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Effects of Tail Loss on Growth and Sprint Speed of Juvenile *Eumeces fasciatus* (Scincidae)

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Abstract.—**Tail autotomy serves as an aid to escape predators in many lizards, but potential costs include loss of fat stores, impaired locomotion, loss of social status, and reduced growth and reproductive output. Two potential costs of tail loss were examined in juvenile skinks, *Eumeces fasciatus*, through manipulation in a laboratory study. Changes in growth and sprint speed were compared among full autotomy, partial autotomy, and control groups of lizards after these treatments at three weeks of age and up to four weeks later. Full tail autotomy was associated with increased growth in mass during the two weeks posttreatment and increased growth of the tail between two and four weeks posttreatment. No other measures of growth were affected by partial or full tail loss. Immediately following treatments, fully autotomized lizards became significantly slower, with respect to maximum sprint speed, relative to both other groups. However, this effect was gone by four weeks after tail loss.**

Many lizards autotomize their tails when harassed by potential predators as an aid in escaping (Vitt et al., 1977; Arnold, 1988). Previous research has shown that potential costs of tail autotomy include loss of fat stores (reviewed in Bellairs and Bryant, 1985; but see Chapple and Swain, 2002; Doughty et al., 2003), impaired locomotion (Formanowicz et al., 1990; Brown et al., 1995; Martin and Avery, 1998), loss of social status (Fox and Rostker, 1982; Martin and Salvador, 1993), reduced growth (Ballinger and Tinkle, 1979; Smith, 1996) and reproductive output (Dial and Fitzpatrick, 1981; Chapple et al., 2002), altered movement and behavior patterns (Salvador et al., 1996), and future loss or reduction of the same defense (Bellairs and Bryant, 1985). However, these costs are not universal to all lizard species (Daniels, 1983; Brown et al., 1995; Fox and McCoy, 2000; McConnachie and Whiting, 2003) and may be variable among populations and life stages (Bellairs and Bryant, 1985; Kelt et al., 2002).

Tail autotomy is common in *Eumeces fasciatus* (Scincidae), the Five-Lined Skink (Fitch, 1954; Vitt and Cooper, 1986). Like many North American skinks and other lizards, juveniles and young adults advertise their tails with bright coloration and undulating displays when threatened (Congdon et al., 1974; Vitt and Cooper, 1986). These attractants for potential predators (Cooper and Vitt, 1985) may indicate a greater importance of tail autotomy for survival in these age classes or lower costs of autotomy relative to adults (Arnold, 1988). Hatchlings and juveniles cannot suffer the immediate costs of reduced reproductive output after autotomy that adults may, particularly in *E. fasciatus*, which do not reproduce in their first year (Fitch, 1954). However, growth may be more strongly affected by autotomy in juveniles than in adults since younger lizards typically experience higher growth rates (Andrews, 1982). Contrary to this suggestion, Vitt and Cooper (1986) found no reduction of growth in hatchlings of *E. fasciatus* whose tails were removed at one week of age. Chapple et al. (2004) also found unimpaired growth in hatchlings of *Niveoscincus metallicus* (Scincidae) autotomized within two days of hatching but demonstrated that tail loss at that age immediately resulted in impaired locomotion. This may indicate important fitness consequences of autotomy in the wild, as sprint speed has been shown to be associated with subsequent survival in lizards (Miles, 2004).

I investigated costs of tail loss in juvenile *E. fasciatus*, with respect to growth and maximum sprint speed, during four weeks after autotomy. Juvenile *E. fasciatus* were induced to autotomize at three weeks of age to increase the number of age classes in which autotomy has been studied. Additionally, juveniles grow substantially in the three weeks following hatching (10–100% body mass), and the proportion of body mass comprised of fat increases with size and age in lizards (Daniels, 1984). Therefore, older juveniles may have lipid reserves in the tail not present immediately at hatching and, therefore, may respond differently to autotomy than new hatchlings.

Materials and Methods

Adult female lizards were collected in Knox, Grainger, and Anderson Counties in east Tennessee during July 2004 by hand and noose. Lizards were housed separately in ventilated plastic containers (18 × 30 × 15 cm) in a laboratory at the University of Tennessee, Knoxville. All lizards were provided with water and fed vitamin-dusted crickets ad libitum every other day. For housing of eggs and adult lizards, temperatures were 24.5–30°C, a range comparable to conditions in the wild (Smith, 1998). Eggs were removed up to two weeks after females oviposited, and either kept separately or together in clutches for other research. Additionally, one clutch of eggs was taken from the wild in Anderson County in early July. Moisture levels and maternal care conditions during incubation varied among clutches but not among experimental treatments.

Immediately after eggs hatched, groups of 3–5 hatchling lizards were housed in 14 × 30 × 15 cm plastic containers with screen lids and given water and

TABLE 1. Average measurements of juvenile lizards, *Eumeces fasciatus*, initially (three weeks of age), after treatments (the following day) and two and four weeks after treatments. Means for snout–vent length (SVL), tail length (TL), mass, and maximum sprint speed are shown ± 1 SD.

	Treatment group	Initial	Posttreatment	2 weeks posttreatment	4 weeks posttreatment
SVL (mm)	Autotomy	31.40 ± 1.87	—	36.70 ± 2.42	41.71 ± 2.07
	Injury	30.87 ± 2.05	—	35.92 ± 2.17	41.01 ± 1.81
	Control	31.09 ± 1.62	—	36.06 ± 1.68	41.16 ± 1.93
TL (mm)	Autotomy	45.43 ± 4.66	7.78 ± 1.03	16.35 ± 2.82	32.33 ± 4.82
	Injury	45.78 ± 4.33	35.80 ± 4.63	44.46 ± 4.36	54.44 ± 2.36
	Control	45.83 ± 4.28	—	55.24 ± 4.27	64.97 ± 4.10
Mass (g)	Autotomy	0.721 ± 0.142	0.622 ± 0.120	1.158 ± 0.224	1.716 ± 0.264
	Injury	0.702 ± 0.162	0.682 ± 0.151	1.117 ± 0.254	1.796 ± 0.238
	Control	0.704 ± 0.119	—	1.174 ± 0.225	1.784 ± 0.199
Maximum sprint speed (cm/sec)	Autotomy	70.83 ± 16.20	54.79 ± 17.68	—	71.28 ± 21.71
	Injury	73.72 ± 14.87	71.02 ± 17.70	—	78.76 ± 20.58
	Control	69.91 ± 15.14	66.32 ± 18.19	—	78.48 ± 18.73

small vitamin-dusted crickets every other day. Full spectrum UVB fluorescent lights were placed 15 cm from the tops of containers with a 12:12 h photoperiod. Temperatures in enclosures ranged from 24.5–25.5°C during the dark cycle to 25.5–33.0°C during the light cycle (varied with ambient temperature). Fourteen days after each clutch hatched, all hatchlings were separated and housed singly for the remainder of the experiment in the same conditions as above.

At three weeks of age, juvenile lizards were measured three times for snout–vent length (SVL) and tail length (TL) to the nearest 0.5 mm with calipers and mass determined to the nearest 0.001 g. For length measurements, lizards were restrained in a plastic bag that was folded over to securely encompass the straightened body and tail. All subsequent length measurements in this study were taken three times to the nearest 0.01 mm with calipers. In all cases, the average of the three measurements was used in analyses. At three weeks of age, three or six hatchlings were chosen, based on similarity of size, from each of 12 clutches for participation in the study ($N = 18$ per treatment). Because clutch origin typically affects growth rates and locomotion capacities of juveniles (Sorci and Clobert, 1997; Warner and Andrews, 2002; also see Results section), I treated clutch as a random blocking factor in analyses. Juveniles were randomly assigned within each block to treatments.

Two controls were used, an unmanipulated group and a partial autotomy or tail injury group, in which only a small portion of the tail was removed. The injury group experienced the stress associated with tail injury or autotomy without the potential energy loss involved in losing a majority of the tail. In some skinks, the distal tip of the tail contains little to no fat reserves (Chapple and Swain, 2002). Also, the injury control group served to separate the potential effects of tail injury on motivation to run from the loss of the tail as a counter balance or contact point during locomotion trials.

Lizards in the full autotomy treatment were grasped near the base of the tail with forceps at a point marked 10 mm from the cloaca and shaken a few times until the tail broke off. Removed portions of tail averaged 40.2 mm (range 33.0–45.0 mm) and 0.086 g (range 0.054–0.131 g). Lizards in the tail injury treatment were grasped with forceps at a point marked 10 mm from the tail tip and shaken until the tip broke off. Removed portions of tail averaged 10.0 mm (range 8.5–12.0 mm) and 0.004 g (range 0.001–0.008 g; for tail portion remaining, see Table 1). Lizards in the control treatment were grasped around the pelvis by hand and shaken lightly a few times to simulate the handling of lizards in the other treatments. Food was not available from the time of treatments until after races the following day to prevent potential differences in feeding behavior following treatments from differentially affecting stomach contents of the groups during racing.

Before and 24 h after treatments, juveniles were raced on 1.2 m of a circular racetrack (1.5 m diameter) marked at 10-cm intervals. Lizards were stimulated to run by prodding gently with a paintbrush, and all races were video-recorded with a digital camera (29.97 frames/sec). Three trials, separated by 30–60 min, were conducted on each day. Lizards rested 1 min in a starting gate before each trial. The best speed over any 30-cm portion of the track, determined by counting video frames, was considered the maximum sprint speed. Four weeks after treatments, sprinting trials were repeated in an identical manner as above. SVL, TL, and mass were measured and recorded again at two and four weeks after treatments.

Randomized block ANOVAs (with clutch as the random block) were used to compare initial SVL, TL, mass, and maximum sprint speed among treatments, and for all analyses that follow. Increases in SVL, TL, and mass for the period from treatment to two weeks posttreatment were compared among groups. Analyses were repeated for these measures of growth between two and four weeks posttreatment to determine the longevity of any treatments effects. Potential immediate effects of full autotomy and tail injury on maximum sprint speed were analyzed using the change in speed (for each individual) between pre- and posttreatment racing trials. Differences between maximum sprint speeds from four weeks posttreatment and those from pretreatment were compared among groups to investigate longer-term effects of autotomy on locomotion. Some lizards died or were subject to accidentally induced tail loss during the study; hence sample sizes were smaller for long-term measures.

All statistical analyses were performed in NCSS (J. Hintze, NCSS and PASS, Number Cruncher Statistical

Systems, Kaysville, UT, 2001) with a designated $\alpha = 0.05$. Assumptions of normality were verified with omnibus normality tests, and assumptions of variance homogeneity were verified with modified Levene equal variance tests. Post hoc multiple comparison tests were applied if ANOVA tests revealed significant effects. All means are given ± 1 SD.

Results

Lizards in the three treatments did not initially differ with respect to mass ($F_{2,40} = 0.61$, $P = 0.546$), SVL ($F_{2,40} = 2.58$, $P = 0.088$), TL ($F_{2,40} = 0.08$, $P = 0.920$) or maximum sprint speed ($F_{2,40} = 0.49$, $P = 0.618$; see Table 1). Clutch origin had significant effects on initial mass, SVL, TL and maximum sprint speed of hatchlings (mass: $F_{11,40} = 26.77$, $P < 0.001$; SVL: $F_{11,40} = 28.68$, $P < 0.001$; TL: $F_{11,40} = 5.10$, $P < 0.001$; speed: $F_{11,40} = 3.95$, $P < 0.001$).

During the two weeks after tail removal, tail loss affected growth in mass ($F_{2,35} = 4.86$, $P = 0.014$). Autotomized lizards gained significantly more mass (0.516 ± 0.177 g) than injured lizards (0.411 ± 0.128 g), and control lizards were intermediate (0.459 ± 0.147 g) and not significantly different from either group (Tukey-Kramer multiple comparison test). Lizards in the three groups did not differ at two weeks posttreatment in SVL or TL growth (SVL: $F_{2,35} = 0.76$, $P = 0.474$; TL: $F_{2,35} = 0.36$, $P = 0.702$). Clutch origin affected some but not all measures of growth over the two weeks posttreatment (SVL growth: $F_{11,35} = 2.23$, $P = 0.035$; TL growth: $F_{11,35} = 1.53$; $P = 0.164$; mass increase: $F_{11,35} = 4.82$, $P < 0.001$).

Between two and four weeks posttreatment, tail removal had no effect on growth in SVL or mass increase (SVL: $F_{2,28} = 0.26$, $P = 0.773$; mass: $F_{2,28} = 0.31$, $P = 0.736$). However, autotomy affected growth in TL ($F_{2,28} = 26.41$, $P < 0.001$). Autotomized lizards grew significantly more in TL (15.91 ± 3.09 mm) than injured (9.10 ± 1.60 mm) and control lizards (9.18 ± 3.03 mm), and the latter two groups did not differ (Tukey-Kramer multiple comparison test). Clutch origin affected some measures of growth over this period (SVL growth: $F_{9,28} = 3.19$, $P = 0.009$; TL growth: $F_{9,28} = 0.63$, $P = 0.765$; mass increase: $F_{9,28} = 4.91$, $P < 0.001$).

Immediately after tail removal, treatments had a significant effect on change in maximum sprint speed ($F_{2,40} = 4.97$, $P = 0.012$). Fully autotomized lizards became slower relative to their initial speed (change in maximum speed = –16.0 ± 3.3 cm/sec), when compared to injured (–2.7 ± 3.3 cm/sec) and control lizards (–3.6 ± 3.3 cm/sec), but there was no significant difference in speed change between injured and control lizards (Tukey-Kramer multiple comparison test). Four weeks after tail removal, treatments had no effect on sprint speed ($F_{2,29} = 1.06$, $P = 0.359$). Clutch origin had no effect on change in maximum sprint speed (posttreatment: $F_{11,40} = 0.84$, $P = 0.605$; four weeks posttreatment: $F_{10,29} = 1.18$, $P = 0.345$).

Discussion

The maternal influence on body size, speed, and some measures of growth in juvenile *E. fasciatus* found here agrees with past research and justifies the use of random block design (with clutch as the random factor) in the current analyses. Full tail autotomy affected one measure of growth in juvenile *E. fasciatus*, mass increase, in the first two weeks after tail loss. The magnitude of this effect was small and only differed between autotomized and injured lizards. However, full autotomy caused a more substantial increase in tail growth relative to both injury and control groups in the period from two to four weeks posttreatment. This result suggests that lizards that lost most of their tails exhibited compensatory growth for that body part, without sacrificing growth in body mass or length. Lizards in the autotomy treatment regenerated tails at an average of 6.1 ± 1.1 mm per week over the four weeks of the study, suggesting that juveniles may fully regrow the original length lost at autotomy within seven weeks. This absolute estimate of tail regrowth following autotomy is much faster than has been reported for juvenile skinks (Vitt and Cooper, 1986; Chapple et al., 2004; five and eight week long experiments, respectively) and other lizard species (Vitt et al., 1977; seven week experiment; also see references within).

Previous studies of younger hatchlings of this and other lizard species indicate that tail loss does not inhibit subsequent growth (Vitt and Cooper, 1986; Chapple et al., 2004). The current study suggests that tail autotomy may cause increased growth of body mass and tail length in some circumstances. However, food supply was *ad libitum* in this and other previous laboratory studies of tail autotomy in juvenile lizards (Vitt and Cooper, 1986; Chapple et al., 2004) and may not reflect natural conditions. A limited food supply in the wild may necessitate trade-offs in growth after autotomy that are not present in the laboratory (Ballinger and Tinkle, 1979). Future research should investigate growth rates of autotomized and control juvenile lizards across varying levels of food abundance that may affect growth rates (Dunham, 1978; Stamps and Tanaka, 1981; Smith and Ballinger, 1994).

Full autotomy in juvenile *E. fasciatus* immediately resulted in a larger decrease in sprint speed relative to other groups, but this effect was mostly gone by four weeks posttreatment. Loss of the tail tip was not associated with change in sprint speed, demonstrating that full tail loss is responsible for the effect shown in this study and not potential stress or infection associated with the act of autotomy. Survival has been positively linked to locomotor performance in lizards (Miles, 2004). Impaired sprinting caused by autotomy in *E. fasciatus* may result in greater susceptibility of tailless juveniles to future predation attempts. Alternatively, accompanying behavioral modifications of autotomized lizards that reduce exposure to predators may offset potential costs of impaired locomotion (Formanowicz et al., 1990; Cooper, 2003).

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