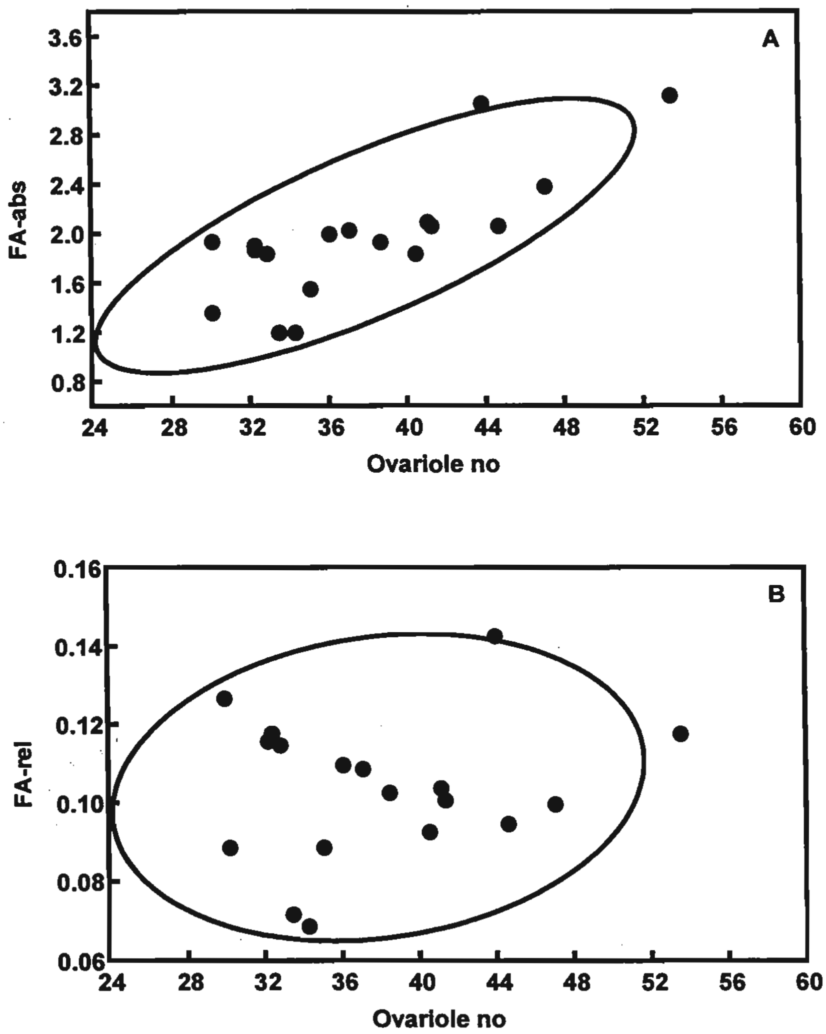

Figure 2. Relationship between ovariole number and FA. A, Positive correlation (r = 0.77) with absolute FA; B, Absence of correlation with relative FA (r = 0.17). Ellipses of 90% confidence are shown.

Acknowledgments: We thank A.P. Moeller for helpful discussion on this paper.

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Effects of thermal stress on desert and cosmopolitan *Drosophila* behavior.

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Abstract:

Organisms have variable responses to stress in their environment. Males from two *Drosophila* species, *D. mojavensis – Sonora SOSC0297* (desert) and *D. simulans – Tempe* (cosmopolitan), were tested for motor activity, mating behavior and offspring production following an acute thermal stressor. The results indicate some differences in mating behaviors for both species as well as an increased production of offspring in heat stressed flies. Finally, there were some marked differences in the mortality rates of cosmopolitan males.

Introduction:

Stress can be either beneficial or harmful to an organism. For example, data suggest that acute stress causes a reorganization of immune cells from the bloodstream to skin and other vital tissue (Dhabhar *et al.*, 1995). This phenomenon would be advantageous to an animal that is attacked and injured by a predator. When an organism is chronically exposed to stress, though, harmful side effects appear and can include suppressed immune function (Jiang *et al.*, 1990), disease (Sapse, 1997), loss of activity (Castro and Matt, 1997), depression (Modell *et al.*, 1997; Mokrani *et al.*, 1997), and infertility (McGrady, 1984). Therefore, how successful an individual is at dealing with stress, acute or chronic, may have a direct impact on their continued good health, survival and reproductive fitness.

Drosophila may encounter stress in its environment as the result of limited water, limited food or temperature fluctuations. In the Sonoran desert, extremely high temperatures pose a unique challenge to surviving and leaving viable offspring. It has been demonstrated previously that males of desert *Drosophila* species survive better than cosmopolitan ones (Stratman and Markow, 1998), perhaps due to alterations in heat shock proteins (Huey and Bennett, 1990). This study compared the effects of acute thermal stress on the behavior of desert and cosmopolitan *Drosophila* males.

Materials and Methods:

Laboratory Stocks: Sixty pairs of each species (*D. simulans – Tempe* or *D. mojavensis – Sonora SOSC0297*) were equally divided between three cornmeal bottles. Three days later, all pairs were transferred to a second identical set of bottles. Breeding pairs were removed after three days and all bottles were kept at room temperature until offspring eclosed (10-14 days for *D. simulans* and 14-18 days for *D. mojavensis*). Offspring were sexed and sorted under light CO_2 and stored in cornmeal vials (n = 10 flies per vial) at room temperature.

Heat Stress: The day before the experiment (*D. simulans – Tempe* flies = four days old; *D. mojavensis – Sonora SOSC0297* flies = 8 days old), half the males were placed in an incubator, calibrated to 38°C, for 90 minutes. All females and the remaining males stayed at room temperature. Heat stressed males were then allowed to recover overnight at room temperature.

Survivorship: After the recovery period, each vial was observed for survivors. Data were recorded and any non-survivors were removed from the glass vial. At the conclusion of the project, data were pooled and the number of non-survivors was divided by total number of flies used within a group.

Activity: Each male fly was aspirated into a piece of clear Tygon® tubing that was closed to form a ring. The Tygon® ring was then placed over a circular grid marked by dashes and the male was allowed to acclimate for 100 seconds according to the protocol outlined by Krebs (Krebs *et al.*, 1991). Activity was measured by how many dashes the fly crossed during a 100-second testing period. Once the male's score had been recorded, it was transferred to its own glass vial. All ten flies within a group (*D. simulans* control, *D. simulans* heat, *D. mojavensis* control or *D. mojavensis* heat) were tested together.

Mating: Ten virgin females were aspirated into ten separate glass vials and allowed to acclimate during activity experiments. One male was then added to a female's vial, with time of introduction noted. Pairs were observed over the course of one hour for male courtship (latency), successful copulation (receptivity) and copulation duration. Once a male successfully displayed a behavior, the time was recorded. Introduction time was subsequently subtracted from the behavior time to give a fly's final score.

Progeny Counts: All flies from a mating experiment were transferred to cornmeal bottles for four days. Parents were then removed and the bottles were kept at room temperature for either 12 days (*D. simulans*) or 16 days (*D. mojavensis*). After the appropriate incubation time, offspring were counted under light CO_2.

Statistics: Means and standard errors for activity and mating experiments were computed using Microsoft Excel. To determine significance of group comparisons, data were subjected to two-way ANOVA tests (unequal sample sizes: $p \leq 0.05$) using Systat® 7.0.1. For progeny counts, total number of offspring recovered for each group was divided by total number of male parents used.

Results:

Activity: Activity means for all groups are given in Table 1. Only comparison between heat stressed groups of *D. simulans* and *D. mojavensis* approached significance ($p = 0.07$).

Mating: *D. simulans* heat stressed males exhibited few differences from controls (Table 1). Only the receptivity score was significantly higher ($p = 0.05$). In contrast, *D. mojavensis* heat stressed flies had a higher latency score ($p = 0.04$) than controls. There was also an almost significance difference in overall score (time elapsed from introduction to start of copulation) between the two groups ($p = 0.09$). However, this may have been due to the differences in latency scores. Interspecific comparisons showed that *D. mojavensis* flies consistently scored lower than their *D. simulans* counterparts ($p < 0.001$) except for latency scores of heat stressed *D. simulans* and *D. mojavensis* ($p = 0.07$).

Table 1. Activity and Mating Means ± Standard Errors for *Drosophila* Groups

Fly Group	Activity (# lines/ 100s)	Latency (seconds)	Receptivity (seconds)	Overall (seconds)	Copulation Duration (minutes)
D. simulans	40.4 ± 6.1	467.6 ± 91.5	442.8 ± 53.3	801.6 ± 104.2	22.8 ± 0.74
Control	n = 47	n = 45	n = 34	n = 34	n = 34
D. simulans	35.1 ± 5.4	474.5 ± 106.9	731.1 ± 168.5	1055.9 ± 160.9	23.8 ± 1.4
Heat	n = 38	n = 34	n = 20	n = 20	n = 20
D. mojavensis	42.4 ± 5.3	143.3 ± 23.0	107.3 ± 22.1	238.7 ± 31.2	3.35 ± 0.16
Control	n = 45	n = 42	n = 35	n = 35	n = 35
D. mojavensis	49.5 ± 5.7	252.1 ± 50.7	96.1 ± 25.2	346.2 ± 55.9	3.18 ± 0.16
Heat	n = 40	n = 33	n = 30	n = 30	n = 30

Table 2. Progeny Counts per *Drosophila*

Fly Group	Progeny / Male Parents
D. simulans — Tempe control	1010 / 39 = 25.9
D. simulans — Tempe heat stress	932 / 33 = 28.2
D. mojavensis — Sonora SOSC0297 control	162 / 45 = 3.6
D. mojavensis — Sonora SOSC0297 heat stress	170 / 31 = 5.5

Progeny Counts: Progeny data are presented in Table 2. More offspring were produced from heat stressed males although the difference is more pronounced in *D. mojavensis*. Heat stressed males produced almost half again as many offspring as controls. There is a slight difference between

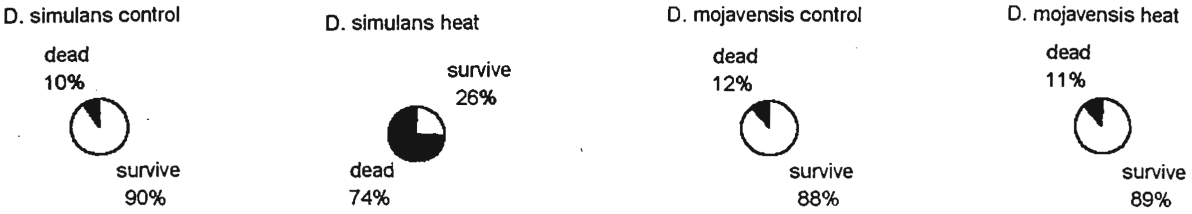

Figure 1. Survival charts for *Drosophila* groups.

the two *D. simulans* groups. It might have been even greater as one bottle included in the heat group produced larvae and pupae that did not hatch in time to make the 12-day cutoff.

Discussion:

Although most scores were not significantly different, the difference in receptivity scores for *D. simulans* is an interesting result. Receptivity is a measure of the male's ability to successfully court and copulate with a female. In order to accomplish this, the male must put together a certain courtship pattern of wing beating and other maneuvers. Perhaps the heat stress event affected the males in such a way that they produced a slightly different wing sound or pattern. If so, the female would recognize this courtship as being "wrong" and might take longer to recognize the male as a suitable partner. An alternate hypothesis is that heat stress induces a change in males' courtship pattern so that mating and egg laying do not occur in adverse environmental conditions.

Differences in latency scores for *D. mojavensis* might be explained in a similar fashion. Latency, unlike receptivity, is purely a measure of male vigor: in this instance, his ability to recognize the presence of a female and start courtship. Perhaps during intense heat, *D. mojavensis* males are less likely to encounter females and, therefore, tend not to mate during those times. This type of suspended mating would have similar results for *D. mojavensis* as was mentioned for *D. simulans*; namely, offspring are produced during relatively cooler times enhancing chances for survival. The ability of an organism to modify its reproductive status based on environmental conditions is referred to as "phenotypic plasticity" (Williams, 1998). This phenomenon occurs in other species as well and "phenotypic plasticity" has been the focus of state dependent life history theory (McNamara and Houston, 1996; Stearns, 1992).

Another interesting trend to note in the *D. mojavensis* data is that heat stressed flies score better in a number of categories. Although differences are not statistically significant between control and heat stressed flies, these trends may indicate that room temperatures inhibit some aspects of *D. mojavensis* behavior. This may have implications for experiments performed in the laboratory using this strain of *Drosophila*.

The most striking result of this study was the high mortality rate of *D. simulans* heat stressed males. Thermal stress produces the potential for damage within an individual, although how much is caused may depend on a variety of factors such as individual variation in heat shock proteins and length of exposure to the stressor. *D. mojavensis*, as desert natives, appear to have a well-developed array of protective mechanisms judging from their survival rate. *D. simulans* may have similar protections to heat but, in light of their increased mortality rate, those are not as well developed. It is also evident that even a small amount of damage at an early age can be lethal for *D. simulans*. These facts would reinforce the idea that cosmopolitan strains must be able to survive in a variety of ecological niches. In order to occupy a broader range of climates, this strain may have evolved away from specificity and specialized desert adaptations. Another hypothesis could be that *D. simulans – Tempe* is just a relative newcomer to the Sonoran desert and has yet to evolve the more specialized adaptations that *D. mojavensis* already have.

Determining what makes adaptations of *D. mojavensis* so superior to those of *D. simulans* and whether it is possible for *D. simulans* to evolve them would provide an interesting expansion to this study. In addition, study of thermal stress on females would aid in understanding its effects on the species as a whole.

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Report on Genus *Dettopsomyia* (Insecta: Diptera: Drosophilidae) from Kumaon region, India.

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Our previous studies on the Drosophilids of Kumaon region have yielded interesting results (Singh and Bhatt, 1988; Singh and Negi, 1989, 1992, 1995; Singh and Dash, 1993, 1998) though many areas remain uncovered from the above point of view. The Kumaon region, a wild hilly area is located at an elevation of 6,000 feet (1828 meters) from the sea level on the North-east periphery of the state of Uttar Pradesh. This region includes six border districts of the state viz., Nainital, Almora, Pithoragarh, Udham Singh Nagar, Champawat and Bageshwar. The area is characterized by having dense evergreen coniferous forest with medium to very steep slopes and extremely moist conditions due to heavy rainfall. This note embodies the results of several surveys undertaken in Kumaon region, India, from July 1996 to April 1999.

Genus *Dettopsomyia* Lamb (New Record) *Dettopsomyia* Lamb 1914, Trans. Soc. Land. (2) (Zool) 16:349. Type species: Formosa Lamb.

Pictostyloptera Duda 1924, Arch. Naturgesch. 90A (3) 1192. Type species: *Drosophila preciosa* de Meijere.

Dettopsomyia nigrovittata Malloch (New Record)