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How Urban-Tolerant Are They? Testing Prey–Capture Behavior of Introduced Jorō Spiders (*Trichonephila clavata*) Next to Busy Roads

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Abstract: An invasive orb-weaving spider from east Asia is now spreading through the southeastern United States; *Trichonephila clavata* (the "jorō spider") makes large, imposing webs seemingly everywhere, including in urban landscapes, and even next to busy roads. However, areas near roads come with frequent disturbances, including auditory and vibrational, which for many animals, leads to physiological or behavioral changes. Here we tested if varying levels of road traffic affect the prey–capture behavior of jorō spiders in northeast Georgia. We visited roadsides that ranged in traffic density and exposed nearby jorō spiders to a simulated prey (a tuning fork at 128 hz frequency, touched to the web), and recorded whether or not the spider attacked it. Out of 357 total trials across 20 different roads, jorō spiders attacked the simulated prey 59% of the time, but at the local scale, there was high variability in this rate; at some roadsides, over 80% of the spiders attacked, while at others, less than 30% did. When all roads were considered collectively, there was a small but significant (negative) correlation between daily road traffic and spider attack rates. Put another way, spiders near moderate- to heavy-traffic roads were slightly less likely to attack than those near low-traffic roads (51% vs. 65%). Jorō spiders appear to be able to live near roads, but this does come with a cost in terms of prey capture. However, spiders near busier roads did not weigh less than those in other sites, suggesting they may be able to compensate for the disturbance. These findings add to the accumulating evidence around this species that points to its ability to exist in human-dominated landscapes, which will likely aid its spread in the introduced range.

Keywords: *Trichonephila clavata*; jorō spider; urbanization; roads; disturbance

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1. Introduction

Urbanization has a wide range of impacts on wildlife, including altering disease prevalence [1], reducing population abundance [2], reducing body size [3], and changing the behavior of individuals [4]. In particular, the ubiquitous noise from urbanization can affect wildlife as well, by interfering with communication [5], altering animal stress hormone levels [6], or by changing foraging behavior (reviewed in [7]).

One feature of urbanization that deserves further attention is the role of roadways, and especially their impact on the myriad of arthropods that reside near them. While it is very clear that vehicle mortality is a major factor impacting insect abundance [8–11], more study is needed to fully understand the range of possible sublethal impacts of roads on arthropods [12]. Roadside landscapes are awash with noise, air pollution, and repeated physical disturbance from passing vehicles. Prior work with butterflies has shown how the noise from traffic can lead to bouts of physiological stress in caterpillars [13]. Excess sodium from roadsalt application has implications for caterpillars developing near busy roads [14]. Another study found vehicle traffic noise led at least one species of cricket to modify its auditory signaling [15]. For animals that rely on auditory or vibrational cues for hunting, this constant disturbance could interfere with their ability to sense prey (reviewed in [12,16]). These disturbances would be especially pronounced in areas immediately adjacent to very busy roads.

In the southeastern United States, a non-native spider from eastern Asia has become established; the "jorō spider", *Trichonephila clavata* L. Koch, 1878, was first discovered around 2013 in northern Georgia [17] and has since expanded its range to neighboring states and beyond [18]. Based on measurements of its physiology, and climate suitability in its native range, jorō spiders are expected to eventually expand their introduced range to most of the eastern United States and possibly even into Canada [19,20]. One of the reasons for their rapid and successful spread may involve their seeming tolerance for urban landscapes. Our lab is in the heart of this introduced range in Georgia, and we have observed their webs both within forested habitats, but also in the middle of cities. In fact, research on other closely related spiders also suggests they too have unique tolerances of urban landscapes, including *T. plumipes* in Australia [21] and *T. clavipes* in Florida [22]. A related species, *Nephila pilipes*, also seems tolerant of urban landscapes, since it has been found across all human-dominated landscapes in the Philippines [23].

Surprisingly, the jorō spider's tolerance for human-dominated landscapes appears not to be because these spiders are inherently bold or aggressive, rather the opposite seems to be true, based on recent work in our lab [24]. The current project is intended to add further insights into the "personality" of this newly invasive species in the United States, this time by focusing on its proclivity to build webs next to (or sometimes over) busy roadways. As pointed out above, such areas are awash with noise, vibration, and air disturbance, as Supplemental Video S1 visualizes, which shows a jorō spider on a web next to an extremely busy road. So, in this project we sought to determine if the level of traffic on roads affects one of their crucial and everyday behaviors, the prey–capture behavior, of these spiders. We had two competing ideas or expectations going into this project. First, since busier roads would expose nearby spiders to excessive noise and vibration (for the 3–4 months of their growth), this could lead to de-sensitization of their sensory perception, or otherwise hinder the normal prey–capture behavior. Alternatively, perhaps the road noise would change the spider aggression levels through some physiological alteration caused by the noise, which may increase their willingness to attack prey. Either way, we went into this project expecting that road traffic would impact the spider's behavior in some manner.

We conducted this project by visiting roads of varying traffic density in northeast Georgia (the center of the outbreak range, and where jorō spider webs are extremely abundant in the fall months), and we exposed any spiders next to the roads to a simulated prey item to evaluate their reaction. The "prey" was a tuning fork that was touched to the web, and which simulates the vibrations of insect wings [25]. By using the same fork (frequency 128 hz) across all spider webs and habitats, we could then determine if the spiders near busy or less-busy roads were more or less likely to attack this same prey item, thereby giving us insights into how the traffic level impacts their willingness or ability to engage in everyday behavior, catching prey.

2. Methods

2.1. Road Selection

Spiders were assessed across a total of 20 different roads for this project, within the counties of Clarke, Oconee, and Madison, GA, each of which are well within the introduced range of *T. clavata* [17,18], and where these spiders are numerous each fall. The field portion of the project was conducted during the month of September 2023. Roads were selected based on ease of access and traffic density (which we determined prior to visiting them). Traffic density was determined by viewing online records of vehicle density from the Georgia Dept. of Transportation (https://www.dot.ga.gov/GDOT/Pages/RoadTrafficData.aspx accessed on 1 September 2023) we specifically chose roads that spanned a wide range of traffic densities, from fewer than 30 cars per day, to over 10,000 cars per day (see Table 1). Roads were located in a range of landscapes, from rural to urban, but in all cases, there was at least a margin of shrubbery or trees on the side of the road, and where we could locate jorō spider webs (see Figure 1). Note that we did not specifically examine the prey availability across these different roads, though we did collect data on the mass of the spiders at each site, which can inform about prey availability.

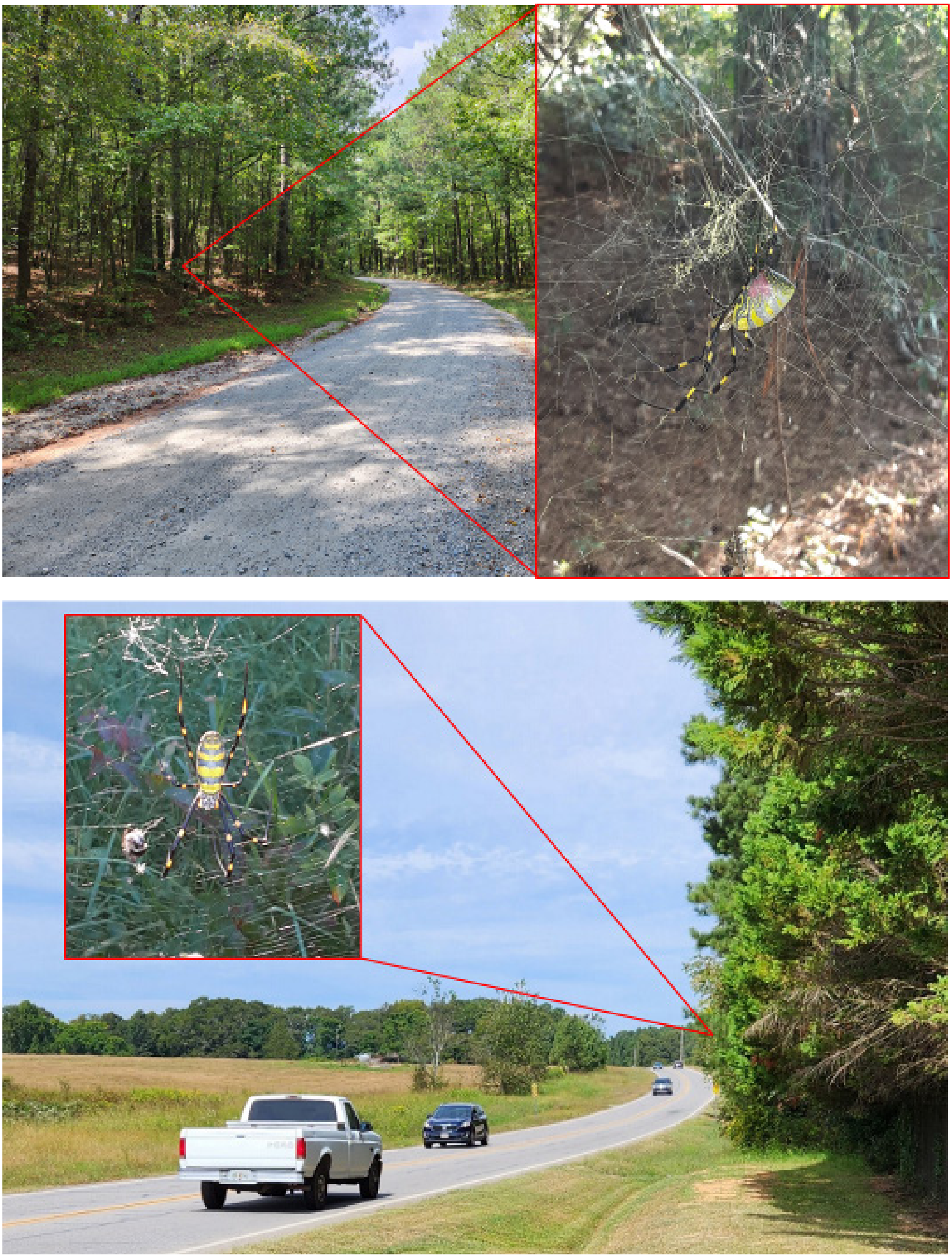

Figure 1. Photos of two roads included in our study: one (**top**) with very low traffic density and one (**bottom**) with higher traffic density. Positions of jorō spider webs in each photo are shown (inset images).

Table 1. Summary of data collected in this study, including locations of trials, numbers of jorō spiders displaying each behavior, and average spider mass at each location. Traffic density data (average number of cars per day) obtained from Georgia Dept. of Transportation.

Road Name	County	Traffic Density	Density Category	# Attack	# Nothing	# Retreat	Total Trials	% Attack	Ave. Spider Mass (g)
Marshall Store Rd.	Oconee	20	1	17	1	0	18	94.4	0.33
Rose Creek Dr.	Oconee	25	1	13	5	0	18	72.2	0.55
Freeman Creek Rd.	Oconee	30	1	12	1	2	15	80.0	0.37
JT Elder Rd.	Oconee	30	1	5	11	1	17	29.4	0.34
Hardigree Bell Rd.	Oconee	50	1	12	4	1	17	70.6	0.23
Old Farmington Rd.	Oconee	70	1	5	7	3	15	33.3	0.66
Old Ila Rd.	Madison	90	1	11	6	2	19	57.9	0.40
Antioch Church Rd.	Oconee	250	2	16	3	1	20	80.0	0.42
Mayne Mill Rd.	Oconee	270	2	14	4	2	20	70.0	0.40
Oliver Bridge Rd.	Oconee	380	2	9	7	2	18	50.0	0.53
Wesley Chapel Rd.	Madison	620	2	14	1	2	17	82.4	0.36
Colham Ferry Rd.	Oconee	2080	3	14	11	1	26	53.8	0.64
South Main St. Watkinsville	Oconee	4040	3	9	7	2	18	50.0	0.35
Greensboro Hwy.	Oconee	4910	3	11	6	2	19	57.9	0.58
E Whitehall Rd.	Clarke	6060	3	7	11	6	24	29.2	0.38
S. Milledge Rd.	Clarke	10,200	4	2	2	3	7	28.6	0.22
US 441	Oconee	10,200	4	13	7	1	21	61.9	0.52
Mitchell Bridge Rd.	Clarke	10,500	4	6	4	2	12	50.0	0.45
Experiment Stn Rd.	Oconee	12,700	4	11	5	0	16	68.8	0.50
Athens Perimeter/10 Loop	Clarke	45,100	4	12	6	4	22	54.5	0.28
Grand Total				213	109	37	359	59.3	0.43

2.2. Stimulus Procedure

At each road location, we randomly selected jorō spider webs for testing. We ensured that any web tested contained a single female, was not connected to others, and that it was within 20 m of the road margin. We also ensured that each female tested was sitting in the center of her web in a hunting position. By necessity, only webs that could be reached with our outstretched arm were included, so that all webs tested were less than 3 m off the ground. At each web, one of us carefully moved close to the web without visually displacing the spider. If the spider did retreat or react in any way, we aborted that trial and moved to a different web. The observer carried a tuning fork (frequency: 128 hz), which was the same fork used throughout the entire study. From preliminary trials with varying forks of different frequencies, we determined that this frequency elicits attacks from jorō spiders about 50% of the time (Davis, unpubl. data), which we felt was an optimal rate for this project; we wished to observe whether the spiders would attack or not in all trials. When in position, the observer struck the tuning fork and touched it to the spider web at a place roughly equidistant from the center and margin. We then recorded the reaction of the spider, which was usually observed immediately. Spiders that attacked the tuning fork would either lunge and directly grab it, as in Figure 2, or would lunge toward it, but refrain from physical contact. We considered both to be attacks. Spiders that did not attack would either remain positioned in the center of the web or would actually retreat off the web. We recorded both of these "non-attack" behaviors, though our statistical analyses focused only on the ratio of attacks versus non-attacks (below). If any spider's behavior was at all ambiguous (less than 5% of trials), we did not record it and moved on to a new web. Once the behavior was recorded, we collected the spider in a 50 mL falcon tube and weighed it on a portable electronic balance. The spiders were each released back to the same locations after the trials. A demonstration video of the procedure, and a spider attacking the tuning fork, is provided online: https://www.youtube.com/watch?v=-gi5JV7DtE0 accessed on 1 September 2023.

Figure 2. Photos of the prey simulation trials that elicited spider behavior. We used a tuning fork (128 hz) to simulate a buzzing insect hitting the web [25]. The fork was struck first to activate, then the handler gently touched it to the spider web at a point midway between the center and perimeter. Spiders can immediately sense the vibrations and either choose to attack the "prey" (right image) or not.

2.3. Data Analysis

After the field trials had been completed, we had a dataset that included n = 359 behavioral trials from 20 different roads, with each road varying in traffic density (see Table 1). For ease of analyses, we pooled the two non-attack behaviors together, so that the outcome of any trial was either attack/non-attack. We used two different approaches to statistically examine these data and to look for evidence of traffic effects on spider behavior, with the approaches differing in how traffic density was treated. First, we treated each road (i.e., traffic density, n = 20) as a continuous predictor (log-transformed) and used logistic regression to determine if the traffic density or spider size (mass) predicted the outcome of the stimulus trials (attack/non-attack) in a linear fashion. Second, we binned the roads into 4 "categories" of traffic density and pooled data from all trials into each of the 4 categories (Table 2). These categories reflected four different levels of traffic density (see Table 1), which we termed "very low traffic", "light traffic", "moderate traffic", and "heavy traffic" for illustrative purposes. Then, we used logistic regression to determine if the traffic density category (this time as a categorical factor) predicted the outcome of the spider trials (attack/non-attack). This approach tested if different levels of traffic density affected spider behavior, though not necessarily in a linear fashion. Spider mass was also included as a continuous covariate. Statistical analyses were conducted using the Statistica 13.3 software package.

Table 2. Summary of jorō spider behaviors when roads were grouped into 4 levels of traffic density (see Table 1 for density groups). Statistically similar groups (based on chi-square tests of attack/non-attack frequencies) are indicated with superscript letters in first column. The red "no attack" column is a sum of both non-attack categories (nothing + retreat).

Traffic Density	Attack	Nothing	Retreat	No Attack	Grand Total	% Attack
1—Very little [a]	75	35	9	**44**	119	63.0
2—Light [a]	53	15	7	**22**	75	70.7
3—Moderate [b]	41	35	11	**46**	87	47.1
4—Heavy [b]	44	24	10	**34**	78	56.4
Grand Total	213	109	37	**146**	359	

3. Results

Across all 359 trials, jorō spiders attacked the simulated prey 59% of the time (Table 1), though we noted a very wide range in this attack rate across the different roadside locations; in some areas, most jorō spiders (80–94.4%) attacked the prey, while in others, only one third of spiders attacked. The size of the spiders did not significantly affect their likelihood of attacking in either model we used, though in one model, the effect was nearly significant (Table 3). Moreover, it can be seen that the average size of the spiders that did attack the prey was slightly larger than those in the non-attack categories (Figure 3). In the model that considered (log-transformed) traffic density as a continuous predictor, there was a significant effect of traffic on the likelihood of spiders attacking the prey ($p = 0.0180$), meaning there was a (slight) linear trend between increasing traffic and spider behavior, such that spiders near high-traffic roads tended to be less likely to attack (Figure 4). Moreover, when traffic density was considered as a categorical variable (very little, light, moderate, and heavy), this effect was also significant ($p = 0.0187$) and showed a similar pattern. Chi-square tests indicated the attack/non-attack frequencies in the two low-traffic groups were not different from each other, and frequencies in the two higher-density groups were statistically similar, but the two low-density groups each differed from the two high-density groups (see Table 2). Given this finding, and as a final test, we pooled the trial data from both low-traffic groups and compared these to the pooled high-traffic groups; the frequencies of attack/non-attack differed (Chi-square test, $\chi 2 = 7.73$, df = 1, $p = 0.0054$), though the magnitude of this difference was not large. Jorō spiders attacked the simulated prey 65% of the time if they were next to low-traffic roads, but only 51% of the time if they were next to moderate- to high-traffic roads.

Table 3. Results of logistic regression models that assessed how prey capture of jorō spiders is affected by varying levels of road traffic. Two different models were used, which differed in the way road traffic was treated. In the first case, road traffic was a continuous covariate (log-transformed), while in the second model, we pooled the roads into 4 categories of traffic density. In each model, whether or not the spider attacked the simulated prey was the response, and spider mass was a continuous covariate in each model.

Predictor	Estimate	SE	Wald	Lower 95% CL	Upper 95% CL	*p*
Spider Mass	0.688	0.442	2.429	−1.177	1.554	0.1191
Traffic Volume	−0.106	0.044	5.592	−0.193	−0.018	0.0180
Predictor	**Estimate**	**SE**	**Wald**	**Lower 95% CL**	**Upper 95% CL**	***p***
Spider Mass	−0.828	0.450	3.391	−1.709	0.053	0.0656
Volume Category	−0.498	0.212	5.534	−0.914	−0.083	0.0187

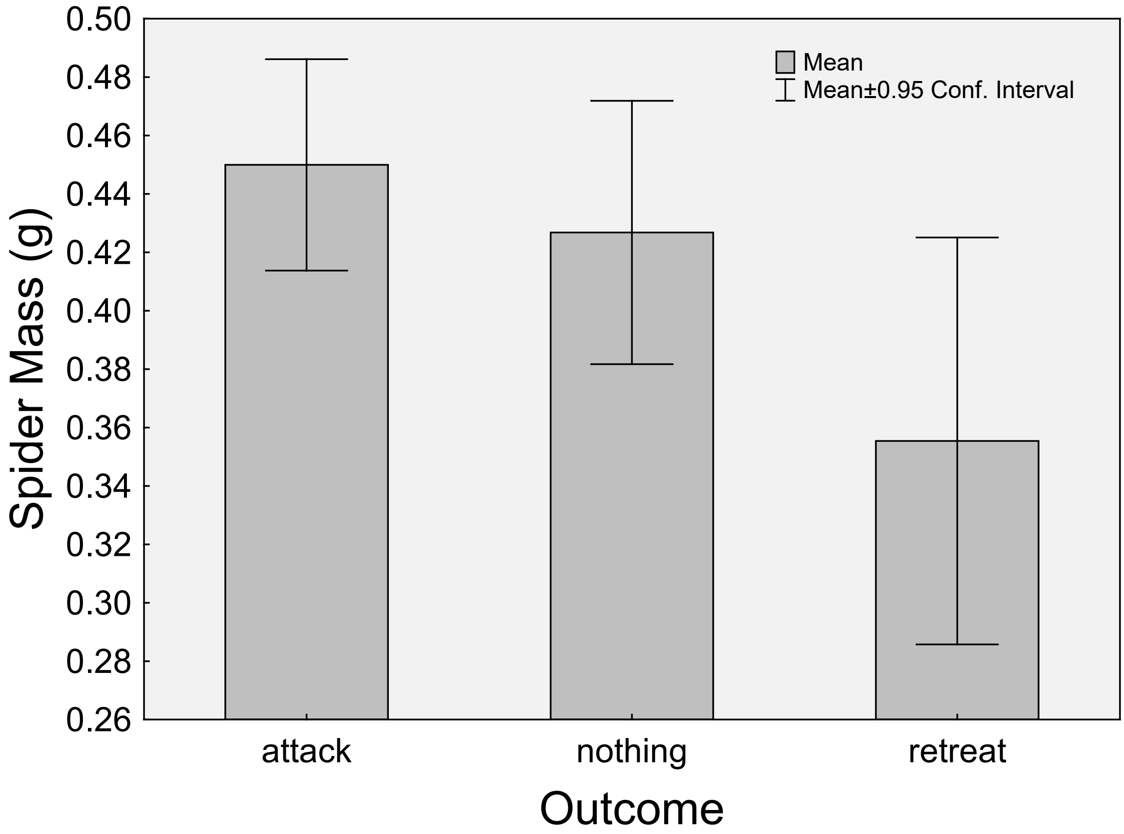

Figure 3. Effect of spider size (mass) on their attack behavior. Those that did attack the simulated prey tended to be larger, though this pattern was not statistically significant.

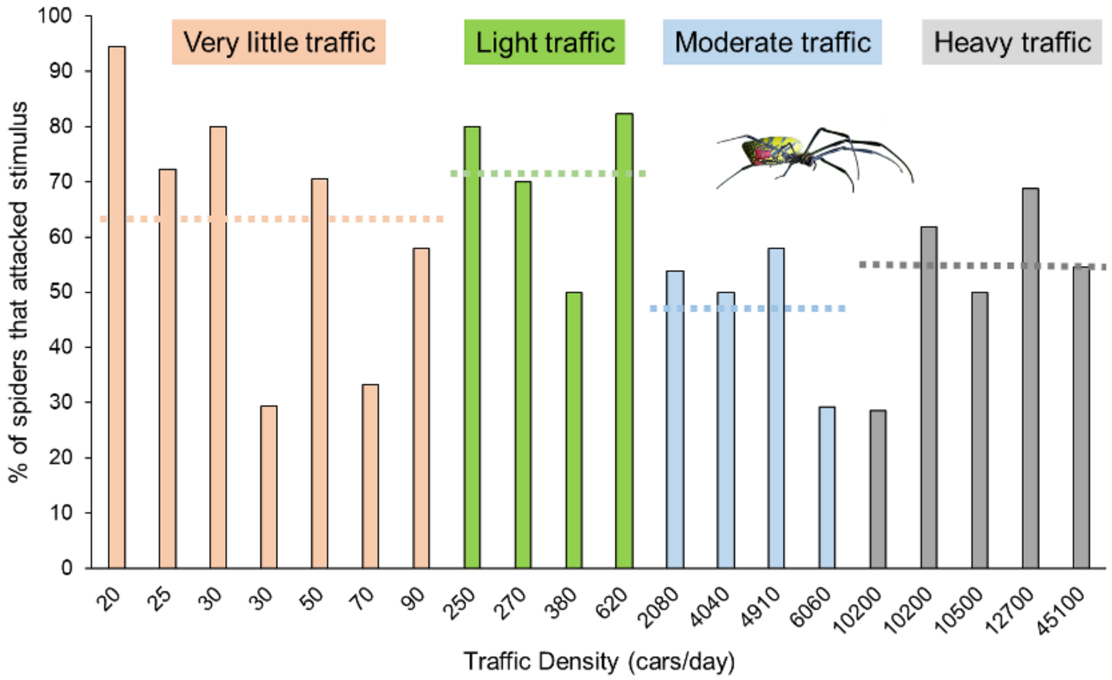

Figure 4. Attack rates of spiders across all roads surveyed in this study (n = 20), which are ordered on the *x* axis by their traffic density. Bars are color-coded to show groupings of different traffic densities. Dotted horizontal lines show the % of spiders that attacked within each traffic group.

4. Discussion

Jorō spiders are rapidly expanding their new territory throughout the southeastern United States and beyond [20]. Since our research lab is located in the heart of this introduced range in northeast Georgia, we have personally observed how this spider appears to be especially suited for living alongside humans, and for taking advantage of anthropogenically altered landscapes, a trait which it seems to share with others of this genus [21,22]. As such, we have observed active jorō spider webs on a wide range of human structures in cities, including on telephone poles, streetlamps, and even traffic signals next to busy roads (pers. obs.). These observations are what stimulated the current study, where we asked if the proximity to roads and their associated vehicle traffic comes with a cost to the spiders, in terms of their ability to carry out their normal prey–capturing activities. We reasoned that since busier roads would expose spiders to a constant drum of noise, and more importantly, vibration, perhaps this could interfere with sensing prey on their webs [12]. Or, perhaps the constant noise would act as a stressor to the spiders, as it does with other arthropods [13], which may alter their aggression levels [26] and make them more (or less) likely to chase certain prey types. Either way, we were expecting to see an effect of traffic density on the spider prey–capturing behavior. We did find a small effect, whereby spiders living next to moderate- to heavy-traffic roads showed a slightly reduced rate of attack compared to those living next to low-traffic roads (65% vs. 51%). However, this tendency was only realized when combining multiple locations and with large sample sizes. At the individual road level, we noted an extremely wide variation in prey–capture behavior; in some areas (roadsides), nearly every spider attacked the simulated prey, while in others, only 30% of them attacked the same prey stimulus (see Table 1 and Figure 4).

The above conclusion suggests that jorō spiders have a degree of tolerance to the noise and stress from anthropogenic disturbance (even though it does come with a cost), which makes sense, given their proclivity to build webs near roads to begin with. This is a trait that is not shared with other orb-weaving spiders outside of the genus; in fact, other orb-weaving species appear to be less abundant near busy roads [27], though it is not clear if this is because the traffic simply kills the spiders during the juvenal ballooning stage, or if the spiders simply avoid high-traffic areas. However, other research on a ground-dwelling, non-orb-weaving species has shown clear negative effects of busy roads on spider abundance, which was attributed to avoidance of vibrational disturbance [28]. In our study, we did not examine if jorō spiders were more or less abundant near roads, though we do note that the majority of roads we examined (even those with high traffic) had an abundance of webs to choose from, and we were only limited by the ease of access to them.

While the results from our trials of prey–capture rates indicate only a minor impact from traffic, the nature of this project prevents us from ascertaining the cause of this change. However, future work could be performed that could target the two most likely explanations, which we consider to be 1) that the constant heavy traffic exposes spiders to excess noise and vibration, which interferes with their ability to sense vibrational cues in their webs, and 2) that the traffic disturbance leads to physiological changes in the spiders (stress) which manifests into behavioral alterations [26]. The latter scenario could be tested using an approach used before in our lab to evaluate how road noise affects monarch butterflies, whereby naïve animals are exposed to simulated road noise, and their heart rates evaluated before and after exposure [13]. In addition, our lab has also demonstrated how heart rates of jorō spiders can be measured non-destructively in other work [19]. Thus, addressing this question seems tenable.

We used a single tuning fork with one frequency (128 hz) across all study sites so that we could evaluate how jorō spiders react to the same stimulus. Work with the related *T. clavipes* showed that different types of prey elicit different frequencies on a spider web [29], with smaller prey generally generating higher frequencies, though with some variation. The frequency we chose appears to be in the middle of these reported ranges [29], which matches our initial exploratory trials; we had initially chosen this frequency because it appeared to elicit attacks from about 50% of jorō spiders (Davis, unpubl. data). Throughout this study, we have assumed that there would be no intrinsic, individual variation in "willingness" to attack a prey item with this frequency, and that any variation we did see would be related to the influence of the traffic. However, it is possible that individual spiders have varying "preferences" for prey types, which could confound our results, though to our knowledge, this idea has not been explored in this or related species.

Regardless of how the busy roads are affecting jorō spiders (by making them less able to sense the prey or less willing to attack), one could interpret the reduction in attack rates near these busy roads as evidence that there could be differing impacts on prey populations compared to areas near less busy roads. Put another way, it is possible that jorō spiders may actually consume (slightly) fewer flying insects near busier roads, because of their reduced attack rates. On the other hand, we noted that the average weight of jorō spiders did not diminish with increasing traffic density (though it did vary between roads; one-way ANOVA, $F_{17,341} = 5.13$, $p < 0.0001$, Table 1, Figure S1), suggesting that the spiders near busier roads are not necessarily suffering from a lack of prey. Possibly, the spiders can compensate for the reduced attacks by simply targeting larger prey items (i.e., by being more selective). Indeed, there is evidence that the majority of energy from a spider's diet comes from only a small number of large insects [30]. This is a question that could be addressed in future studies.

The fact that the spiders near busier roads were not underweight is also important for informing about the availability of prey at such sites, though indirectly. While we did not set out to evaluate the insect prey composition at the various roadside areas, this is a factor to consider when interpreting the differences in prey attack rates. As pointed out above, the mass of jorō spiders varied between roads, though with no obvious pattern (see also Figure S1). This does not rule out the possibility that the prey composition or availability differed between sites (i.e., between busy roads compared to less busy roads), though we consider this unlikely. Further, a separate study of the jorō spider diet has recently been published, where the stomach contents of spiders were examined from varying sites across Georgia and South Carolina [31]. The most common arthropod Orders found included Coleoptera, Diptera, Hemiptera, and Hymenoptera, though there was no indication that the diet composition varied from site to site.

The findings from this study add to a growing consensus about the future range spread of this introduced spider in North America, which is predicted to be large (i.e., continental) based on its physiology [19] and climate suitability [20]. Roadsides represent one of the most anthropogenically disturbed landscapes possible for an arthropod, yet jorō spiders appeared to still be capable of living in these areas. This says a lot about their tolerance for other human-dominated landscapes that also have constant auditory, visual, and other sensory stressors, such as areas within cities. In fact, these data could be used to argue that the jorō spider spread will likely not be hindered by landscapes dominated by human disturbance. So, given that such landscapes dominate the predicted range of this species, this paper adds even more evidence showing how this species will readily colonize this new territory.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/arthropoda2010004/s1, Figure S1: Graph of average jorō spider mass across the 20 different roads in this study. The roads are ordered by their traffic density (cars/day). There was significant variation in spider mass across roads (one-way ANOVA, F17,341 = 5.13, $p < 0.0001$), though there was no obvious trend with respect to traffic density.; Video S1: Jorō spider on a web next to a busy road.

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