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SHORT COMMUNICATION

A sticky situation: solifugids (Arachnida, Solifugae) use adhesive organs on their pedipalps for prey capture

Rodrigo H. Willemart · Roger D. Santer · Andrew J. Spence · Eileen A. Hebets

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Abstract Solifugids (Arachnida, Solifugae) have unique evertable adhesive organs on the tips of their pedipalps, named 'suctorial' or 'palpal' organs. Previous studies have shown that these organs enable solifugids to climb smooth glass-like surfaces and have hypothesized that these structures facilitate prey capture. Here, we use high-speed videography to demonstrate that the suctorial organs of *Eremochelis bilobatus* are its primary means of capturing insect prey. We also present calculations of the adhesive pressure exerted by these suctorial organs during real prey capture events.

Keywords Solifuge · Adhesion · Foraging · Suctorial organ · Palpal organ

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R. H. Willemart · R. D. Santer · E. A. Hebets
School of Biological Sciences, University of Nebraska, Lincoln, NE, USA

Present Address:
R. H. Willemart (✉)
Escola de Artes Ciências e Humanidades, Universidade de São Paulo, Rua Arlindo Béttio, 1000, Ermelino Matarazzo, São Paulo 03828-000, Brazil
e-mail: willemart@usp.br

Present Address:
R. D. Santer
Department of Life Sciences, Schrodinger Building, University of Limerick, Limerick, Ireland

A. J. Spence
Structure and Motion Laboratory, Royal Veterinary College, University of London, Hertfordshire, UK

Introduction

The diverse array of animal adhesive organs are fascinating subjects for study, not least because these intricate and evolutionarily-honed structures can inspire the design of effective man-made adhesives (Lee et al. 2008; Schubert et al. 2008). Among arthropods, adhesive organs are common (Betz and Kölsch 2004; Clemente and Federle 2008), and most play important roles in locomotion, prey capture, or both (e.g., Rovner 1980; Kesel et al. 2003; Betz and Kölsch 2004).

Certainly enigmatic among arthropod adhesive organs are the 'suctorial organs' of solifugids (arachnids commonly called camel spiders or sun scorpions). Unlike other arachnids, solifugids possess an evertable membranous organ on the tip of each pedipalp (Cushing et al. 2005; Klann et al. 2008) (Fig. 1). These organs allow solifugids to climb smooth surfaces (e.g., Cushing et al. 2005), and convey water to their mouthparts for drinking (Savory 1964). Anecdotal observations indicate that these organs are also used in prey capture: solifugids directly strike at prey with their chelicerae or grasp them with their suctorial organs, depending on factors such as prey size and sclerotization, and solifugid size and species-specific behavior (e.g., Muma 1966; Punzo 1998). However, these observations have remained anecdotal because the rapidity of prey capture makes detailed observation difficult. Equally problematic, although outside the scope of this study, is understanding the adhesive mechanism involved: although named for a presumed suctorial function, recent morphological studies suggest that surface features, and the lack of glandular openings, indicate that dry adhesive mechanisms, for example van der Waals forces, predominate (Cushing et al. 2005; Klann et al. 2008).

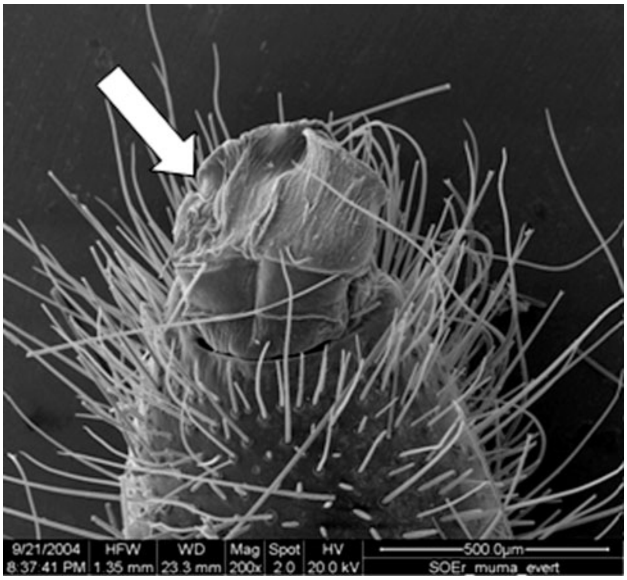

Fig. 1 Tip of the pedipalp of *Eremorhax mumai* Brookhart, 1972, showing the everted suctorial organ (*arrow*), ventral view (by P. Cushing)

Here, we use high-speed videography to substantiate previous impressions that the suctorial organs of *Eremochelis bilobatus* are its primary means of capturing insect prey of various sizes. We also make tentative calculations of the adhesive pressure developed by these organs during prey capture.

Materials and methods

Two adult male and one adult female *Eremochelis bilobatus* (family Eremobatidae, subfamily Therobatinae) were collected from Crow Valley Recreation Area, Pawnee National Grassland, Colorado, USA (40°38.684′N, 104°20.647′W, elevation 1,479 m) in June 2007.

Solifugids were filmed capturing laboratory-reared crickets of various sizes (*Acheta domestica*, *Gryllus lineaticeps* and *Gryllus firmus*), which comprised the solifugids' normal diet in the laboratory. Crickets occur in the Pawnee National Grassland and are often the most consumed prey item in field studies of solifugids (Punzo 1997; Punzo 1998). Films were recorded using a Fastcam 1024PCI high-speed digital camera (Photron USA, San Diego, CA, USA) at 500 fps. Prey capture was filmed from the side with the animals contained within an arena 130 mm wide × 137 mm high × 35 mm deep. The narrow depth of the arena limited movement in the *z*-plane, allowing 2-dimensional (*x*, *y* plane) analysis of movement. In total, we successfully filmed 27 prey capture sequences.

Results

High-speed videos clearly showed that *E. bilobatus* used its pedipalps as its primary means of prey capture. In all 27 prey capture events, a solifugid reacted behaviorally to a walking cricket only after contact, and crickets were always attacked first with the tip of the pedipalp (bearing the suctorial organ), never with the chelicerae. A single pedipalp was characteristically used for prey capture. Upon contact, the prey became immediately 'stuck', adhering to the suctorial organ (Fig. 2). Solifugids were able to bring airborne jumping crickets to the ground with their suctorial organs, demonstrating strong adhesive forces (supplementary materials). In all observed instances of prey capture, the suctorial organs were the primary means of capture. Solifugids were also observed to use their suctorial organs to grasp the experimenter's forceps prior to an attack with their chelicerae, potentially indicating an additional defensive function for these suctorial organs.

Discussion

Using high speed videography, we were able to verify a prey capture function for the solifugid suctorial organs. Observations of our 27 prey capture sequences clearly corroborate the intuition of previous researchers regarding the foraging function of these specialized organs. Despite their previously demonstrated capacity to function in climbing smooth surfaces (Cushing et al. 2005), the natural history of most solifugids calls into question the natural relevance of such behavior. Solifugids are typically found in dry, arid habitats, under rocks or other debris, in crevices, or in burrows (Punzo 1998), meaning that they should rarely have to climb smooth, vertical surfaces. In cases where such surfaces do occur (such as smooth leaves), then the suctorial organs could also help in locomotion.

Arachnids are predators and many, if not most, members of this group utilize their pedipalps during prey capture and manipulation. The pedipalps of many arachnid groups are modified into pincer-like or raptorial appendages specialized for prey capture (e.g., amblypygids, uropygids, schizomids, some opilionids, scorpions, and pseudoscorpions; see Beccaloni 2009). Some groups also possess pincer-like modifications of their chelicerae (e.g., opilionids, scorpions and pseudoscorpions; see Beccaloni 2009). Previously, spiders were confirmed to use adhesive organs for prey capture, by means of adhesive setae on the legs (Rovner 1980), and a few species of harvestmen from the northern hemisphere were known to use sticky glandular setae on the pedipalps to capture prey (e.g., Gruber 1970, 1974). Solifugids are now the third arachnid group

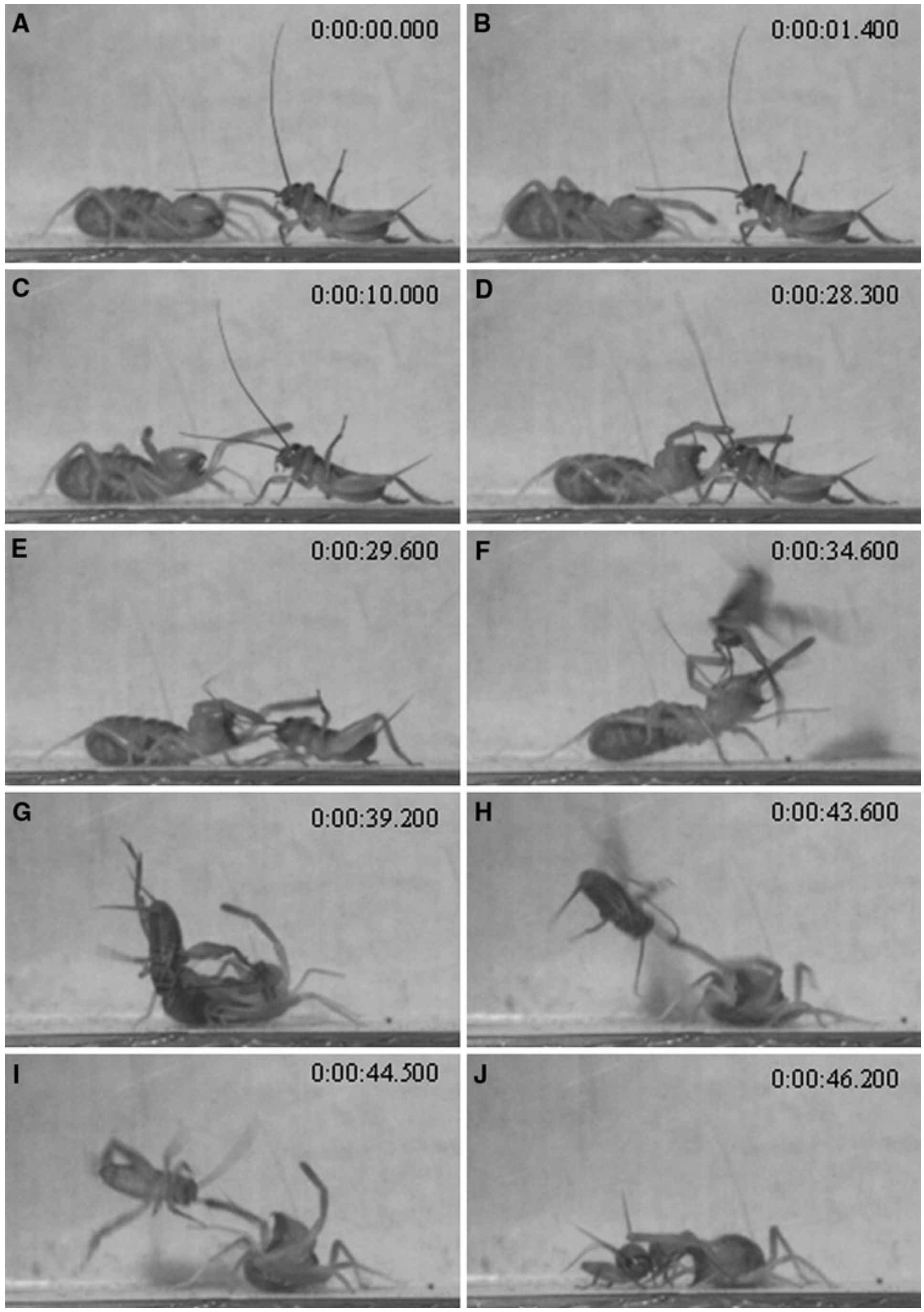

Fig. 2 Example frames from a 500 frames/s recording of *E. bilobatus* capturing a jumping cricket using the suctorial organ on the tip of the pedipalp: The unalarmed cricket approaches and touches the solifugid (**a**), which backs up (**b**), raises its pedipalps (**c**) and approaches the cricket with the chelicerae open (**d**). One pedipalp makes contact with an antenna of the prey, which pulls back (**e**) and jumps (**f**). Still held by the tip of the solifugid's pedipalp, the cricket kicks (**g**) and jumps again in unsuccessful attempts to escape (**h**, **i**). The solifugid approaches the cricket with the chelicerae open (**j**). The solifugid measures 25 mm from the tip of the chelicerae to the end of the abdomen. Time in seconds

substantiated to use adhesion for capturing prey. Interestingly, these are groups that also lack strong spines or pincer-like structures in the pedipalps. The suctorial organs of solifugids, the adhesive seta of spiders, and the glandular setae of harvestmen are located on different body parts and are structurally very different, indicating independent evolutionary pathways.

The suctorial organs of solifugids differ from typical arthropod adhesive organs used in prey capture in two ways—they are not hairy and they do not use gland secretions (Betz and Kölsch 2004; Cushing et al. 2005; Klann et al. 2008). It is interesting to know, therefore, if the adhesive pressures developed by such an atypical organ are comparable to the ones that have evolved in other groups. From our high speed films of prey capture events, we were able to make some tentative calculations on the adhesive pressures that the suctorial organs are able to develop during prey capture. From four prey capture sequences in which an airborne jumping cricket's trajectory deviated as a result of adhesion to a solifugid's suctorial organ, we tracked the cricket's position in *x*, *y* co-ordinates, obtained the cricket's velocity at each frame, and from that calculated the change in velocity resulting from adhesion to the solifugid's suctorial organ. From this change in velocity, and the cricket's mass, we calculated the force exerted on the cricket through the suctorial organ in each sequence (details of our calculation methodology are provided in the Electronic supplementary material). The maximum adhesive force we calculated (F_a) was 0.026 N, which gave a maximum observed adhesive pressure (force per area of suctorial organ) of 7.3×10^4 N/m^2 (mean $\pm$ SD $= 4.0 \pm 2.3$ N/m^2, $n = 4$ captures, one solifugid, four crickets of varying size). This estimate is within the region of adhesive pressures developed by the adhesive organs of other arthropods—as examples: 2×10^3 N/m^2 for the bush cricket *Tettigonia viridissima* (Orthoptera) (Jiao et al. 2000), and 2.24×10^5 N/m^2 for the jumping spider *Evarcha arcuata* (Salticidae) (Kesel et al. 2003), and is in excess of that required to support the solifugid's weight during climbing ($F_a = 0.003$ N, adhesive pressure $= 9.0 \times 10^3$ N/m^2).

In summary, the suctorial organs of solifugids serve an important function as the primary means of capturing fast, mobile prey items. Future study of variation in grasping organs across arachnid groups, and variation in their ecological function, may not only enable an understanding of their evolutionary history, but might one day help in the design of bio-inspired grasping devices.

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