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Do spiders (Araneae) feed on rose leafhopper (*Edwardsiana rosae*; Auchenorrhyncha: Cicadellidae) pests of apple trees?

Joanna WISNIEWSKA and Ronald J. PROKOPY

Department of Entomology, Fernald Hall, University of Massachusetts, Amherst, MA 01003, USA

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Abstract. We evaluated the ability of Philodromidae and Salticidae, the two spider families most commonly found in commercial apple orchards of Massachusetts, to feed on rose leafhoppers, *Edwardsiana rosae* (L.), important pests of apple foliage. We conducted two different laboratory feeding tests: a leaf test (in which individual spiders were exposed to leafhopper nymphs and adults on single leaves within paper cups for 72 h) and a branch test (similar to the leaf test but foliage on netted branches was used). Controls consisted of cups with leaves or netted branches and leafhoppers but without spiders. In both tests, we found more dead leafhoppers when spiders were present, with most leafhoppers killed during the first 24 h of confinement. In both tests, the two spider families did not differ significantly with respect to the numbers of leafhoppers killed. Smaller spiders consumed more leafhoppers than larger ones in the leaf test, but in the branch test consumption was similar among size groups. Our findings suggest that Salticidae and Philodromidae are capable of preying upon rose leafhoppers and that this capability may vary according to environmental conditions or other factors not tested in this study, such as the physiological state and/or species of spider.

INTRODUCTION

Studies of spider abundance and diets in agroecosystems suggest that spiders contribute to the suppression of insect pests in field crops and orchards by inflicting substantial density-independent mortality (Wise, 1993). In apple orchards, however, the extent to which spiders act as pest control agents has not yet been clearly elucidated.

For apple orchards in England, Chant (1956) concluded that certain spiders, especially small species and immature stages, feed readily on phytophagous orchard mites; larger species often confine their feeding to other orchard insects, notably winter moth larvae (*Operophtera bruceata* Hulst; Lepidoptera: Geometridae), apple suckers [*Psylla mali* (Schmidberger); Sternorrhyncha: Psyllidae], aphids, and predacious bugs. In an apple orchard in Australia, spiders of the families Theridiidae, Thomisidae, Clubionidae, Salticidae, and to a lesser extent Araneidae, comprised 78% of the predators present in the sampled orchard and fed readily on different life stages of prey, but especially on larvae of the light brown apple moth (*Epiphyas postvittana* Walker; Lepidoptera: Tortricidae) (MacLellan, 1973). Using numerical, serological, and forced feeding techniques, MacLellan (1973) showed that spiders, particularly a theridiid *Achaearanea veruculata* (Urquhart), supported for a short period of time by chrysopids and mirids, were able to suppress populations of the light brown apple moth to an equivalent of less than 1% of total eggs laid each season. In apple orchards in Israel, larval populations of *Spodoptera littoralis* (Boisduval) (Lepidoptera: Noctuidae) did not develop to damaging levels on apple trees on which spiders were permitted to forage freely. On those trees from which spiders were "eliminated" (by tapping the branches with a stick over a silken funnel, removing the spiders and returning all other arthropods to the trees), damage was significant (Mansour et al., 1980). In laboratory feeding tests, spiders (Philodromidae, Salticidae and Theridiidae) found in apple orchards of central Virginia in the USA readily consumed the most common foliar orchard pests, which were leafhoppers, aphids and thrips (McCaffrey & Horsburgh, 1980).

Rose leafhoppers, *Edwardsiana rosae* (L.), are important foliar pests of apple trees in commercial apple orchards of Massachusetts. They often are abundant in orchards from mid August through September. Spiders, particularly Salticidae and Philodromidae, are also most abundant in Massachusetts apple orchards during late summer, with Salticidae constituting 37% and Philodromidae 21% of the total spider fauna sampled at the time (Wisniewska & Prokopy, unpublished). On some occasions, we have observed immature stages of both Salticidae and Philodromidae feeding on rose leafhoppers in Massachusetts apple trees. In this study, we aimed to determine the extent to which selected members of these two spider families feed on rose leafhoppers under laboratory conditions of no choice and close confinement.

MATERIALS AND METHODS

We offered last instar rose leafhopper nymphs and adults as potential prey to the most abundant spider species collected in six Massachusetts commercial apple orchards managed under second-level IPM practices, where insecticides and fungicides were applied during the first part of the growing season but not after early June (Prokopy at al., 1994). Spiders tested were mostly immature and included members of the families Salticidae and Philodromidae. Adult salticids included five *Metaphidippus protervus* (Walckenaer) and one *Eris marginata* (Walckenaer). Adult philodromids included one *Philodromus cespitum* (Walckenaer) and two *Philodromus rufus* Walckenaer. We could not identify the immature spiders to species (no keys available). However, based on adult specimens identified in a previous study that involved collecting large numbers of spiders in the same orchards in 1993, 1994 and 1995 (Wisniewska, 1996), salticid species encountered in the orchards included *M. protervus*, *Metaphidippus galathea* (Walckenaer), and *E. marginata*. Philodromids consisted entirely of members of the genus *Philodromus* including *P. cespitum*, *P. imbecillus* Keyserling, *P. marxii* Keyserling, *P. placidus* Banks, *P. rufus*, *and P. vulgaris* Hentz. Both Salticidae and Philodromidae are hunting spiders; instead of using a web, they actively seek prey by touch or sight. Salticidae hunt strictly during daylight and rely mainly on their eyesight to catch prey (Nyffeler et al., 1994). Philodromidae are not visually oriented; instead, they depend mostly on olfactory and vibrational signals to find prey during both day and night. They move quickly through foliage, pursuing and pouncing on prey (Nyffeler et al., 1994; Hatley & Macmahon, 1980). We collected spiders by tapping tree branches with a rubber mallet over a cloth tray. We collected leafhopper nymphs by handpicking leaves that bore them. Many nymphs metamorphosed into adults during the course of study. We examined the ability of spiders to feed on the leafhopper nymphs and adults using two types of tests: the leaf test and the branch test.

Leaf test

For this test, conducted in the laboratory in August and September of 1993, we confined individual spiders with leafhoppers in waxed paper cups (10 cm tall × 8 cm wide), each with a transparent lid. Into each cup with a spider we inserted an apple leaf kept turgid by placing its stem in a cotton wick saturated with water. Twenty-four hours later we replaced the leaf with another which harbored three to four leafhopper nymphs and/or adults. Controls consisted of similar numbers of leafhoppers on leaves in cups without spiders. We tested a total of 46 Salticidae and 73 Philodromidae.

We inspected the cups every 24 h for 72 h. We examined the dead insects under an enlarging scope and compared their appearance to that of dead leafhoppers from the control cups. The leafhoppers killed by spiders appeared shriveled, which would indicate that spiders were feeding on them. For each 24-h period, we calculated the cumulative percentage of cups where we found dead leafhoppers to determine when most spiders consumed their first leafhoppers. We used χ^2 test to determine differences between treatments. To determine if spiders consumed increasing numbers of leafhoppers over time, for each 24-h period, we counted numbers of dead leafhoppers and calculated the cumulative percentage of available prey that died. We tested the effect of spider family, time spent in cups, and spider body length (three categories: small = body length 1.2–1.5 mm, medium = body length 1.6–2.5 mm, and large = body length 2.6–5.0 mm) on the percentage of leafhoppers that were dead in cups. Depending on the species of spider in question, these body length categories corresponded to specific instars which, unfortunately, could not be determined because we were not able to identify spiders to species (no keys are available to identify immature spiders and we were not able to find adult females with egg sacs so that appearance of different immature instars of a given species could be observed). We analyzed data using the repeated measures analysis option of the SAS general linear model procedure with Scheffe's comparison of means (SAS Institute Inc., SAS Circle; Box 8000; Cary, NC 27512, USA). We did not compare percentages of dead leafhopper nymphs versus dead leafhopper adults because many nymphs metamorphosed into adults during the course of study.

Branch test

For this test, which also was conducted in the laboratory in August and September of 1993, we examined spider feeding on leafhoppers confined on netted branches. We included 20 salticids and 28 philodromids that we starved for 24 h by holding them in paper cups containing apple leaves. We collected 25-cm-long foliated branches from unsprayed apple trees at the Horticultural Research Center in Belchertown, MA (each branch contained approximately 20 leaves). We transferred 12 leafhoppers (10 nymphs and 2 adults; one per each randomly selected leaf) onto each branch using a fine hair brush, tied fine netting around each branch, and placed the branch in a water bottle. To maintain the branches, we added fertilizer and trace amounts of Chlorox® bleach (which inhibits fungal growth) to the water. Controls consisted of leafhoppers on netted branches held in an identical manner but without spiders.

After 72 h, we counted numbers of dead leafhoppers within each net. After examining the dead leafhoppers under the enlarging scope, we again observed that many leafhoppers in nets containing spiders were shriveled, indicating that the spiders were not merely killing the insects but they were feeding upon them. We did not inspect netted branches before 72 h so as to allow the spiders to forage without disturbance. We compared mean numbers of dead leafhoppers per branch across the two spider families and three spider size categories using the SAS general linear model procedure with Scheffe's comparison of means (SAS Institute Inc., SAS Circle; Box 8000; Cary, NC 27512, USA). As in the leaf test, we did not compare percentages of dead leafhopper nymphs versus dead leafhopper adults because many nymphs metamorphosed into adults during the course of study.

RESULTS

Leaf test

For both salticids and philodromids, approximately 90% of all individual spiders fed on leafhoppers within the first 24 h; mortality of leafhoppers in control cups was significantly lower ($\chi^2 = 40.29$, $p < 0.001$) (Fig. 1A). After 48 or 72 h, however, neither of the spider families tested differed from the control in effect on leafhopper mortality ($\chi^2 = 0.70$, $p = 0.71$ for 48 h; $\chi^2 = 8.05$, $p = 0.08$ for 72 h).

In the first 24-h period, 95% of small, 90% of medium, but only 65% of large sized spiders fed on leafhoppers (Fig. 1B). During this time, significantly more cups contained dead leafhoppers than expected for small and medium but not for large sized spiders, and significantly fewer control cups contained dead leafhoppers than expected if leafhoppers in all cups were dying at the same rate ($\chi^2 = 44.86$, $p < 0.001$). In the remaining two time periods, the numbers of cups containing dead leafhoppers were not different between test groups (48 h: $\chi^2 = 1.77$, $p = 0.62$; 72 h: $\chi^2 = 5.04$, $p = 0.17$).

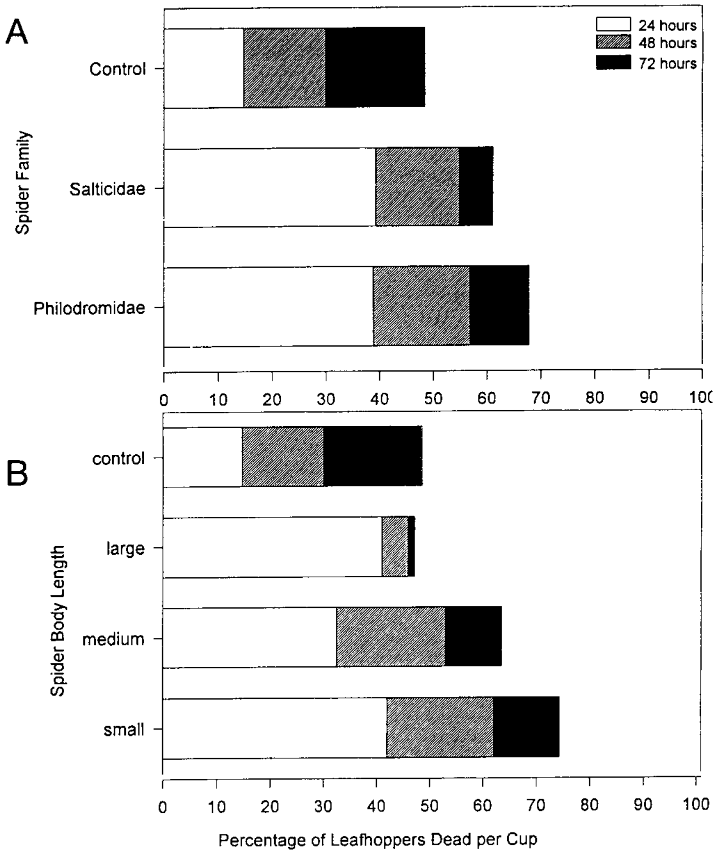

Fig. 1. Leaf Test. Cumulative percentages of cups with at least one dead leafhopper after 24, 48, and 72 h when spiders were grouped according to family (A) and body length categories (B). Total numbers of spiders tested were: 73 for Philodromidae, 46 for Salticidae (A), and 56 for small, 34 for medium, and 27 for large body lengths (B). There was one spider and 3–4 leafhoppers per cup. There were 38 controls that consisted of cups with leafhoppers but without spiders.

Cumulative percentages of leafhoppers dead per cup in control cups and in cups containing philodromid and salticid spiders are shown in Fig. 2A. According to a repeated measures ANOVA with independent variables of family (between subject effect) and time (within subject effect), the two spider families did not differ with respect to consumption of leafhoppers ($p = 0.52$). On the other hand, there was a significant effect of time on leafhopper mortality ($p < 0.001$). Significantly more leafhoppers were dead after 24 and 48 h in cups containing salticids and philodromids than in control cups without spiders, but after 72 h, only cups with philodromids showed significantly greater leafhopper mortality than control cups (Scheffe's comparison of means; $\alpha = 0.05$).

Cumulative percentages of leafhoppers dead per cup in control cups and in cups containing spiders with small, medium and large body lengths are shown in Fig. 2B.

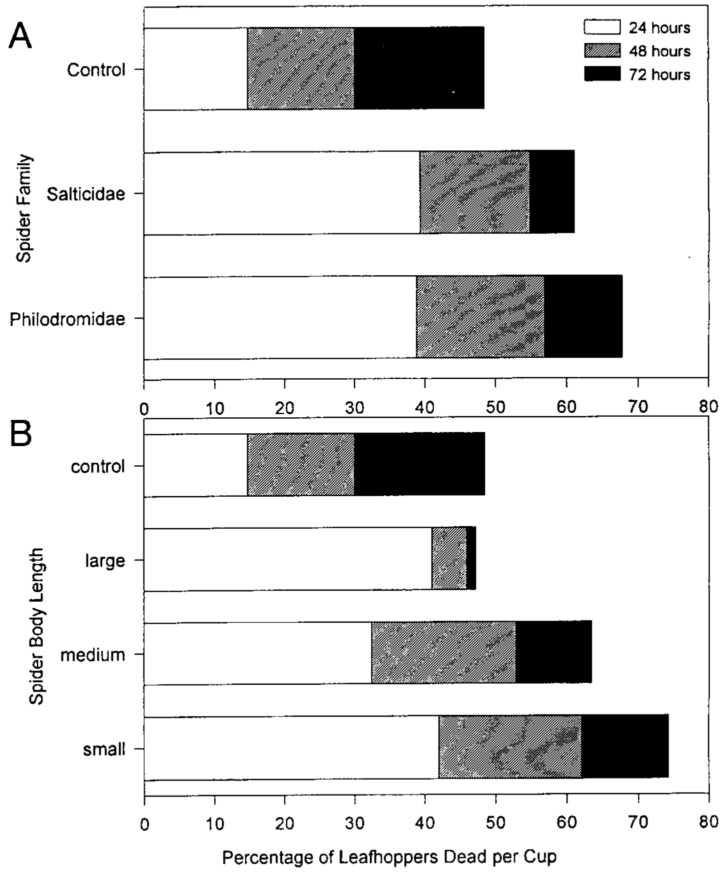

Fig. 2. Leaf Test. Cumulative percentages of leafhoppers dead per cup after 24, 48, and 72 h when spiders were grouped according to family (A) and body length categories (B). Total numbers of spiders tested were: 73 for Philodromidae, 46 for Salticidae (A), and 56 for small, 34 for medium, and 27 for large body lengths (B). There was one spider and 3–4 leafhoppers per cup. There were 38 controls that consisted of cups with leafhoppers but without spiders.

According to a repeated measures ANOVA with independent variables of spider body length (between subject effect) and time (within subject effect), spider body length had a significant effect on the number of leafhoppers dead per cup ($p < 0.001$). There was also a significant interaction between time and body length ($p < 0.001$). Significantly more dead leafhoppers were found in cups containing spiders than in control cups in the first 24 h, and during this time, there was no significant effect of spider body length on leafhopper mortality. After 48 h, leafhopper mortality remained greater in cups with spiders than in control cups for all spider body length categories, but differences were statistically significant only for small and medium sized spiders. After 72 h, such differences were significant only for small spiders.

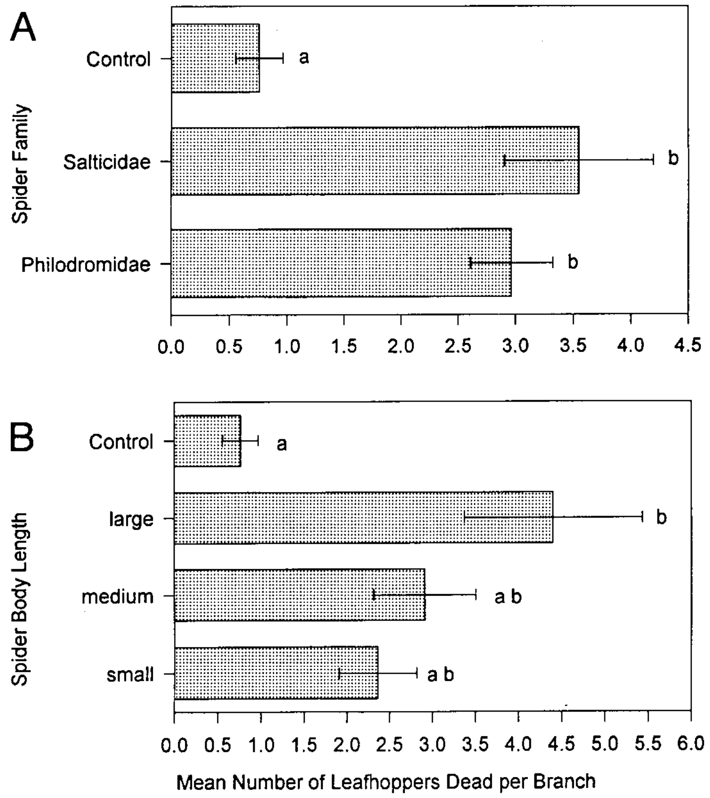

Fig. 3. Branch Test. Mean numbers of leafhoppers dead per branch when spiders were grouped according to family (A) and body length categories (B). Total numbers of spiders tested were: 27 for Philodromidae, 20 for Salticidae (A), and 14 for small, 18 for medium, and 15 for large body lengths (B). Each branch segment contained 12 leafhoppers. After 72 h, numbers of dead leafhoppers were recorded. There were 21 controls that each consisted of 12 leafhoppers enclosed on branch segments without spiders. Error bars indicate the standard errors of the means. Treatments without a letter in common are significantly different ($\alpha = 0.05$).

Branch test

According to a two-way ANOVA where spider family and body length were treated as independent variables, the combined effect of spider family and body length accounted for 28% of the variation in number of dead leafhoppers per branch ($p = 0.02$). This was overwhelmingly due to spider family ($p = 0.02$) and an interaction of spider family with body length ($p = 0.008$). The interaction was due to small salticids consuming the most leafhoppers per branch, followed be large and medium-sized salticids and large philodromids killing the most per branch, followed by medium and small philodromids. Because only three small salticids were used in the test, this result may have been affected by small sample size.

According to Scheffe's comparison of means ($\alpha = 0.05$), both Salticidae and Philodromidae consumed significantly more leafhoppers than died in controls. Differences between the two spider families in leafhopper consumption were not statistically significant (Fig. 3A). Due to small sample size (see above), salticid spiders were not included in the comparison of spiders of different body lengths. Philodromids in all body length categories consumed more leafhoppers than the numbers that died in controls (Fig. 3B), but the difference was not statistically significant for small and medium sized spiders. There were no significant differences in leafhopper consumption among the three body length categories, but numerically, large spiders consumed the greatest and small sized spiders the least number of leafhoppers per branch.

DISCUSSION

Irrespective of whether we measured leafhopper mortality in the small confined environment of a paper cup or in a larger, less restricted environment of a netted branch, we observed the same result: the presence of spiders of the families Salticidae and Philodromidae had a significant positive effect on mortality of rose leafhoppers. Although measured only in leaf tests, this result was true irrespective of whether the criterion was the percentage of spiders feeding on leafhoppers or the percentage of leafhoppers eaten by spiders. Therefore, it may be concluded that under laboratory conditions, spiders of these two families are capable of consuming leafhoppers. This result is in agreement with our field observations as well as findings obtained by other workers in other agricultural systems.

Based on direct field observations in peanut fields, Agnew & Smith (1989) concluded that spiders were capable of consuming potato leafhoppers (*Empoasca fabae* Harris) and three-cornered alfalfa hoppers [*Spissistilus festinus* (Say)]. These spiders, however, were mostly *Oxyopes salticus* Hentz (Oxyopidae), a species not tested in our study. Salticidae and Philodromidae were not abundant in the peanut agroecosystem studied by these workers. Using precipitin tests, Rothschild (1966), Solomon (1973), and Waloff (1980) concluded that spiders were the dominant predators of grassland leafhopper nymphs and adults from late July onward. Waloff (1980) discussed several other studies in which spiders have been identified as predators of leafhoppers. Yet, none of these studies list Salticidae or Philodromidae as dominant spider families. Letourneau (1990) observed that when squash was grown in polyculture, the number of *Erigone* spiders (Micryphantidae) increased and the number of *Empoasca* leafhopper adults (but not nymphs) decreased. This suggests that under conditions of polyculture, *Erigone* spiders may have a negative effect on abundance of leafhopper adults. In a grassland, Waloff & Hassell (1982) observed that population density of spiders increased as the population density of leafhoppers (Cicadellidae and Delphacidae) increased, indicating a numerical response of spiders to leafhopper density. Only McCaffrey & Horsburgh (1980) found that spiders, including Philodromidae and Salticidae, were able to feed on nymph and adult leafhoppers in apple orchards. However, they identified the leafhoppers only to subfamily level (Typhlocybinae) and they conducted their tests under very artificial conditions (Petri dishes without leaves).

Here we report that in paper cups containing a leaf, both salticid and philodromid spiders fed on leafhoppers to a significant degree during the first 24 h; but after 24 h, leafhopper mortality in cups containing spiders decreased. The average prey to predator body size ratios (mean spider body length in a category divided by the mean leafhopper body length of 3 mm) were 2.2, 1.5, and 0.8 for small, medium and large spiders respectively. According to Nentwig & Wissel (1986), spiders prefer prey sizes of less than 80–100% of their own size; crickets 50–80% of spider size yielded the highest acceptance rates for spiders of 13 different families. This indicates that for both small and medium size spiders, last instar nymphal and adult rose leafhoppers tested here may have been of greater than preferred body size. According to Young & Lockley (1986) in a study of *Oxyopes salticus* Hentz feeding on *Lygus lineolaris* (Palisot de Beauvois), no significant increases occurred in predation from 24 to 48 h for small spiders feeding on large plant bugs due both to difficulty in prey capture and to satiation after one or more successful prey captures. This suggests that in our study, small and medium size spiders may have experienced difficulty in prey capture and/or may have been satiated.

Numerically, we found that small spiders consumed the most and large spiders the fewest leafhoppers. When we consider the prey to predator body length ratios mentioned above, this result may seem counterintuitive. However, the leaf tests were performed under confined and artificial conditions that may have affected the behavior of spiders of different species and physiological states (immatures at different stages of development) in different ways, either by inhibiting or enhancing their ability to feed on leafhoppers. For example, adult leafhoppers had no place to which to escape and tended to accumulate near the lids of the cups, where light was greatest. The majority of spiders also aggregated in these areas, which resulted in the predators and their prey being in unnatural proximity. According to a study by Haynes & Sisojevic (1966), the number of prey (*Drosophila melanogaster* Meigen) killed by spiders (*Philodromus rufus* Walckenaer) increased with increasing prey density. Thus, increased density of leafhopper adults near the paper cup lids may have given rise to increased predation in those cups, especially in cups located closest to the light source.

A netted branch is clearly a more natural environment than a small cup for foraging spiders. Hence, greater weight should probably be placed on the branch test results. Although there were no significant differences, a trend existed in the branch test where large spiders consumed the most leafhoppers and small spiders the least. This suggests an increased ability of larger spiders to kill leafhoppers, possibly due to their greater agility and ability to handle prey as well as their higher energy demand.

Overall, our findings suggest that orchard hunting spiders are indeed capable of preying upon rose leafhoppers. This capability may vary according to spider family, body size, and environmental conditions that, among other factors, may affect prey density. Other possible factors influencing this ability, but not tested here, include spider species, sex (for adult specimens) and physiological state (Haynes & Sisojevic, 1966). To what extent this capability is expressed under apple orchard conditions remains to be determined.

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