaviours (Réale *et al.*2007, Ives and Dobson 1987, Krebs *et. al.* 2019, Powell and Gartner 2011). Predation is recognized as a mortality risk for bold and exploratory animals and is considered an important factor in the evolution of these traits (Kortet *et al.* 2010), therefore, the opposite of these traits, such as stillness, has the potential to be selected for. Anti-predation behaviours can reduce death rates, increase density of prey, decrease the density of predators and damp oscillations of predator-prey cycles (Lind and Cresswell 2005, Ives and Dobson 1987). Predation can have many non-consumptive impacts on small mammals such as behavioural changes, foraging opportunities, changes to activity levels which leads to increased energy use and morphology changes (Schmitz 2017, Kotler *et al.* 1994, Randall *et al.* 1995). Anti-predator behaviours include; vigilance, crypsis, habitat selection (Ives and Dobson 1987) and increased levels of activity (Lind and Cresswell 2005). The sample of jumping mice used in this study exhibited anti-predator behaviours throughout the open field test.

I found that this sample of *Zapus hudsonius* varied in their position along the anti-predator axis. This could potentially be a result of variations between the animal's perceived risk in the open-field test. House mice (*Mus musculus domesticus*) choose habitat and assess predation risk via the amount of vegetated cover in a given area and show high avoidance of open areas (Powell and Banks 2003), these habitat qualities are not found in the open-field test in this study. Other mammals like lemurs have been known to act cryptically when faced with a threat of avian predators, while the same sample populations acted frantically, running and climbing to safety when faced with land-based threats (Rahlfs and Fichtel 2010).

CONCLUSION

Meadow jumping mice have been known to be still in the presence of conflict or threats (Whitaker 1972). The open-field test has been as an environment in which small mammals such as *Zapus* are known to feel stressed or threatened, likely because of an increased perceived risk of predation (Powell and Gartner 2011, Powell and Banks 2003). *Zapus hudsonius* anti-predator behaviour varied along an axis from still to frantic. This range of anti-predator behaviours is likely due to individual variation, the type of risk perceived and the relative amount of perceived risk.

One downfall of this study is that it was not intended to test anti-predator behaviours, therefore if I was to redo this study I would have conducted a startle test or something similar. Another potential downfall to this study is the amount of time individuals spent in the arena. Other studies suggest 30 minutes in an arena to reduce the shock of the new environment (Krebs *et al.* 2019).

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APPENDIX

Appendix 1. Description of Behaviour Codes

Behaviour codes	Description
Walk1	Time measured in seconds spent walking in the first minute of the video
Run1	Time measured in seconds spent running in the first minute of the video
Rear1	Time measured in seconds spent rearing in the first minute of the video
Sniff1	Time measured in seconds spent sniffing in the first minute of the video
Scan1	Time measured in seconds spent looking around in the first minute of the video
Groom1	Time measured in seconds spent auto-grooming in the first minute of the video
Still1	Time measured in seconds spent being still in the first minute of the video
Insepct1	Time measured in seconds spent inspecting the covers in the first minute of the video
Ins.SH.1	Time measured in seconds spent inspecting the side hole of the arena in the first minute of the video
In.Cov.1	Time measured in seconds spent underneath or partially underneath the covers in the first minute of the video
Ab.Cov.1	Time measured in seconds spent on top or partially on top of the covers in the first minute of the video
Dip 1	Number of times animal dips head in the first minute of the video
Jump1	Number of times animal jumps in the first minute of the video
Und.Cov.1	Number of times animal enters or partially enters a cover in the first minute of the video
On.Cov.1	Number of times animal climbs on top of or partially on top of the cover in the first minute of the video
Exp.Hole.1	Number of times animal inspected/explored the hole in the first minute of the video
Perim.1	Number of times animal steps over perimeter lines in the first minute of the video
Inside.1	Number of times animal steps over interior lines in the first minute of the video
Tot.Line1	Total number of times animal steps over lines in the first minute of the video (= Perim.1 + Inside.1)

Walk4	Time measured in seconds spent walking in the subsequent four minutes of the video
Run4	Time measured in seconds spent running in the subsequent four minutes of the video
Rear4	Time measured in seconds spent rearing in the subsequent four minutes of the video
Sniff4	Time measured in seconds spent sniffing in the subsequent four minutes of the video
Scan4	Time measured in seconds spent looking around in the subsequent four minutes of the video
Groom4	Time measured in seconds spent grooming in the subsequent four minutes of the video
Still4	Time measured in seconds spent being still in the subsequent four minutes of the video
Insp.4	Time measured in seconds spent inspecting the covers in the subsequent four minutes of the video
Ins.SH.4	Time measured in seconds spent inspecting the side hole of the arena in the subsequent four minutes of the video
In.Cov.4	Time measured in seconds spent underneath or partially underneath the covers in the subsequent four minutes of the video
Ab.Cov.4	Time measured in seconds spent on top or partially on top of the covers in the subsequent four minutes of the video
Dip4	Number of times animal dips head in the subsequent four minutes of the video
Jump4	Number of times animal jumps in the subsequent four minutes of the video
Und.Cov.4	Number of times animal goes under or partially under the cover in the subsequent four minutes of the video
On.Cov.4	Number of times animal goes on top of or partially on top of cover in the subsequent four minutes of the video
Exp.Hole.4	Number of times animal inspected/explored the side hole in the subsequent four minutes of the video
Perim4	Number of times animal steps over perimeter lines in the subsequent four minutes of the video
Inside.4	Number of times animal steps over inside lines in the subsequent four minutes of the video
Tot-Lines4	Total number of times animal steps over lines in the subsequent four minutes of the video
F.Ent.Cov	Time measured in seconds before the animal enters one of the covers
Beforet	Time in the final five minutes before contact with a novel object
Encounter	Number of times the animal encounters the novel object in the final five minutes