

SHORT COMMUNICATION

Female attack is not necessary for male copulatory organ breakage in the sexually cannibalistic spider *Argiope argentata* (Araneae: Araneidae)

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Abstract. In sexually cannibalistic spiders, males usually only copulate with one female. This selects for male strategies to improve paternity success in their single mate. Male mating strategies can include genital damage during female attack in some cannibalistic orb-weaving spiders, where males are dwarf and females polyandrous. We explored whether sexual cannibalism is necessary for male genital damage in the silver spider *Argiope argentata* (Fabricius 1775) by performing mating trials with recently killed virgin females. We found that males can break off their copulatory organs without female intervention and spontaneously die during copulation. Results suggest that genital damage evolved in response to sperm competition in this species.

Keywords: Genital damage, sperm competition, mating plug

Sexual cannibalism, defined as instances where females kill and consume conspecific males before, during, or after copulation, has been considered an extreme case of conflict of interest between the sexes (Elgar 1992). Males benefit by fertilizing more eggs, while females can benefit by remating (Simmons 2005), leading to sexual antagonistic coevolution (Arnqvist & Rowe 2005). Sexual cannibalism has been reported for a variety of invertebrates, including crustaceans, insects, and arachnids, and is particularly frequent among spiders (Elgar 1992). If males transfer sperm successfully, then sexual cannibalism may be part of a male mating strategy (Elgar & Schneider 2004). In these cases, males maximize their paternity in an act of single mating, becoming monogynous. Such terminal investment without parental care has been shown to evolve under a male-biased effective sex ratio with high risk of sperm competition (Fromhage et al. 2005).

In a framework of high sperm competition, males will develop offensive and defensive strategies to protect paternity, including the use of mating plugs. Mating plugs can be substances that become hard while occluding genital ducts (Baer et al. 2001; Polak et al. 2001; Aisenberg & Eberhard 2009), or parts or the entire male copulatory organ, a process known as genital damage (Eberhard 1985; Kamimura 2003; Uhl et al. 2010). Genital damage is widespread among sexually cannibalistic spiders, where males usually break off parts or the entire copulatory organ during copulation (Andrade 1996; Andrade & Banta 2002; Elgar & Schneider 2004; Foellmer & Fairbairn 2004; Miller 2007; Nessler et al. 2008). Male spiders' copulatory organs are paired (palpal bulbs) and the intromittant features, the emboli, are introduced into the paired female genital openings during mating, usually one at a time. In spiders, all known cases of genital damage occur in entelegyne spiders in which the genitalia are sclerotized and the ovipository duct is independent from the copulatory ducts, and therefore not occluded by mating plugs (Uhl et al. 2010).

In spiders, paternity success is usually linked to copulation duration and sperm transfer (Elgar 1995). Schneider et al. (2006) and Nessler et al. (2006) suggested the occurrence of a sexual conflict over copulation duration in the orb-web spider *Argiope bruennichi* (Scopoli 1772), where female attack occurs precisely when the male dislodges the used copulatory organ and tries to insert the other one (Schneider et al. 2006). In the orb-web spider *Nephila plumipes* (Latreille 1804), palpal organ breakage increases male survivorship, allowing a second

insertion and increased copulation duration, whereas males that do not break their organs are cannibalized (Schneider et al. 2001). In *Argiope lobata* (Pallas 1772), cannibalized males break off their genital copulatory organs more frequently than surviving males, suggesting that sexual cannibalism facilitates genital damage (Nessler et al. 2008).

The silver spider *Argiope argentata* (Fabricius 1775) is an araneid spider with Pan-American distribution (Levi 1968). In the field, Robinson & Robinson (1980) observed that males arrive on females' webs, court from the periphery, and afterwards move to the hub of the web where mating usually occurs, and sexual cannibalism always occurs during or after copulation. In the laboratory, virgin females are usually receptive to courting males, but they attack them during the first insertion, forcibly dislodging males from their genitalia with their third pair of legs, resulting in 70% of the males dying (Ghione 2008). Surviving males reinitiate courtship and perform a second insertion; after that they are consumed by the females. Males always break the apical region of the embolus, including a singular sclerite or spur of unknown function (Levi 1968), that remains stuck inside the female ducts (Ghione et al. 2006; Ghione 2008).

In the present study, we used freshly killed females to explore experimentally if males can break off their copulatory organs by themselves, or if female cannibalistic attack determines male genital damage. We hypothesize that the female's attack has a direct impact on the copulatory outcome, both in the removal of the male and the breaking off of the inserted copulatory organ.

We collected nine subadult males, 11 subadult females, and 18 adult males of *A. argentata* between September to March (spring and summer of 2005–2006 and 2006–2007), in meadows at Piedras de Afilar, Canelones, Uruguay (34°45'42.5"S and 55°33'10.8"W), a temperate region. We housed spiders individually in 500-ml glass containers, providing water daily, and *Tenebrio* sp. larvae (Tenebrionidae) twice per week.

In order to determine if the male can break off his copulatory organs by himself or if it is the female that breaks them off when she abruptly removes the male from her genitalia, we carried out experiments with recently killed virgin females. We killed them by means of hypothermia, placing them at a low temperature for 20 minutes. Afterwards, dead females were carefully attached "face down" (typical "sit and wait" and mating posture) to their own web's radii, fixed by adding melted paraffin onto each of their eight leg tarsi. Once females were fixed to the web in the proper position, we



Figure 1.—a) Dead male attached to female genitalia in *Argiope argentata*; b) the same male inserting the right palpal organ and showing the left one with the broken embolus tip (arrow).

carefully removed silk with forceps from their spinnerets and added it to the hub or center of the web, as naturally occurs when females are positioned in the web.

For each trial, two adult males were carefully placed equidistantly from the margin of the orb-web of a recently attached killed female. We placed two males to increase the likelihood of copulation. We simulated female behaviors observed in a sexual context (Ghione, pers. obs.) by softly shaking the web, using a pencil to prod the female's corpse, in response to male courtship. We replaced males when a male did not court during a 15-min period, a male courted

from the periphery but did not move to the hub within one hour, or a male initiated courtship but did not proceed to copulation over the course of two hours. This exchange of unsuccessful males continued until either copulation occurred or a total of 5 hours had elapsed, limited by the rapid decay of the dead female in warm experimental conditions. When one male achieved copulation, the other male was immediately (but carefully) removed from the web in order to avoid male-male interferences.

We performed a total of 11 trials and obtained four successful copulations. The occurrence of copulations was highly unpredictable

and difficult. Male genital damage was determined under a dissecting microscope. We deposited voucher specimens in the arachnological collection of Facultad de Ciencias, Montevideo, Uruguay.

In all the 11 trials, males courted the females and responded to the simulations of female sexual behaviors. All copulating males died immediately after copulation. Three males performed two palpal insertions. They jumped off the female epigynum a few seconds after their first insertion and escaped from the female web, but immediately returned and courted again. After their second insertion, all three died spontaneously, remaining attached to female genitalia. One male died spontaneously after performing a single palpal insertion. We did not know the exact time of death, but death was confirmed after we proceeded to carefully touch unmoving males (in mating position) with a candy pin after an arbitrary period of 30 minutes of immobility. Each of the three males that performed two insertions broke off the first inserted organ and the embolus tip remained inside the female reproductive tract. The second inserted copulatory organs were not broken off due to males dying and remained connected to female epigynum (Fig. 1).

Results indicate that males spontaneously die in copula, evidenced by the absence of female intervention, as was observed for other *Argiope* species (*A. aurantia* [Lucas 1833]; Foellmer & Fairbairn 2003; *A. aemula* [Walckenaer 1841]; Sasaki & Iwahashi 1995; *A. keyserlingi* Karsch 1878; Herberstein et al. 2005; *A. bruennichi*: Schneider et al. 2006). In entelegyne spiders, the hematodochae expands during copulation, allowing the penetration of the embolus into the female genital tract (Foelix 1996). In *A. argentata*, the expansion of the haematodochae probably requires sequestration of a large percentage of hemolymph from body circulation, provoking males' deaths. The single male which died after his first insertion could possibly have mated previously in the field. However, this male was previously examined under the dissecting microscope, and possessed both intromittant organs intact. Therefore, a previous mating in the wild of this individual is improbable.

Three males were able to disengage and break off their copulatory organs without female intervention, contrary to our prediction. Our results confirm that males alone engage in genital autotomy; female action during cannibalism is not required. This is the first demonstration of voluntary emasculation by males during copulation in *Argiope* species. Each male of *A. argentata* did not dislodge himself from the epigynum after the second insertion and died firmly attached to female genitalia, suggesting that the entire male body could act as a whole-body mating plug, as was stated by Foellmer & Fairbairn (2003) for *Argiope aurantia*. In *A. argentata*, the expanded copulatory organ could continue ejaculating seminal fluids after the male's death, as was indicated by Knoflach & van Harten (2001) for theridiid spiders. Interestingly, males would be impeded from remaining attached to the genitalia if the female was alive.

In the present study, we found that males of *A. argentata* can voluntarily break off their genital organs, suggesting that there is no obligate relationship between genital damage and sexual cannibalism in this species. This suggests that sperm competition would be the sexual selection mechanism that underlies this particular behavior of voluntary genital mutilation. Male monogyny has been stated to evolve under a male-biased effective sex ratio (Fromhage et al. 2005), favoring extreme male strategies to ensure paternity. Nevertheless, an increased sample size and experiments with other modifications interfering with sexual cannibalism would help to confirm this hypothesis in this spider.

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LITERATURE CITED

- Aisenberg, A. & W.G. Eberhard. 2009. Female cooperation in plug formation in a spider: effects of male copulatory courtship. *Behavioral Ecology* 20:1236–1241.
- Andrade, M.C.B. 1996. Sexual selection for male sacrifice in the Australian redback spider. *Science* 271:70–72.
- Andrade, M.C.B. & E.M. Banta. 2002. Value of male remating and functional sterility in redback spiders. *Animal Behaviour* 63:857–870.
- Arnqvist, G.A. & L. Rowe. 2005. *Sexual Conflict*. Princeton University Press, Princeton, New Jersey.
- Baer, B., E.D. Morgan & P. Schmid-Hempel. 2001. A nonspecific fatty acid within the bumblebee mating plug prevents females from remating. *Proceedings of the National Academy of Sciences USA* 98:3926–3928.
- Eberhard, W.G. 1985. *Sexual Selection and Animal Genitalia*. Harvard University Press, Cambridge, Massachusetts.
- Elgar, M.A. 1992. Sexual cannibalism in spiders and other invertebrates. Pp. 128–155. *In* *Cannibalism: Ecology and Evolution Among Diverse Taxa*. (M.A. Elgar & B.J. Crespi, eds.). Oxford University Press, Oxford, UK.
- Elgar, M.A. 1995. Duration of copulation in spiders: comparative patterns. *Records of the Western Australian Museum (Supplement)*. 52:1–11.
- Elgar, M.A. & J.M. Schneider. 2004. The evolutionary significance of sexual cannibalism. *Advances in the Study of Behavior* 34:135–163.
- Foelix, R.F. 1996. *Biology of Spiders*, Second edition. Harvard University Press, Cambridge, Massachusetts.
- Foellmer, M.W. & D.J. Fairbairn. 2003. Spontaneous male death during copulation in an orb-weaving spider. *Proceedings of the Royal Society B* 270:S183–S185.
- Foellmer, M.W. & D.J. Fairbairn. 2004. Males under attack: sexual cannibalism and its consequences for male morphology and behavior in an orb-weaving spider. *Evolutionary Ecology Research* 6:163–181.
- Fromhage, L., M.A. Elgar & J.M. Schneider. 2005. Faithful without care: the evolution of monogyny. *Evolution* 59:1400–1405.
- Ghione, S. 2008. Comportamiento sexual de la araña orbicular solitaria *Argiope argentata* (Fabricius 1775) (Araneae, Araneidae): canibalismo sexual y posible tapón copulatorio. MSc. Dissertation Thesis, Facultad de Ciencias, Universidad de la República, Montevideo, Uruguay.
- Ghione, S., C. Viera & F.G. Costa. 2006. Sexual cannibalism and broken copulatory organs in the orb-weaving spider *Argiope argentata* (Araneae, Araneidae). Abstracts, 23rd European Colloquium of Arachnology, Sitges, Barcelona:42.
- Herberstein, M.E., A.C. Gaskett, J.M. Schneider, N.G.F. Vella & M.A. Elgar. 2005. Limits to male copulation frequency: sexual cannibalism and sterility in St Andrew's cross spider (Araneae, Araneidae). *Ethology* 111:1050–1061.
- Kamimura, Y. 2003. Effects of broken male intromittent organs on the sperm storage capacity of female earwigs, *Euborellia plebeja*. *Journal of Ethology* 21:29–35.
- Knoflach, B. & A. van Harten. 2001. *Tidarren argo* sp. (Araneae: Theridiidae) and its exceptional copulatory behaviour: emasculation, male palpal organ as mating plug and sexual cannibalism. *Journal of Zoology* 254:449–459.
- Levi, H.W. 1968. The spider genera *Gea* and *Argiope* in America. *Bulletin of the Museum of Comparative Zoology* 136:319–352.
- Miller, J.A. 2007. Repeated evolution of male sacrifice behavior in spiders correlated with genital mutilation. *Evolution* 61:1301–1315.

- Nessler, S.H., G. Uhl & J.M. Schneider. 2006. Genital damage in the orb-web spider *Argiope bruennichi* (Araneae: Araneidae) increases paternity success. *Behavioral Ecology* 18:174–181.
- Nessler, S.H., G. Uhl & J.M. Schneider. 2008. Sexual cannibalism facilitates genital damage in *Argiope lobata* (Araneae, Araneidae). *Behavioral Ecology and Sociobiology* 63:355–362.
- Polak, M., L.L. Wolf, W.T. Starmer & J.S.F. Barker. 2001. Function of the mating plug in *Drosophila hibisci* Bock. *Behavioral Ecology and Sociobiology* 49:196–205.
- Robinson, M.H. & B. Robinson. 1980. Comparative studies of the courtship and mating behaviour of tropical araneid spiders. *Pacific Insects Monographs* 36:1–218.
- Sasaki, T. & Iwahashi, O. 1995. Sexual cannibalism in an orb-weaving spider *Argiope aemula*. *Animal Behaviour* 49:1119–1121.
- Schneider, J.M., M.L. Thomas & M.A. Elgar. 2001. Ectomised conductors in the golden orb-web spider *Nephila plumipes* (Araneoidea): a male adaptation to sexual conflict? *Behavioral Ecology and Sociobiology* 49:410–415.
- Schneider, J.M., S. Gilberg, L. Fromhage & G. Uhl. 2006. Sexual conflict over copulation duration in a sexually cannibalistic spider. *Animal Behaviour* 71:781–788.
- Simmons, L.W. 2005. The evolution of polyandry: sperm competition, sperm selection and offspring viability. *Annual Review of Ecology, Evolution, and Systematics* 36:125–146.
- Uhl, G., S.H. Nessler & J.M. Schneider. 2010. Securing paternity in spiders? A review on occurrence and effects of mating plugs and male genital mutilation. *Genetica* 138:75–104.

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