Sticking ability in Spix’s disk-winged bat, *Thyroptera tricolor* (Microchiroptera: Thyropteridae)

Daniel K. Riskin and M. Brock Fenton

**Abstract:** Roosting Spix’s disk-winged bats, *Thyroptera tricolor*, use disks on their wrists and ankles to cling to smooth leaves. In 584 trials we tested the ability of 31 *T. tricolor* and 121 other bats lacking disks (461 trials with 18 species from three families) to adhere to (i) medium-grade sandpaper, (ii) Lexan polycarbonate, (iii) solid sheet aluminum, and (iv) porous sheet aluminum. While *T. tricolor* readily adhered to smooth surfaces, the other species did not. *Thyroptera tricolor* did not show the same ability to adhere to rough surfaces as the other species that were tested. As was demonstrated by their performance on porous aluminum and sandpaper, the disks of *T. tricolor* worked by suction and sometimes by wet adhesion. In the course of adapting to adhere to smooth surfaces, *T. tricolor* appear to have lost some ability to roost on rough ones, although one adult *T. tricolor* climbed on a screen covering the inside walls of the polycarbonate cage by interlocking its thumb claws with the surface.

**Introduction**

Researchers have investigated the ability of animals in four phyla to adhere to and walk on smooth vertical or overhanging surfaces. Limpets and cephalopods (Mollusca), starfish (Echinodermata), frogs, and geckos (Chordata) cling to smooth surfaces using mechanisms ranging from suction in the Mollusca (Smith 1991, 1992a, 1992b) to intermolecular adhesion in geckos (Autumn et al. 2000). The ability to adhere to smooth surfaces also appears in the Arthropoda (e.g., Stork 1980; Walker et al. 1985; Lees and Hardie 1988; Roscoe and Walker 1991). Other taxa exhibit similar abilities but are less well studied. Although some mammals climb easily on smooth surfaces, our knowledge of how attachment is maintained has been inferred from anatomical investigations. Observations of living animals, which have been essential to our understanding of this behaviour in other taxa (Emerson and Diehl 1980; Hanna and Barnes 1991; Smith 1991), have been lacking for mammals.

Disk-like structures on the wrists and ankles of four species of bats, one from Madagascar (Myzopodidae) and three from the Neotropics (Thyropteridae), are presumed to give these animals the ability to grip to smooth surfaces such as the waxy cuticles of furled leaves (Altringham 1996; Fenton 2001, p. 183). The most studied of these species, *Thyroptera tricolor* (Spix’s disk-winged bat), which weighs ca. 3.5 g, is from lowland forests from Veracruz, México, to tropical South America (Wilson and Findley 1977). By day, *T. tricolor* have most often been found roosting in the furled leaves of *Heliconia* spp. (Heliconiaceae) and *Calathea* spp. (Marantaceae). At maturity these leaves are elliptical, but during their development they are rolled and tube-like for ca. 24 h, providing roosts for thyropterid bats (Findley and Wilson 1974).

For a bat to remain stationary on a smooth non-horizontal surface, such as the vertical face of a *Heliconia* leaf, it must resist slipping or falling by applying forces that act in static opposition to gravity. In other animals, six mechanisms for achieving this have been reported: gluing, intermolecular adhesion (Nachigall 1974), wet adhesion, suction, interlocking, and friction (Emerson and Diehl 1980). Gluing involves hardening and combines adhesion (the intermolecular forces between two dissimilar materials) and cohesion (the intermolecular forces among identical molecules), and involves a
cement spread between the surfaces (Nachtigall 1974). Inter-
molecular adhesion describes the attraction between the closely
contiguous surfaces of adjacent materials, and requires a
very small distance of separation (Nachtigall 1974). Wet ad-
hesion occurs when two solids are held together by an inter-
vening layer of liquid, and there are two types, Stefan
adhesion and capillarity. Stefan adhesion occurs when the
liquid is present both at the surface interface and around it.
The two adhering surfaces are so close that the viscosity of the
intervening liquid causes it to resist the flow that must
accompany the separation of the surfaces (Smith 1991b).
Capillarity occurs when the intervening liquid is not present
outside the joint. The force in capillarity results from the
surface tension of the liquid. Both types of wet adhesion are
positively related to the surface area of contact between the
two surfaces (Emerson and Diehl 1980). They require no
muscular exertion, and function even in holding wet paper
to glass (Hanna and Barnes 1991). Suction occurs when an
animal creates a partial vacuum over some area of the
substrate–body interface (Emerson and Diehl 1980). It is
limited by the magnitude of the air-pressure differential pro-
duced, and depends on both an uninterrupted seal between
the sucking organ and surface (Emerson and Diehl 1980)
and a non-porous surface (Smith 1991a). Interlocking, the
intermeshing of projections from two solid surfaces, is lim-
ited by the roughness of the interacting solids. The force
supplied results from the resistance of the substrate to com-
pression and its ability to resist breaking (Emerson and Diehl
1980). Interlocking differs from friction, which is the poten-
tial energy analogue of interlocking, and only occurs in the
presence of a normal force. While the disk may be non-rigid,
the surface is rigid, so bending will not put any part of the
contact area at an angle other than that of the surface as a
whole. Once the surface passes 90°, there is no twisting
back to angles <90° as might occur when two non-rigid
surfaces meet. The breakdown of Amonton’s laws on the
molecular scale is due to the interference of other forces,
like intermolecular adhesion, which we have addressed. Fric-
tional forces depend on a normal force holding the surfaces
together, but after 90° the normal force is negative, so no
amount of friction will hold the surfaces together. The great-
est functional difference between friction and interlocking is
that friction will allow animals to adhere to an inclined
surface but not a vertical or overhanging one. Using inter-
locking, animals can adhere to surfaces at all angles. Both
friction and interlocking are independent of the surface area
of contact (Emerson and Diehl 1980).

Since the species’ description in 1823, many researchers
have focused on the disks of T. tricolor (Fig. 1), and most
have proposed suction as the mechanism of sticking (Wimsatt
and Villa R. 1970; Schliemann 1970a, 1970b, 1974; Thewissen
and Etnier 1995). De la Espada (1870) noted that its disks,
when adhering to the skin of an observer, produced a sensa-
tion similar to that experienced when the air was drawn out
of a thimble with the mouth and the tongue was placed over
the opening. He stated that the suckorial ability of the disks
depended on exerting musculature intrinsic to the disks. Dobson
(1876) later found no musculature in the disks and proposed
that evacuation of air from beneath the disk was achieved
when the body of the bat pressed the disk into position on a
surface. A suction cup could work on the basis of elasticity
when elastic elements are present, but detachment of the cup
would be more difficult.

Beneath each disk a cartilaginous plate is attached to a tendon
leading to muscles outside the disk, at the metacarpophalangeal
joint of the thumb in the foredisks and the metatarsophalangeal
joints of anchylosed digits III and IV in the hind disks
(Wimsatt and Villa R. 1970). This arrangement permits the
disk shape to be manipulated from without, and explains
how disk shape could be controlled even without intrinsic
musculature. These data led Wimsatt and Villa R. (1970) to
conclude that the functional mode of the disks is suckorial
rather than any other sticking mechanism.

The purpose of this study was to investigate the ability of
T. tricolor to adhere to different surfaces and thus to deter-
mine the underlying mechanism, while examining its impact
on roost selection and roosting posture. Using behavioural
data from live bats we tested two hypotheses, first that suc-
tion is the mechanism of sticking (Wimsatt and Villa R.
1970) and second that T. tricolor is specialized for roosting
on leaves and smooth surfaces to the exclusion of other pos-
sible roosts (Findley and Wilson 1974).

Materials and methods

Study areas and animals

From 6 May to 12 June 1999, we conducted fieldwork at the
Caño Palma Research Station near Tortuguero, Costa Rica
(10°35’N, 83°32’W), where we caught most bats after dusk, using mist nets.
We caught some Rhynchonycteris naso (Emballonuridae) with hand
nets at their day roost in the boat house of the station. Also during
daylight hours we searched the forest for plants of any species that
exhibited the young, rolled leaves commonly used by T. tricolor as
day roosts. After experimentation we returned all T. tricolor to
their roosts of capture and released other bats from the research
station.

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On the nights of 27 and 28 August 1999 we caught bats with a harp trap (Tuttle 1974) at an abandoned mine near Perth Road Village, Ontario, Canada (44°35’ N, 76°19’ W). Each night we left the trap at the mine for a mine before sunset and removed bats from it after midnight. We brought the bats back to nearby Queen’s University Biological Station for experimentation and release.

We clipped a patch of hair from every bat before release so that it would be recognised if recaptured. For most species we took the hair from the top of the head, but in Micropteris spp. (Phyllostomidae) we clipped hair from the back to avoid damaging the interaural band. We released recaptured individuals without experimentation.

### Rotating platform

To quantify the ability of a bat to stick to a surface we used the protocol of Emerson and Diehl (1980). We placed each bat on the 15.0 by 30.0 cm surface which we rotated with an electronic motor from 0° (horizontal) through 90° (vertical) to 180° at 3°·s⁻¹. A scale divided into 1° increments revealed the angle of the platform at all times.

During rotation the bat could move about on the surface to attain whatever orientation it preferred. We had attached a transparent Lexan polycarbonate cage to the surface and it remained stationary relative to the surface during rotation. This prevented bats from escaping during experimentation. Since T. tricolor climbed easily on the surface of the polycarbonate cage, we followed the methodology used in the rotation of tree frogs (Hanna and Barnes 1991), holding open hands about 2 in. from the rotating T. tricolor to prevent flight. This was not always entirely effective, so we conducted the rotations inside an enclosed tent. When bats did escape we could quickly recapture them with a hand net.

Some bats fell from the surface during rotation. Other bats still held after their rotation was stopped at 180°. In all cases we recorded the last angle at which a bat maintained its hold on the rotating platform. When a bat of any species jumped from the surface prematurely, or used the contours of the cage for gripping, we stopped the trial, placed the bat at the centre of the surface, and repeated the trial. The values obtained for the points at which bats fell are therefore accurate indications of when they lost their grip. Some bats, after several attempts, still would not cling to a surface long enough to allow an accurate measurement of when they lost their grip, so we could not record data for all bats on all surfaces.

We rotated each bat on four surfaces (Fig. 2): medium-grade aluminum oxide sandpaper (emery cloth, ca. 120 diamond grid); smooth transparent Lexan polycarbonate; aluminum utility sheet; aluminum sheet perforated by small holes (ca. 4.5 × 10⁻⁶ m in diameter) evenly distributed across the surface with a frequency of 1.72 × 10⁶ holes per square metre (Fig. 2d). These holes permitted air to flow from one face of the aluminum sheet to the other and reduced its surface area by 27% compared with the solid utility sheet. The size and frequency of the holes were such that hind or thumb disks at any position on the surface would completely cover at least three holes. These four surfaces were presented to each bat in a random order. Scanning electron micrographs of each surface demonstrate the texture of the surface at the scale of a T. tricolor disk (Fig. 2).

### Experimental detection of sticking mechanisms

Gluing can only occur after a liquid cement, spread between two surfaces, has had time to harden, allowing cohesive forces to act (Nachitagall 1974). In invertebrates that use gluing, such as limpets, this process takes several hours (Smith 1991b). Because the entire rotation of a bat through 180° took only 60 s, the secretion and subsequent hardening of a glue beneath the disks were unlikely to have occurred during a trial. The lack of a solid residue remaining after the bats had moved on also suggests that T. tricolor did not use gluing to adhere to any of the surfaces we tested.

Sudoriparous (sweat) glands open into the outermost zone of each T. tricolor disk (Schliemann 1974). They secrete a substance that is non-mucoid and of low viscosity, consisting mostly of water and soluble proteins (Wimsatt and Villa R. 1970). Grooming T. tricolor spend considerable time licking the disks of both the thumbs and the feet (Carvalho 1939; Findley and Wilson 1974; Wimsatt and Villa R. 1970), keeping them free of debris. The combination of saliva and exudate from the sudoriparous glands keeps the disk face moist at all times (Wimsatt and Villa R. 1970), producing a fluid-filled joint between the disk and any surface it contacts. The presence of liquid between them prevents intermolecular adhesion, which normally functions only at separation distances of ca. 0.3 nm (Autumn et al. 2000), but may not completely disappear at greater distances (Israelachvili 1992).

The mechanism of friction can only occur when there is a normal force holding two surfaces together, which means that it was experimentally eliminated when animals were rotated past 90°. The mechanisms available to bats after 90° were thus limited to interlocking, wet adhesion, and suction.

To determine whether suction is used by living T. tricolor, we compared the sticking ability of T. tricolor on sheet aluminum, where suction was possible, with that on porous aluminum and sandpaper, where the seal necessary for suction could not be created. The decrease in surface area from the non-porous to the porous surface is ca. 27%, so if T. tricolor used only wet adhesion and not suction, this decreased surface area would result in a lower sticking ability. But T. tricolor can hang beneath a smooth surface by only one ankle disk (Wimsatt and Villa R. 1970), indicating that a decrease in disk surface area of 88% (the result of removing two large wrist disks and one smaller ankle from a surface) does not induce falling. Therefore, any decrease in ability to stick to the porous surface can be attributed to the absence of suction.

Interlocking only occurs on a surface that is rough enough to facilitate intermeshing with some part of the organism. Hooke (1665–1667) and Leeuwenhoek (1690) postulated that the adhesive setae...
of insects could catch on the minute irregularities of apparently smooth surfaces. But this was dismissed when scanning electron microscopy (SEM) views of glass and Perspex revealed them to have remarkably smooth surfaces, even at the scale of insect setae (Stork 1980). SEM inspection of the polycarbonate and sheet aluminum surfaces we used revealed that they are smooth even well below the scale of a T. tricolor disk (Figs. 2b, 2d). On these two surfaces, bats could adhere only by wet adhesion, suction, and (or) friction.

Results

Rotating platform

In 584 trials, we put 152 bats from 19 species in four families through a rotating-surface experiment (Table 1). On the rotating platform the postures of bats varied among families, but we observed no intrafamilial variation. At angles approximating 90°, vespertilionids, phyllostomids, and emballonurids maintained a head-down orientation, while T. tricolor roosted head-up. Vespertilionids and phyllostomids held on only with their hind feet at angles close to 180°, while emballonurids and thyropterids maintained a four-point stance with wrists and hind feet in contact with the surface.

The angles at which bats, grouped by family, stuck to sandpaper, sheet aluminum, perforated aluminum, and polycarbonate (Fig. 3) show that the performance of thyropterids can be readily distinguished from that of other families. Because we stopped trials at 180°, there is an upper limit beyond which bats cannot continue to cling, resulting in data that are not normally distributed. This necessitates the use of non-parametric statistical tests. We performed a Kruskal–Wallis test with tied ranks (Zar 1999) to assess interfamilial differences in sticking ability on each of the four surfaces among bats grouped by family.

We performed a Kruskal–Wallis test with tied ranks (Zar 1999) to assess interfamilial differences in sticking ability among the families on every test surface (P < 0.0005; Table 2) and then set out to determine where those differences existed, i.e., which families differed from each other in ability to stick to a given surface. Testing each surface separately, we made multiple two-tailed comparisons using rank sums (Table 3), which permitted analysis despite unequal group sizes and tied ranks (Zar 1999).

Sticking mechanisms

A comparison of the performance of T. tricolor on sandpaper as well as on solid and perforated aluminum surfaces demonstrates that suction is the sticking mechanism: the bats adhered readily to smooth surfaces but not to perforated ones. On smooth surfaces 93.5% of T. tricolor held on through 180° (n = 31), while on the perforated surface, T. tricolor adhered only to an average of 90.0° (n = 31, SD = 25.02°); no bats held on past 121°. Nevertheless in the absence of suction, 54.8% of T. tricolor (n = 31) held on past 90°, indicating the use of interlocking and (or) wet adhesion. Because SEM views of the surface at the scale of a disk revealed very few irregularities that might interlock with the disk face (Figs. 2c, 2d), and since the disks of living T. tricolor are kept moist (Wimsatt and Villa R. 1970), we conclude that wet adhesion was probably the central mechanism of sticking on that surface.

Use of thumb claws

Originally we had intended to use the same cage around rotating T. tricolor as we used for the other bats. To stop T. tricolor from crawling on the polycarbonate walls of the

| Table 1. Species of bats used in the rotating-platform experiment. |
|-----------------------|----------------|-----|-----------|
| Family                | Species            | Mass (g) | n  |
| Emballonuridae        | Rhynchonycteris naso | 4.5 ± 0.43 | 8  |
| Phyllostomidae        | Artibeus jamaicensis | 50.8    | 2  |
|                      | Artibeus watsoni  | 10.7 ± 1.40 | 20 |
|                      | Carollia breviceuda | 16.0 ± 1.49 | 5  |
|                      | Carollia castanea | 14.1 ± 2.40 | 10 |
|                      | Carollia perspicillata | 18.1 ± 2.58 | 8  |
|                      | Glossophaga commissaris | 8.1    | 3  |
|                      | Glossophaga soricina | 7.8    | 2  |
|                      | Hylonycteris underwoodi | 7.3    | 1  |
|                      | Micronycteris brachyotis | 13.0   | 3  |
|                      | Micronycteris microtus | 5.7 ± 0.47 | 6  |
|                      | Platyrrhinus helleri | 17.2    | 2  |
|                      | Uroderma bilobatum | 17.6    | 1  |
|                      | Vampyressa nymphaea | 11.8    | 1  |
| Thyropteridae         | Thyroptera tricolor | 3.5 ± 0.79 | 31 |
| Vespertilionidae      | Myotis leibii     | 4.9     | 4  |
|                      | Myotis lucifugus  | 7.0 ± 1.00 | 26 |
|                      | Myotis nigricans  | 5.6     | 3  |
|                      | Myotis septentrionalis | 6.0 ± 0.82 | 16 |

*Values are given ± standard deviation when n ≥ 5.

| Table 2. Kruskal–Wallis tests for differences in sticking ability on each of the four surfaces among bats grouped by family. |
|-----------------------|----------------|-----|-----------|
|                     | F₁ₐₙₛ | F  | P          |
| Sandpaper            | 2.67  | 26.009 | <0.0005 |
| Sheet aluminum        | 2.67  | 50.415  | <0.0005 |
| Perforated aluminum   | 2.67  | 80.343  | <0.0005 |
| Polycarbonate         | 2.67  | 50.051  | <0.0005 |

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cage we covered its inside walls with screen, a surface upon which *T. tricolor* should not be able to crawl (Findley and Wilson 1974). The first *T. tricolor* placed in the cage, an adult male (forearm 34.0 mm long; mass 3.8 g), immediately climbed on the walls by interlocking the claws of its thumbs with the holes of the screen. Because the cage was ineffective at preventing bats from leaving the test surface we did not use it in the rotation experiments. No other bats were

![Graphs](https://example.com/graphs)

**Fig. 3.** Percentage of individuals in each family of bats tested that had not fallen from a rotating surface (velocity = 3°·s⁻¹), with changing angle of the surface. Surfaces are sandpaper (*a*), polycarbonate (*b*), aluminum sheet (*c*), and perforated aluminum sheet (*d*); 0° is horizontal with the bat on top, 90° is vertical, and 180° is horizontal with the bat below. Note that 54.8% of *T. tricolor* held onto the perforated aluminum sheet (*d*) past 90° (vertical line), indicating that these bats used wet adhesion.

**Table 3.** *Q* statistics obtained from multiple comparisons (two-tailed) of sticking ability among groups on each of the four surfaces.

<table>
<thead>
<tr>
<th>Family Comparison</th>
<th>Sandpaper</th>
<th>Sheet aluminum</th>
<th>Perforated aluminum</th>
<th>Polycarbonate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emballonuridae vs. Phyllostomidae</td>
<td>3.24**</td>
<td>1.56</td>
<td>0.73</td>
<td>0.42</td>
</tr>
<tr>
<td>Emballonuridae vs. Thyropteridae</td>
<td>5.97***</td>
<td>2.89*</td>
<td>5.58***</td>
<td>4.23***</td>
</tr>
<tr>
<td>Emballonuridae vs. Vespertilionidae</td>
<td>2.77**</td>
<td>1.69</td>
<td>0.93</td>
<td>0.19</td>
</tr>
<tr>
<td>Phyllostomidae vs. Thyropteridae</td>
<td>5.10***</td>
<td>7.86***</td>
<td>8.73***</td>
<td>8.37***</td>
</tr>
<tr>
<td>Phyllostomidae vs. Vespertilionidae</td>
<td>0.85</td>
<td>0.31</td>
<td>0.41</td>
<td>1.19</td>
</tr>
<tr>
<td>Thyropteridae vs. Vespertilionidae</td>
<td>5.66***</td>
<td>7.72***</td>
<td>8.41***</td>
<td>6.94***</td>
</tr>
</tbody>
</table>

* *P* < 0.05.
** *P* < 0.01.
*** *P* < 0.001.
placed in the screen cage. We did not observe any *T. tricolor* interlocking the thumb claws with the sandpaper or porous aluminum surfaces.

**Discussion**

Our data support the predictions from anatomical work that the disks of *T. tricolor* adhere to smooth surfaces by suction (Wimsatt and Villa R. 1970; Schliemann 1970b; Thewissen and Etnier 1995), with a secondary role for wet adhesion. The fluid-filled joint between the disk face and the substrate probably assists in maintaining a seal for suction, but the fluid can also provide the vehicle for wet adhesion. We could not determine which of the two possible components of wet adhesion, Stefan adhesion or capillarity, was used by *T. tricolor*. These components are distinguishable because in Stefan adhesion, the sticking force is exponentially correlated to the surface area of contact, and in capillarity the correlation is arithmetic (Emerson and Diehl 1980). By observing the sticking abilities of several different-sized species of tree frogs, researchers determined that capillarity was the component of wet adhesion in these animals (Emerson and Diehl 1980).

Wet adhesion may serve as an energy-conserving device. A locking mechanism (tendon-locking mechanism; TLM) opposite the proximal phalanges of each toe and pollex allows some bats to hold the digits in flexed positions with no muscular effort. Because *T. tricolor* lack a TLM (Quinn and Baumel 1993), attachment by suction presumably requires constant muscular exertion, so roosting over long periods of time could represent a significant energetic cost if elasticity is not involved. Wet adhesion may conserve energy by allowing complete or partial relaxation of the musculature controlling disk shape. Gluing may also be used when the period of attachment is long, though we did not test for gluing in this experiment.

Although *Thyroptera* species have most often been found in furled leaves (e.g., Findley and Wilson 1974), there are records of them roosting elsewhere. In Trinidad, Goodwin and Greenhall (1961) found *T. tricolor* roosting with *R. naso* in a curled dead *Heliconia* leaf. In French Guiana, 3 of 12 roosting groups of *T. tricolor* found by Simmons and Voss (1998) roosted in dry, curled, dead leaves of *Phenakospermum* sp. (Strelitziaceae). *Thyroptera discifera* have been reported roosting under dead banana leaves (Robinson and Lyon 1901; Torres et al. 1988). Our data demonstrate how the thumb claws can be used by *T. tricolor* to attach to rough surfaces, potentially demonstrating how these bats might use other, unknown types of roosts.

Disks allow the three species of *Thyroptera* and *Myzopoda aurita* (Myzopodidae) to move on smooth surfaces. Schliemann (1970a) described a plausible scenario by which the wrists and ankles of a diskless bat might be modified to form functional suction disks by gradual evolutionary change. Our results indicate that in the course of this evolution, *T. tricolor* lost some ability to use its claws for roosting the way its diskless ancestors did. The thumb of *T. tricolor* is bent dorsally and rotated away from the metacarpophalangeal joint (Wimsatt and Villa R. 1970). This arrangement, not seen in diskless bats, keeps the thumb clear of the disk on smooth surfaces, and appears to have diminished the functionality of the thumb as a means of gripping rough surfaces. Some vespertilionids without disks (*Tylonycteris pachypus, Pipistrellus nanus, and Myotis bocagei*) may also have some capacity for movement on smooth surfaces (Thewissen and Etnier 1995; Brosset 1966).

Compared with the disk-winged bats, other species of Chiroptera use interlocking, usually between toenails and substrate, to gain purchase and roost on rough surfaces and roost head-down. In *T. tricolor*, the roosting orientation reflects the roosting situation. In furled, tube-shaped leaves, the entrance is at the top, so *T. tricolor* roosting head-up face the entrance, allowing rapid emergence. This provides two selective advantages. First, because emergence time is shortened, the roost is made less conspicuous to predators, and second, for an individual under threat by a predator, rapid emergence decreases the likelihood of being caught (Fenton et al. 1994).

Although adhesive disks have appeared in only one superfamily (Nataloidea) of the Chiroptera (Simmons and Geisler 1998), differences in structural details between the disks of Myzopodidae and Thyropteridae do not support the view that the disks were an ancestral feature of the nataloids (Schliemann 1970b). Although the earliest fossil nataloids occur in Eocene strata, no fossils have been assigned to the Myzopodidae or Thyropteridae (Simmons and Geisler 1998), and some studies indicate that the Myzopodidae and Thyropteridae are not closely related and may not belong in the same superfamily (Van Den Bussche and Hooper 2001). Paul-like structures on the wrists of some vespertilionids suggest considerable flexibility in structures associated with roosting in bats (Thewissen and Etnier 1995), reflecting the variety of roosting opportunities exploited by bats (Altringham 1996; Fenton 2001). In a sense, adhesive disks are another way to exploit the roosting opportunities presented by foliage, a variation on the tents used by other bats, mainly phyllostomids (Kunz and McCracken 1996).

Suction occurs in many animal taxa and serves a variety of functions. The suckers of octopus (Cephalopoda), for example, serve in locomotion, anchoring the body, holding prey, collecting and manipulating small objects, chemotactile recognition, and cleaning manoeuvres (Packard 1988). Although mammals rely on suction during feeding, particularly before weaning, its use in locomotion is very rare, probably occurring only in the Hyracoidea and Chiroptera (Dobson 1876). If the data for *T. tricolor* are representative of other thyropterids and the myzopodid, then bats provide yet another example of animals that rely on suction for staying in place and moving about.

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