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# Jumping spiders in outer space (Araneae: Salticidae)

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**Abstract:** A YouTube/Google-sponsored study of the behavior of a *Phidippus* jumping spider in the International Space Station produced video documentation of the ability of this spider to walk on surfaces and to make short, direct jumps to capture small flies in the absence of gravity. Future experiments that involve evaluation of the behavior of salticid spiders in space, including those that require a longer jump away from a surface to capture prey, or completion of an indirect pursuit that would normally require the use of gravity as a reference direction, are recommended. Because of their unique features that include the ability to adhere to and walk normally on surfaces in any orientation, their reliance on gravity, and their many behaviors (including use of draglines, jumping attacks and detoured pursuit) that can be readily observed in captivity, salticid spiders are excellent subjects for these experiments in space.

**Key words:** gravity, orientation, International Space Station, *Phidippus*, salticid

## Introduction

The following summary is drawn from a series of accounts or videos posted on the Internet (NASA Johnson Space Center 2012, Williams 2012; Pearlman 2012a, 2012b; Scientific American Space Lab 2012; Smithsonian Newsdesk 2012; Smithsonian Science 2012a, 2012b; Mohamed 2013; NASA Space Station 2013, 2016; Atkinson 2015; Countryman, pers. comm.; Cushing, pers. comm.):

> In late 2011 a *YouTube Spacelab Contest* resulted in the selection of several student proposals for YouTube/Google-sponsored research by NASA astronauts in orbit on the International Space Station (ISS). One of the winners was Amr Mohamed of Alexandria, Egypt, who suggested that a jumping spider should be launched into orbit to determine if the absence of gravity (or the presence of only "microgravity") interfered with its ability to capture prey. Since these spiders normally rely on gravity when they jump on their prey, they might be unsuccessful at capturing prey in space. For this study, Amr Mohamed was listed as Principal Investigator, with Louis S. Stodieck and Stefanie Countryman of BioServe Space Technologies of Boulder, Colorado as collaborators. On the ISS, NASA astronaut Sunita L. Williams conducted trials in which fruit flies (*Drosophila* sp.) were released into containers containing jumping spiders. One of these containers contained a female *Salticus* ("Cleopatra"), identified as *S. scenicus* (Clerck 1757), and the other contained a female *Phidippus* ("Nefertiti"), identified as *P. johnsoni* (Peckham & Peckham 1883). The *Salticus* fed in space but its behavior was not recorded and it died during the return to Earth. Prey capture by the *Phidippus* in orbit (21 July to 28 October 2012) was recorded, and this spider was alive when placed on exhibit in the Smithsonian 29 November 2012. However, only a few days later (3 December 2012) she was found dead, cause unknown.

The *Phidippus* specimen has not been located (Coddington, pers. comm.), but came from Arizona (Countryman, pers. comm.), and photographs suggest that this was a female *P. johnsoni* as reported (Edwards, pers. comm.). The *Salticus* specimen is presently on display in the Space Odyssey exhibit at the Denver Museum of Nature & Science (Cushing, pers. comm.).

My evaluation of the behavior of this *Phidippus* in orbit is based on video records of her movement and predation, either posted at several internet sites (Scientific American Space Lab 2012, NASA Johnson Space Center 2013, NASA Space Station 2013, Atkinson 2015; see also Figure 1), or furnished directly to me (Figure 2). I am presently not aware of any formal publications that have reported related results.

One video clip shows this *Phidippus* walking on the interior surfaces of her container and includes a short (~1.5 cm) jump to capture a fly on the surface occupied by the spider (Figure 1: 7-8). A second video clip shows this *Phidippus* jumping ~2 cm away from a surface to capture a fly, subsequently recoiling on her dragline while floating in space (Figure 2). A third video clip shows the same spider after her return to Earth, jumping from a vertical surface to collide with the clear polycarbonate front (window) of her container (Figure 1: 9-10).

**Figure 1. 1,** NASA astronaut Sunita L. Williams holding two spider boxes in the International Space Station (Expedition 33). **2,** NASA astronauts Joseph M. Acaba and Sunita L. Williams photographing a spider in the ISS. **3,** Female *Salticus scenicus* (Clerck 1757) named "Cleopatra." **4,** Female *Phidippus* named "Nefertiti." **5-6,** Two views of female *Phidippus* walking on walls of spider box. **7-8,** Sequential frames from video showing the female *Phidippus* in orbit, before (7) and after (8) ~1.5 cm jump to capture a fruit fly. **9-10,** Sequential frames from video showing the female *Phidippus* after her return to earth, before (9) and after (10) an unsuccessful jump to capture a fruit fly. After hitting the transparent front of the box, the spider struggled to right herself for several seconds. Photos 1-3 courtesy of NASA, 4-10 courtesy of BioServe Space Technologies.

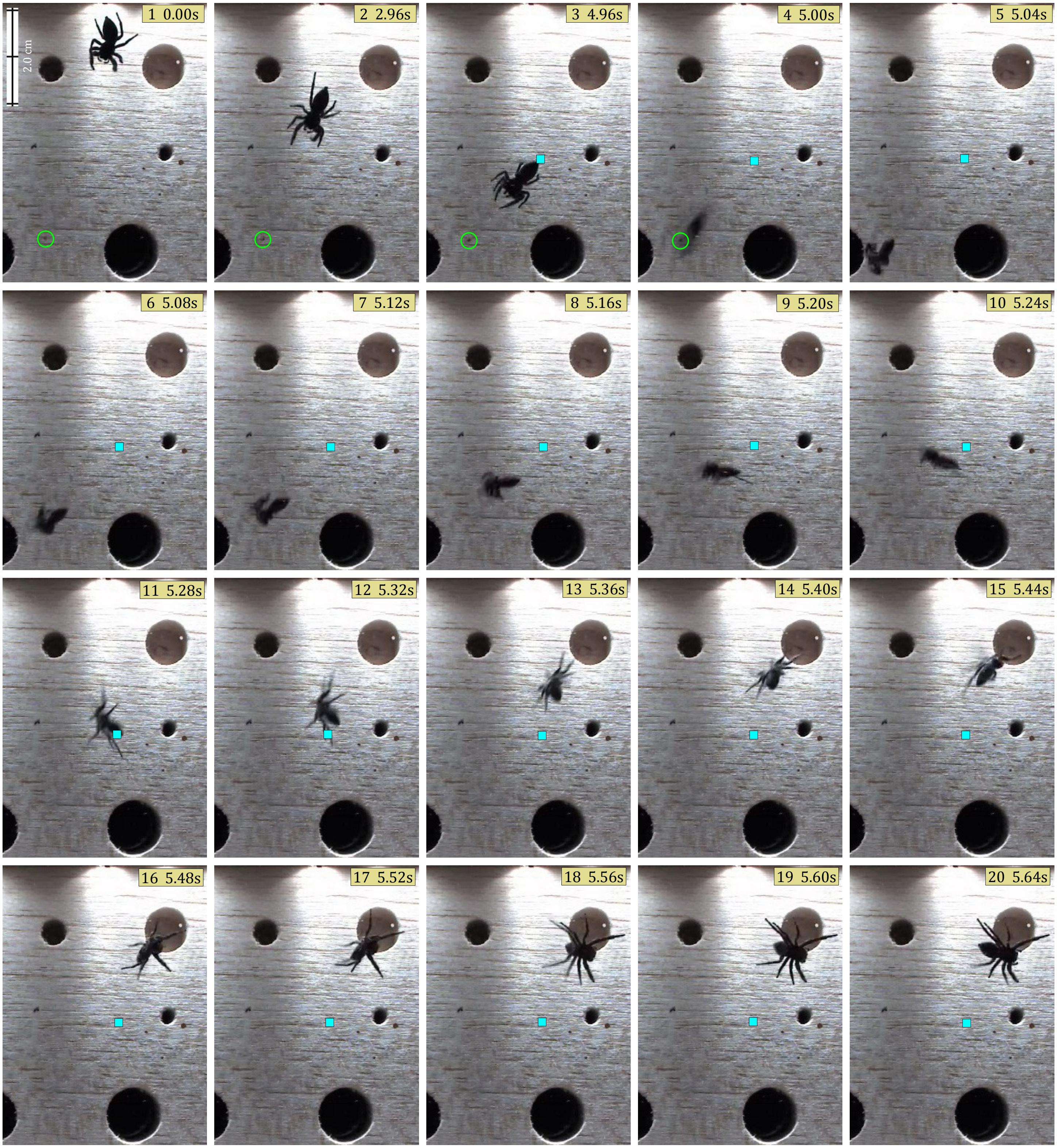

**Figure 2.** Frames from a 25fps video showing capture of a 'floating' *Drosophila* by the female *Phidippus* in orbit. Frames 3-20 are consecutive. **1,** Spider walking inside of clear polycarbonate window, just after completing a rapid lateral turn to face the fly (in green circle). **2,** Spider stalking or approaching the fly by walking on the window. **3,** Spider in position at start of jump, with legs IV flexed against the window. In this and in subsequent frames the small blue rectangle shows the assumed position of the spider's attachment disk, on the window. **4,** Spider in flight to the prey position. **5,** Maximum extension of dragline during prey capture. **6-10,** Successive positions of spider during recoil after prey capture. Note that these retraced the original flight trajectory, in the opposite direction. **11-20,** Continuing her rotation and recoil movement, the spider regained her hold on the surface of the window, apparently at the maximum extension of the dragline in a direction opposite to the attack direction. This video record was provided by Stefanie Countryman, courtesy of Bioserve Space Technologies.

## Discussion

From the recorded observations of the behavior of this female *Phidippus*, we can conclude that this kind of spider can walk rapidly on surfaces in the absence of gravity, and it can also make a short, direct jump to capture and then to feed upon a small fly. From this it is clear that, although gravity can affect the stability of a salticid based on its orientation on a surface, the adhesive mechanism of the salticid foot (Hill 1977, 2010c), thought to rely on van der Waals forces, is still functional in the absence of gravity. This agrees with the fact that salticids easily walk not only on the top of surfaces, but also beneath them, or on vertical surfaces.

It was reported that this *Phidippus* went through a period of adaptation or "trial and error" learning on the ISS before she was able to successfully capture fruit flies, and that she subsequently had difficulty ("fighting with gravity") with jumps intended to capture these flies after her return to Earth (Mohamed 2013; Atkinson 2015; Figure 1: 9-10).

It is well-known that gravity plays an important role in the ability of salticid spiders to observe and to remember directions in space and to complete accurate targeted jumps, often at a considerable distance, that compensate for the effects of gravity (Hill 1978, 1979, 2010a, 2010b). Although *Phidippus johnsoni* live near the ground (Jackson 1978, 1979), we have no reason to suspect that their use of gravity is any different from that observed in other members of the genus. Gravity plays a similar, important role in the orientation of other animals living on the surface of planet Earth. There are many published studies of the disorientation that occurs when humans are deprived of gravity (*e.g.*, Lackner & DeZio 2000; Oman 2001; Lopez *et al.* 2009; Clark *et al.* 2015). Visual cues such as the observation of the relative direction of the feet or head, or the perception that a line or figure is vertical, may substitute for the use of gravity by humans. Illusions or symptoms of disorientation are also experienced by human subjects in the absence of gravity. For example, an astronaut may suddenly obtain a strong sense of falling or vertigo, or may become convinced that he or she is upside-down. We can understand disorientation with respect to a person on Earth who becomes lost on a cloudy day and quickly loses all sense of map direction. We know nothing about the gravireceptors of salticids, but we do know that their ability to function normally when upside-down or in any intermediate orientation is exceptional. This includes the ability to successfully complete predatory jumps while upside-down (Hill 2010b). In the absence of relevant external cues, however, it is quite possible for a salticid to become disoriented (Hill 1978, 1979, 2010a).

An attacking *Phidippus*, like other salticids, typically makes an attachment disk just before a jump, and then brakes on the dragline near the expected position of its prey (Hill 1978, 2010b, 2012; Chen *et al.* 2013). This braking reverses the backward pitch of the spider in flight and brings the legs of the spider forward, around the prey. Recoil associated with elasticity of the dragline ('bungee effect') can also serve to pull the salticid with its prey away from a surface, limiting the ability of that prey to maintain a foothold and thereby struggle with its captor (Hill 2012).

To complete longer targeted jumps in the presence of gravity, salticids can jump faster and launch themselves in a direction well above the target to attain the greater range that is required (Hill 2010b). In comparison, a short (~ 2cm or less) jump on a surface requires little elevation, and any elevation that does take place is easily compensated by the reversal of pitch at the end of the jump, bringing the spider back into contact with the underlying surface, even in the absence of gravity (Figure 1: 7-8). Similarly, salticids often capture prey with short jumps on the underside of leaves without losing their footing.

The video recording of this *Phidippus* jumping away from the window of its container to capture a fly in orbit (Figure 2) is of particular interest. Our view of this successful jump does not allow accurate measurement of direction relative to the prey, but since the fly was captured in the chelicerae of this spider it is reasonable to assume that the jump was direct (no elevation of trajectory). Did this *Phidippus* make direct jumps in the absence of gravity by default, or did it learn to do so by trial and error? These are good questions for future study. Again, since this was a short jump for a *Phidippus* (~2 cm; I have observed successful downward jumps of ~20 cm by an adult *Phidippus audax*), even on Earth one would expect this short jump to be fairly direct. The distance of this jump was about 1.5 cm in the projection that we can see, but since the fly was somewhere back in the container (depth ~4 cm; Countryman, pers. comm.) an additional component of flight away from the window must also be considered. Assuming that this spider followed the usual practice and secured its dragline just before takeoff (Figure 2: 3), it is clear that recoil from the elastic dragline pulled her back to a position where a foothold could once be secured on the window, equidistant to the jump and in the opposite direction. Although not visible, the extended dragline must have limited the distance of this recoil trajectory. On Earth, one would never observe recoil flight (or free flight) like this because of the continuous force of gravity on the spider, and predatory jumps often end with a spider hanging downward from its dragline, the prey securely held with the fangs. Some salticids feed in this position (Figure 3), but most climb back up the dragline with legs IV before they feed.

**Figure 3.** Young instar of *Colonus sylvanus* (Hentz 1845) feeding on a captured plant hopper (Hemiptera: Fulgoromorpha) in the woodland understory of southern Greenville County, South Carolina. Each scale bar = 1.0 mm. **1-2,** This spider held the dragline with legs IV as it manipulated its prey with the other legs while feeding. **3,** After feeding, this spider dropped its prey and almost immediately the remains were found by a small ant and a slug (at right) on the forest floor. Photographs by the author.

Although gravity represents an omnipresent source of directional information on the surface of the Earth, there is no reason to assume that it is required for the assessment of relative position by spiders. As with humans, gravity may serve to maintain the up-down orientation of a spider's internal representation of its surroundings (internal perception of "space"), but a three-dimensional representation should still be present in the absence of gravity. Direction-finding in the absence of gravity should be supported by both idiothetic (referent to body position in space) and visual information. Earlier studies have shown that the araneid spider *Araneus diadematus* can build a complete, planar orb web in the absence of gravity (Witt *et al.* 1977). To accomplish this, however, the *Araneus* in outer space could not simply descend on a dragline to initiate the framework of its web as it would have done on Earth, but instead crawled around the frame of its container to secure lines used to anchor that web. This took some time. In addition, more subtle differences in the normal (Earthbound) spacing of lines in the upper and lower parts of this spider's web were not observed in the absence of gravity.

There are many simple and revealing experiments that could be performed with a jumping spider like *Phidippus* in orbit. One simple trial would involve the presentation of a larger prey stimulus (*e.g.*, an artificial fly) at a distance that would require the spider to make a longer jump away from a surface at a distance of 5-10 cm, subject to a lateral view or projection for accurate video recording of position in the plane of the jump. Would the spider jump directly at the prey (perhaps assuming that it was "down"), or would it compensate for a perceived (illusory) gravity vector based on visual cues, and miss? Assuming that the spider would brake on its dragline upon arrival at the expected prey position (Hill 2010a, 2010b), early results described here (Figure 2) suggest that the spider would not be able to climb up the dragline after a jump, but that dragline would at least serve as a tether. If a simple detour problem like indirect pursuit of prey on a route (stick or rod) were presented (Hill 1979, 2010a), one would expect to observe (at least) relative disorientation with respect to radial direction in agreement with loss of the horizontal reference plane defined by gravity. Would a salticid be able to substitute a visual cue (such as a line perpendicular to that route) for the absence of gravity and still retain a memory of relative direction? Based on human experience and the frequent use of visual cues by salticids in circumstances where gravity cannot be used, we might expect this to be the case.

Because they have feet that allow them to hold on to objects in the absence of gravity, come readily equipped with a tether that provides recoil propulsion for return to a starting point, are versatile in remembering directions in three-dimensional space regardless of their orientation, and readily perform in captivity, salticid spiders remain excellent subjects for future studies of animal behavior in a gravity-free environment.

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