The Masking Effect of Anthropogenic Noise on Alarm Calls of the Eastern Chipmunk, *Tamias striatus*

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Abstract. With the increasing threat of noise pollution due to urbanization, its effects on many organisms are now being studied. Past studies have shown that anthropogenic noised tends to increase the vigilance of an organism (i.e. Rabin et al. 2006), but few have demonstrated the specific masking capabilities of such noise. This study aimed to determine whether traffic noise had the ability to mask alarm calls of the eastern chipmunk (*Tamias striatus*) as reflected in vigilance behavior. Chipmunks were video taped while foraging during silence and the playing of traffic noise, alarm calls, and alarm calls with traffic noise. It was expected that the chipmunks would show a slightly increased rate of vigilance in the presence of noise, and an extremely elevated level of vigilance during alarm call playbacks. Residence time should also have increased due to the more time spent being vigilant. When the traffic noise and alarm calls were played in tandem, the noise should mask the alarm calls, and therefore the chipmunks should not show a significant increase in vigilance. The results of this study show that traffic noise does have the potential to mask alarm calls. Chipmunks showed a significantly greater rate of vigilance behavior during the alarm call playback (one-way ANOVA, $F_{0.05,3,66}=7.78$, $p=0.00016$; Tukey's HSD, $p<0.001$, $p=0.015$, $p=0.015$) than any of the other treatments, which were all statistically equivalent ($p=0.95$, $p=.1$, $p=0.91$). There was no significant relationship between treatment and residence time (one-way ANOVA, $F_{0.05,2,22}=2.69$, $p=0.09$). This is the first study to demonstrate that traffic noise can mask alarm calls, and this could have serious ramifications on the ability of organisms to detect predators in noisy environments.

Introduction. Urban expansion is making noise pollution an increasingly popular topic of ecological research (reviewed by Slabbekoorn and Ripmeester 2008). Anthropogenic noise has the potential to mask biological sounds used by the organism for survival and reproduction, which could ultimately affect the fitness of the organisms inhabiting the affected area. Animals living in noisy areas may have difficulty hearing mates, offspring, predators, or prey due to masking effects (Barber et al. 2010).

Although conservation biologists have only recently started investigating how anthropogenic noise affects wildlife, numerous studies have already chronicled the behavioral changes that noise has caused in various organisms. In marine systems, noise pollution from boat traffic and military operations has become an especially significant concern due to its effects on mammal communication. Foote et al. (2004) found that killer whales increase the duration of their calls in the presence of boat traffic, and studies have found a similar response of other whales in duration (Miller et al. 2000), as well as amplitude (Parks 2010) to environmental noise.

Anthropogenic noise is also having an impact on terrestrial organisms, with its effects on amphibians, birds, and mammals being the most documented. Like the killer whales, many organisms change aspects of their vocalizations, such as frequency or timing, to avoid signal masking. For example, Parris et al. (2009) found that frogs shift their calls to a higher frequency when in traffic noise, and Brumm (2004) reported that nightingales increased the volume of their calls on weekday mornings in response to increased environmental noise. Rabin et al. (2006) found that California ground squirrels living near wind turbines are more vigilant during alarm call playbacks than squirrels that do not regularly experience the turbine noise. Clearly, the squirrels are putting more of their energy towards vigilance to ensure that they can detect alarm calls through the noise.

Besides the study by Rabin et al. (2006), not much research has been done on the potential masking effects of anthropogenic noise in Sciurids, and the resulting impact on their behavior. This study aims to determine the potential of anthropogenic noise to mask alarm calls of eastern chipmunks (*Tamias striatus*). Previous studies have shown that chipmunks react to conspecific alarm calls with an increase in vigilance behavior (Weary and Kramer 1995, Baack and Switzer 2000). Chipmunks have even been seen to respond with increased vigilance to titmouse mobbing (alarm) calls (Schmidt et al. 2008). Clearly, chipmunks place a large emphasis on indirect cues when detecting predators. They also tend to have an increased residence time (the total time at a site) after hearing an alarm call, probably due to their increased vigilance reducing their seed load. (Baack and Switzer 2000). Similar increases in vigilance have also been observed in other Sciurids (Leger et al. 1979, Harris et al. 1983, Carey and Moore 1986).

The eastern chipmunk, *Tamias striatus*, is a central place forager, with small but overlapping home ranges, usually of less than one acre (Dunford 1970). When under predation pressure, chipmunks give alarm calls of three different types: a 'chuck' in response to an aerial predator, a 'chip' in response to a terrestrial predator, and a 'trill' when actively evading capture (Dunford 1970). These calls, when properly received by another chipmunk, may improve its chances of detecting and successfully avoiding a predator. Eastern Chipmunks are abundant at our study site, the University of Notre Dame Environmental Research Center (UNDERC), in the upper peninsula of Michigan. They are excellent study organisms for this project because they habituate to humans quickly and hoard seeds insatiably (Kramer and Weary 1991).

Since very little research on the effects of anthropogenic noise on chipmunks has been done before, this study has potential to provide new and valuable information for those interested in the effects of noise pollution. Chipmunks will be exposed to 4 different sound treatments (silence, traffic noise, alarm calls, and traffic noise plus alarm calls) during foraging, and their rate of vigilance behaviors after the sound will be recorded. Since it is reported that noise has caused increased vigilance levels for other Sciurids (Rabin et al. 2006), it is expected that the playing of anthropogenic noise will cause the chipmunks to be more vigilant. Furthermore, as has been documented in the past, the chipmunks should be the most vigilant during the playing of conspecific alarm calls (Dunford 1970, Weary and Kramer 1995, Baack and Switzer 2000). They should also have a greater residence time at a site after the alarm calls due to this increased vigilance time. Finally, the chipmunks should react to an alarm calls plus noise treatment with an only slightly increased vigilance level, due to the noise masking their ability to hear the alarm calls.

If anthropogenic noise is shown to have the potential to mask cues necessary for predator detection in chipmunks, it could have repercussions for conservation efforts for not only Sciurids but many other types of organisms as well (Barber et al. 2010).

Materials & Methods. The subjects of this study were eastern chipmunks (*Tamias striatus*) at the University of Notre Dame Environmental Research Center (UNDERC) in the upper peninsula of Michigan. Thirty mixed coniferous-deciduous forest sites around the property were baited with sunflower seeds for approximately one week before trials began. The general area used was selected due to its relatively high abundance of chipmunks (M. Cramer, personal communication). Locations were chosen along the road in 0.1mile increments, with the side of the road being randomized. From each of these locations, seed was placed at a site 15 to 50 m into the forest. For all sites, refuges were located within one meter or less, so distance to a refuge was not taken into consideration in this study. Since chipmunk home ranges are generally less than one acre (Dunford 1970), this spacing should have discouraged the same chipmunk from being sampled more than once at separate sites.

After the one week baiting period, trials began. If a chipmunk was present in the area when a site was visited, a trial would be run. Each trial consisted of a silent control period of 15 seconds while the chipmunk was foraging, followed by a 50 second randomized sound treatment (traffic noise, alarm calls, or alarm calls plus traffic noise) played at 60 dB through a SME-AFS Amplified Field Speaker (Saul Mineroff Electronics, Inc.) placed above ground level. During the trial, I was crouched approximately 2 m away from the food pile and relatively motionless. The recording of the eastern chipmunk aerial alarm call (cluck calls #1-NY) was acquired from

The Music of Nature (http://www.musicofnature.org/nsf/index.html). The alarm call used was a "chuck," one generally emitted in response to an aerial predator and seen to evoke the largest vigilance response among chipmunks (Weary and Kramer 1995). Previous studies have shown that chipmunks do not distinguish between alarm calls from different individuals (Weary and Kramer 1995), so the source of the recording should not have an effect on the behavioral responses of the chipmunks. The traffic noise was recorded at the rest area off of I-65 in Lake Forest, IL. The behavior of the chipmunk before, during, and after the trial was recorded on a Sony video camera.

The videos were transferred to a Macintosh computer and analyzed in a QuickTime format to find the rate of vigilant behaviors for the treatments. A "vigilant behavior" was defined as a pausing, freezing, looking up, standing up, or scanning during foraging. These behaviors are easily recognizable and generally involve a complete lack of movement. Rates were determined by dividing the number of vigilant behaviors by the time spent at the food site during a particular treatment, followed by conversion into behaviors per minute. For the sound treatments, behaviors during and after (return trip to pile) were combined to determine the effect of the treatment on all behavior after its playing. Trials in which the individual fled as soon as the treatment began and never returned were not analyzed because a post-treatment rate of vigilance could not be determined. In addition, if a chipmunk fled during a treatment, the time before it returned to the food pile was also recorded.

Statistical analysis (paired t-tests, ANOVAs) of this data was performed using the program SYSTAT.

Results. A total number of 39 chipmunks were tested at 16 sites. The mean rates of vigilance behavior for the four treatments (control silence=14.59±1.27, traffic noise=16.68±2.86, alarm calls=28.08±3.45, and alarm calls plus traffic noise=16.31±1.83) were compared with a one-way Analysis of Variance (ANOVA) and a Tukey's honestly significant difference test. An example of a spectrogram for the traffic noise used is shown in Figure 1. Noise treatment was shown to have a significant effect on vigilance rates (one-way ANOVA, $F_{0.05,3,66}=7.78$, $p=0.00016$). There was no significant difference between the alarm plus noise/control ($p=0.95$), alarm plus noise/noise ($p=1$), and control/noise ($p=0.91$) vigilance rates, showing that they were all statistically equivalent. The rate of vigilant behaviors for the alarm calls treatment was significantly higher than that of the control ($p<0.001$), noise ($p=0.015$), and alarm plus noise ($p=0.011$) treatments (Figure 2).

Paired t-tests were performed for each control vigilance rate (vigilance before noise treatment) and its corresponding treatment vigilance rate (combined during and after treatment for each individual tested). There was no difference between before and after vigilance rates for the noise ($t_{0.05,9}=-1.03$, $p=0.33$) and alarm call plus noise ($t_{0.05,9}=-1.18$, $p=0.27$) treatments. There was a statistically significant difference between the before and after vigilance rates for the alarm call treatment ($t_{0.05,12}=-3.21$, $p=0.007$; Figure 3). For both the ANOVA and the t-tests, the trials in which a chipmunk ran away immediately when the sound treatment began and never returned were not included since a post-treatment vigilance rate could not be established.

A second one-way ANOVA revealed that there was no significant effect of treatment on residence time during the second visit to the food pile ($F_{0.05,2,22}=2.69$, $p=0.09$; Figure 4).

Discussion. The results suggest that the traffic noise did have a masking effect on the alarm calls, as was expected. The chipmunks were only significantly vigilant during the alarm calls treatment, and the vigilance rates of the other treatments were statistically equivalent. As previously mentioned, numerous studies have found similar evidence of masking by anthropogenic noise in frogs (Bee and Swanson 2007, Parris et al. 2009), birds (Quinn et al. 2006, Patricelli and Blickley 2006), and mammals (Egnor et al. 2007, Schaub et al. 2008). There have been very few studies of anthropogenic noise in Sciurids, and this may be the first to show that noise can and does mask alarm calls. As a result of the alarm calls plus noise treatment, the chipmunks' rate of vigilance was the same as the noise-only treatment. It seems as though they were unable to detect the alarm calls through the traffic noise and therefore did not adjust their vigilance behavior. If this masking effect is common occurrence due to anthropogenic noise, there could be serious consequences for the predator detection abilities of organisms in noisy areas.

Contrary to my initial prediction, the traffic noise alone did not have a significant effect on vigilance rate. There are several possible explanations for this. First, the control vigilance rate attained in this study may not be an accurate measure of baseline vigilance due to the nearby presence of a human observer. Dunford (1970) noted that chipmunks often give alarm calls in the presence of humans, so it is possible that the presence of a human observer may have affected their vigilance behavior. If their vigilance behavior was already elevated due to observer presence, control vigilance rates might have been too high to detect a significant difference between control and noise vigilance levels, although the vigilance rate during noise was slightly higher. Additionally, the chipmunks may not have exhibited a change in vigilance behavior during the traffic noise because it was of a similar frequency as wind noise. Since wind is a noise that the chipmunks are likely adapted to, they may not have felt the need to be more vigilant. Although noise has been shown to increase vigilance in birds (Quinn et al. 2006), it has not been documented often in mammals, and it is possible their responses to noise are different than those of birds. Certainly, future research in this area would be interesting and useful.

The alarm call treatment resulted in a significantly higher vigilance rate than all the other treatments. This has been illustrated in the past by numerous studies (Dunford 1970, Weary and Kramer 1995, Baack and Switzer 2000). The magnitude of the effect on vigilance, however, is privy to many factors, such as rate, amplitude, and distance (Weary and Kramer 1995), which were not explored or quantified in this experiment. The rate of the alarm call has been shown to communicate variation in predation risk (Blumstein and Armitage 1997) and therefore result in different vigilance responses. In addition, Leger et al. (1979) found that California ground squirrels showed a greater change in vigilance behavior in response to louder calls. Harris et al. (1983) reported that Columbia ground squirrels showed a greater response to alarm calls originating from a close speaker than a distance one. Future research in this area should take these factors into consideration when measuring vigilance responses to alarm calls.

There are many factors that can have an effect on the vigilance behavior of an organism, and although they were well controlled in this study, they should be considered in future experiments. Individuals with a poor body condition will tend to be less vigilant, as food intake is their priority (Bachman 1993). The profitability of the food source may also be a factor. If the food quality is good, an individual may tend to be less vigilant because they are focused on acquired the nutritionally rich food (Wood 1993). In this study, food profitability may have played a role since the sunflower seeds are such a high quality food. Wood (1993) suggests that this would tend to reduce vigilance responses. Predator abundance in a given area may also be a factor, as a high level of previous exposure to predators could cause an increase in vigilance. Habitat type also influences vigilance behavior. Carey and Moore (1986) and Bowers et al. (1993) suggest that individuals would tend to spend less time and be more vigilant when foraging in open (versus closed canopy) areas. All of the sites in our experiment were under closed canopy, and there seemed to be minimal variance in the both the habitat structure and distance to refuges that may have played roles in the vigilance behaviors recorded. In this study, sites and treatments were randomized so as to minimize the influence of these factors.

The factor that may have played the largest role in affecting vigilance in this study is the presence of other chipmunks. Some of the sites used to run trials in this study were home to numerous chipmunks. During trials, there was sometimes more than one chipmunk foraging, and this certainly could have affected their vigilance behavior. Giraldeau and Kramer (1994) suggest that vigilance will increase in the presence of competitors, and in my opinion, this was true in this experiment. The food piles were often competed over, and antagonistic behavior was common. When a chipmunk was foraging and another approached the food pile, they tended to become alert, sometimes for long periods of time. Clearly, this increase in vigilance could have skewed the results from some sites. Future studies should attempt to control for competition by trapping and testing one chipmunk at a time.

Intraspecific competition also might have had an impact on residence time. Ydenberg et al. (1986) predicted that the presence of competitors would increase residence time due to a corresponding increase in vigilance behavior. Even without competition as a factor, there are currently two opposing findings in the literature as to the effect of alarm calls on residence time. Burger et al. (1991) suggest that residence time should be greater after alarm calls, not because of competitors, but because the individual is using that extra time to assess the risk of predation and find an escape route. Bowers and Ellis (1993) suggest otherwise, stating that residence time should be less after the alarm call in order to minimize the time spent exposed to predation. This study did not find support for either finding, as there was no significant effect of treatment on post-sound residence times. It should be noted that some of the trials had to be thrown out due to the absence of a return trip to the pile. Therefore, more replication may reveal a more meaningful relationship between treatment and residence time.

In conclusion, the results of this study suggest that anthropogenic noise does indeed have the potential to mask aspects of chipmunk communication, especially the reception of alarm calls. This is the first study to find that traffic noise has the potential to mask alarm calls, affecting the ability of the recipient chipmunk to detect predators. Clearly, properly receiving an alarm call may mean the difference between life and death for an individual, and with increasing urbanization and human expansion, communication between all kinds of organisms may be compromised. This could be extremely damaging to a population already in distress due to habitat fragmentation, pollution, or some other environmental factor. Future research could examine the masking potential of different types of anthropogenic noise, as well as the other type of communication (besides alarm calls) that are being compromised. Noise pollution should be a consideration when conserving or managing at risk populations, especially those exposed to considerable environmental noise. Limiting the construction of roads through nationally protected areas, the boat traffic load of coastal areas, and the number of people allowed on hiking trails in National Parks could all help alleviate noise pollution and protect the organisms that may be at risk of experiencing its negative effects.

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Figures.

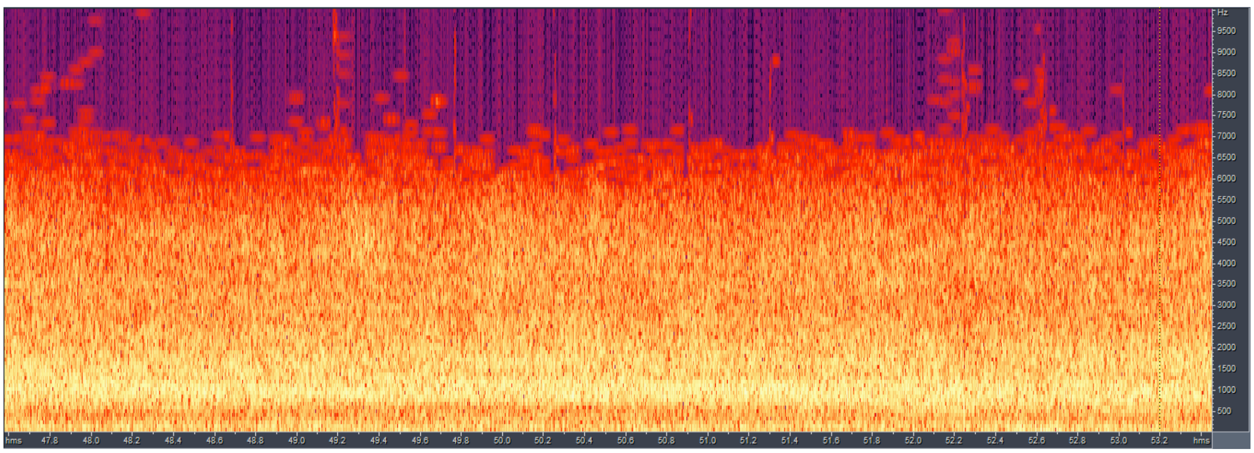

Figure 1. Example of spectrogram of traffic noise used for noise and alarm call plus noise treatments.

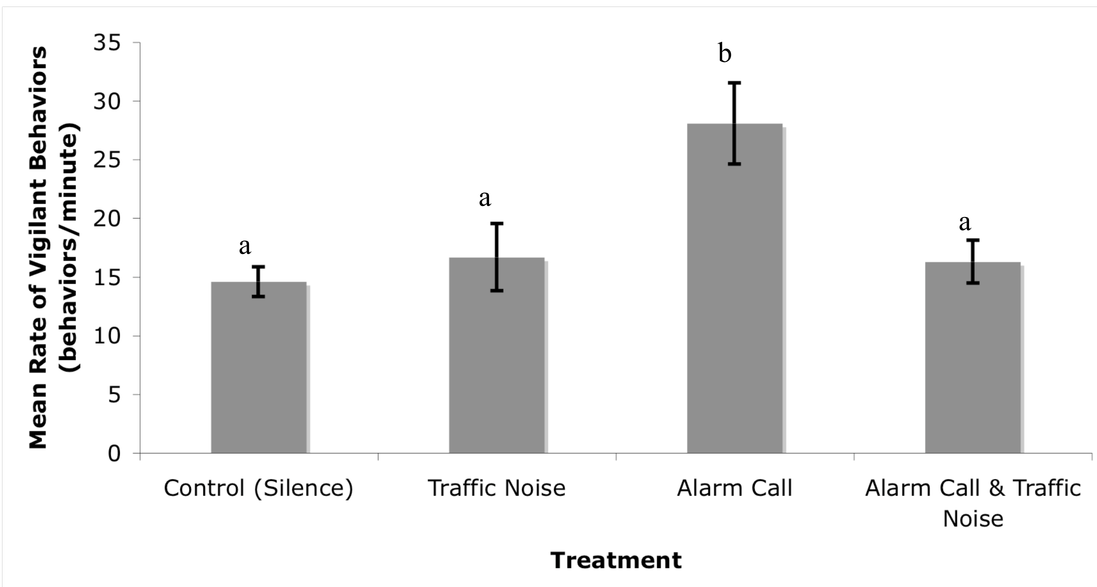

Figure 2. *Mean Vigilance Rate of Chipmunks for Four Sounds Treatments.* The mean rates of vigilance behavior for the four treatments (control silence, traffic noise, alarm calls, and alarm calls plus traffic noise) were compared with a one-way Analysis of Variance (ANOVA). Treatment was shown to have a significant effect on vigilance rates ($F_{0.05,3,66}=7.78$, $p=0.00016$), and a Tukey's Honestly Significant Difference Test revealed that the rate of vigilant behaviors for the alarm calls treatment was significantly higher than that of the control ($p<0.001$), noise ($p=0.015$), and alarm plus noise ($p=0.011$) treatments, which were all statistically equivalent. Different letters denote statistically significant differences.

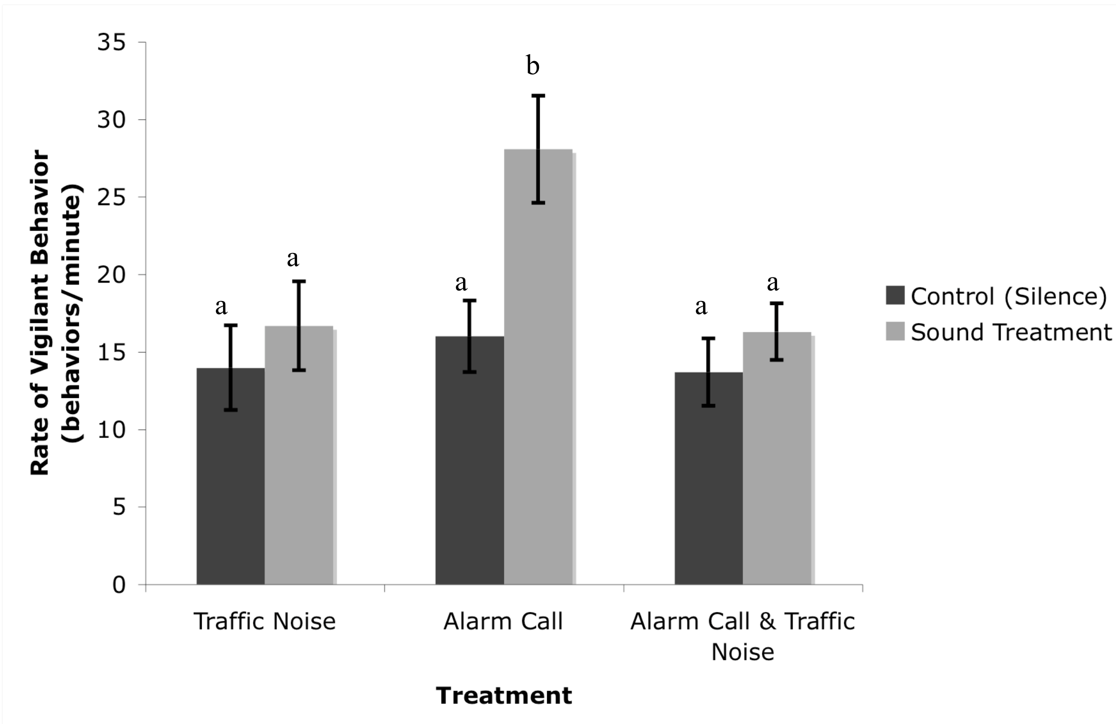

Figure 3. *Before and After Comparison of Mean and Control Vigilance Rates.* Paired t-tests were performed for each control vigilance rate and its corresponding treatment vigilance rate (before and after for each individual tested). There was no difference between before and after vigilance rates for the noise ($t_{0.05,9}$=-1.03, p=0.33) and alarm call plus noise ($t_{0.05,9}$=-1.18, p=0.27) treatments. There was a statistically significant difference between the before and after vigilance rates for the alarm call treatment ($t_{0.05,12}$=-3.21, p=0.007). Different letters denote statistically significant differences.

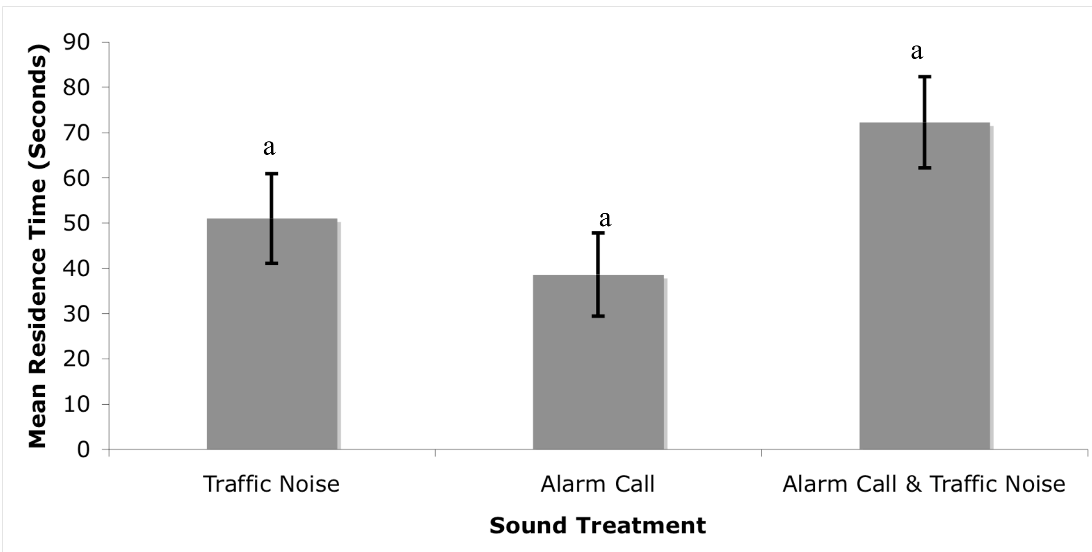

Figure 4. *Mean Residence Time During Return Trip to Food Pile.* There was no significant effect of treatment on residence time during the second visit to the food pile ($F_{0.05,2,22}$=2.69, p=0.09). Different letters denote statistically significant differences.

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