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A computerised method to observe spider web building behaviour in a semi-natural light environment

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Abstract
Spider webs are a record of the application of a series of behavioural patterns. Web building behaviour is of great interest to ethologists and taxonomists studying the evolutionary relationships of spiders. However, due to the inability of the researcher to observe the spider around the clock during web building, many details of the behavioural patterns remain undetected. To overcome this problem we developed a novel, computerised method to continually observe the spider during web building. The spider is kept in a temperature controlled room, on a reversed light cycle, confined to an observation arena placed in front of an infrared illuminated background. An infrared sensitive digital video camera is used to capture live images which are transferred to a computer where they are analysed in real time. A separate program allows a detailed study of the recorded movements, including various spatial and temporal analyses. It also allows for the export of movement patterns. The method of observation and data analysis developed by us, enables the detailed study of the web building behaviour of nocturnal spiders and eliminates most constraints encountered to date. Due to the inaccuracy of human observation of long chains of behavioural events and the stereotypic nature of web building behaviour, computerised observation systems are preferable.

Key words: Araneae, spiders, web building behaviour, computerised observation, computerised data analysis

INTRODUCTION

Spider webs are a semi-permanent record of the application of a series of behavioural patterns. The web building behaviour and the finished web of a spider are of immense interest to ethologist and taxonomist studying the evolutionary relationships within different spider taxa (Eberhard 1982).

However, due to the inability of the researcher to observe the spider continuously during web building, many details of the behavioural patterns can remain undetected. For instance, the earlier stages of web construction, which are considered important for deducing taxonomic relationships, are the least studied. The complicated movement patterns of the spider during this stage of construction make it difficult for the observer to keep an accurate frame of reference (Eberhard 1990; Zschokke 1996). The time of initiation is very unpredictable. An observer would have to continuously keep an eye on the spider for a minimum of 24 hours to detect the first steps of the web building process. As discussed in detail in Eberhard (1990), these constraints have led to many irregularities in the description of web building behaviour.

Probably to avoid predation, most spiders

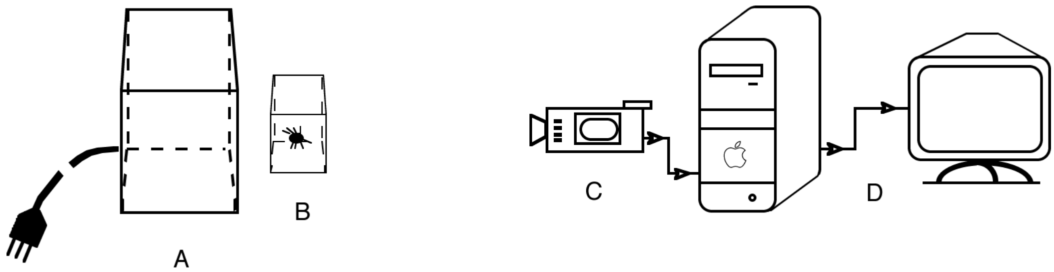

Fig. 1. Basic laboratory layout, which consists of the infrared illuminated background (A), a perspex box in which the spider is kept (B), an infrared capable digital video camera (C) used to capture live images and the computer (D).

build their webs during the night and many are disturbed even by very small amounts of light, typically leading to an interruption of web building. Consequently it is rather difficult to observe undisturbed web construction behaviour of these spiders.

These constraints can be best overcome with computerised observation using infrared light. We developed and tested a novel method, using an infrared sensitive digital video camera and a high end computer with real time analysis of the video frames, to observe the spider during web building.

MATERIALS AND OBSERVATION METHOD

The study animals are kept in 8*8*16 cm perspex boxes in a lab with a reverse 12L:12D light cycle. As day light sources we use 'Osram Daylight ' (Osram GmbH, Hellabruner Strasse 1, D-81536, München) fluorescent bulbs.

To record the spider's movements, we place the perspex box with the spider in front of an infrared illuminated background (Fig. 1, *A*). An infrared sensitive digital video camera (Fig. 1, *C*) is used to capture live images which are transferred to a computer where they are analysed in real time. The computer records the position of the spider at a maximal rate of 14 frames per second.

Background light sources

To overcome the problem that some spiders are disturbed in their web construction by small amounts of normal light, we use infrared light. Background infrared illumination consists of a PVC box 30.5*30.5*15 cm in size, containing 16 light bulbs arranged in 4 rows of 4 bulbs each. Light bulbs with a capacity of 24.0 Volt, 50 mA and 1200 mW each were used. The front side of the box is covered by an infrared transmitting filter (Farnell AG, Postfach 675, CH-8027 Zurich) and a diffuser. The inner side of the box is painted with a reflective paint.

The use of normal light bulbs enables the construction of a intensive but inexpensive infrared background. An intense light source is necessary to achieve sufficient contrast between the spider and the background. To the human eye and presumably also to the spider's eye (Yamashita 1985), web construction takes place in complete darkness.

Observation arena

The spiders are kept in transparent enclosures, the observation arenas. The size of the observation arena depends on the size of the spiders' webs in nature, but should not exceed the size of the infrared background. In our present studies where we are recording the web construction of small theridiid spiders, we keep them in 8*8*16 cm perspex boxes. Alternatively, U-shaped supporting structures similar to structures used by Zschokke (1994) for the recording of orb-webs can be used. All structures and enclosures are constructed with transparent material. In the case of material with a smooth surface, scratches with a sharp

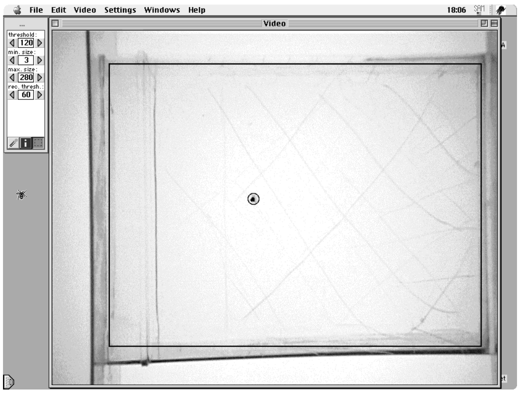

Fig. 2. Screen shot of the recording program. The small window on the left is the control window where the user can set the intensity threshold, minimum and the maximum size of the spider and the minimal distance the spider is required to move before a new position is recorded. The larger window on the right shows the most recent video frame (rotated by 90° to optimise the use of the available area). The black rectangle indicates the observation area in which the objects are detected, the black pixels indicate all pixels that are darker than the defined intensity threshold and the circle highlights the position of the spider as it is detected by the program.

tool were made to enable the spider to crawl about freely.

Video camera

Sony digital video cameras (DCR-TRV10E and DCR-TRV6E) with high infrared sensitivity ('NightShot' function) are used. The 'NightShot' function enables the recording of the spiders' movements in the dark using infrared light instead of normal light. The built-in infrared lamp of the camera is turned off to achieve maximum contrast. The boxes we used were more high than wide (16 cm and 8 cm), whereas the video frames were more wide than high (720 pixels wide and 576 pixels high). To optimise the use of the available area we rotated the camera by 90°. This rotation is compensated for during data recording.

The video camera is connected to the computer using a digital video (DV) link, also known as FireWire (FireWire is a registered trademark of Apple Inc.) or i.LINK (i.LINK is a registered trademark of Sony Corporation). With digital-to-digital connection, video signals are transmitted at high quality, with a vastly reduced amount of noise compared to analogue video signals. This improved image quality greatly, and decreased disturbances which may cause problems during image analysis (see below).

Data recording

The program to record the data continuously grabs single video frames and analyses them. The following is a simplified schematic outline of the algorithm. Once a video frame has been grabbed, it is scanned within the observation area (user definable) to find all pixels that are darker than a user defined intensity threshold (Fig. 2). Ideally, these dark pixels include just the spider, but typically they may also include some smaller objects (e.g. dirt particles) within the observation area. In a second step, objects are detected by clustering all contiguous dark pixels, using the fill-algorithm described in Zschokke (1990). All objects that are smaller or larger than the user definable minimum and maximum sizes are then discarded. This eliminates most noise created when dirt particles adhere to the perspex boxes. In most cases (if the settings are appropriate), the program should then end up with a single object, the spider. If multiple objects are detected, the object whose position is closest to the previous position of the spider is considered. The program has now successfully detected the current position of the spider. This position is then compared with the previously recorded position. If these two positions differ more than a user defined distance, i.e. the spider has moved, this new position is recorded, together with the exact time. Without delay, the next video frame is then grabbed and analysed. We use an Apple PowerMac G4 computer running at a speed of 400 MHz which allows acquisition and analysis of 14 video frames per second. At any time, the user can stop the recording and save the recorded data on disk.

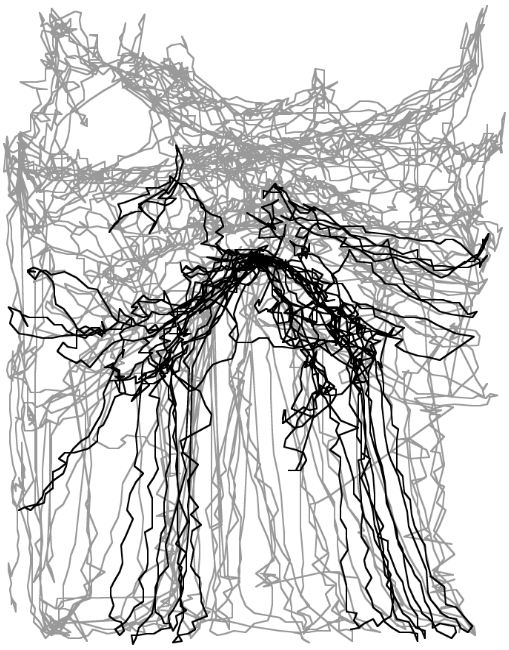

Fig. 3. Example of a recorded track of the theridiid *Achaearanea tepidariorum* (C.L. Koch, 1841) during construction of its tangle web. The construction of the supporting structure is shown in grey, whereas the construction of some gumfooted lines is highlighted in black.

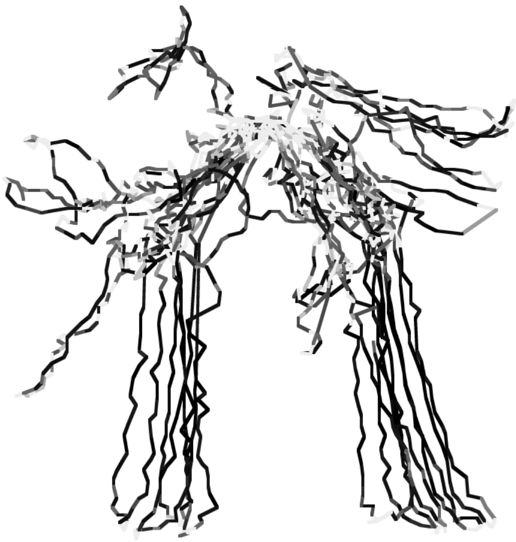

Fig. 4. Gumfooted line construction of the web shown in Fig. 3 with speed codes. Lighter lines denote slower movements and darker lines denote faster movements. It can easily be seen that the spider slowed down wherever it attached a thread.

DATA ANALYSIS

The recordings are analysed with a separate program, typically running on another computer. This program can draw the track of all or parts of the recording. It also allows the colouring of different parts of the track to, for example, highlight a certain stage of web construction (Fig. 3). It is furthermore possible to replay the movement of the spider at the original speed or a multiple thereof allowing rapid visual analysis of movement patterns.

Different numerical analyses are also possible. Probably the most important one is the activity pattern which plots speed against time (cf. Zschokke & Vollrath 1995a,b), or against distance. To visualise the speed of the spider during different parts of the web construction, the movements of the spider can be drawn in a colour corresponding to the speed of the movement (Fig. 4). This allows for rapid localisation of those parts of the web construction, where the spider moved slowly or hastily. In some cases, the speed of the spider can be used to determine the kind of silk it produces (Zschokke & Vollrath 1995b) or to locate the position where a thread was attached or cut (Zschokke 2000). It is furthermore possible to identify areas where the spider was most active or spent most of the time with the so-called position pattern (Fig. 5). For this, the observation area is divided into squares with a user definable resolution, and the program then counts either the time the spider spent (Fig. 5A) or how often the spider entered each square (Fig. 5B). With this analysis, the observer can find the focal point or focal points in the web that are probably important for the spider. This is especially important in the study of non orb-weaving spiders where the existence of such a focal point (possibly equivalent to the hub in orb-webs) is of great interest. All analyses can be done on the entire or just a part of the web construction. In all windows, the user can select single or multiple elements and the program

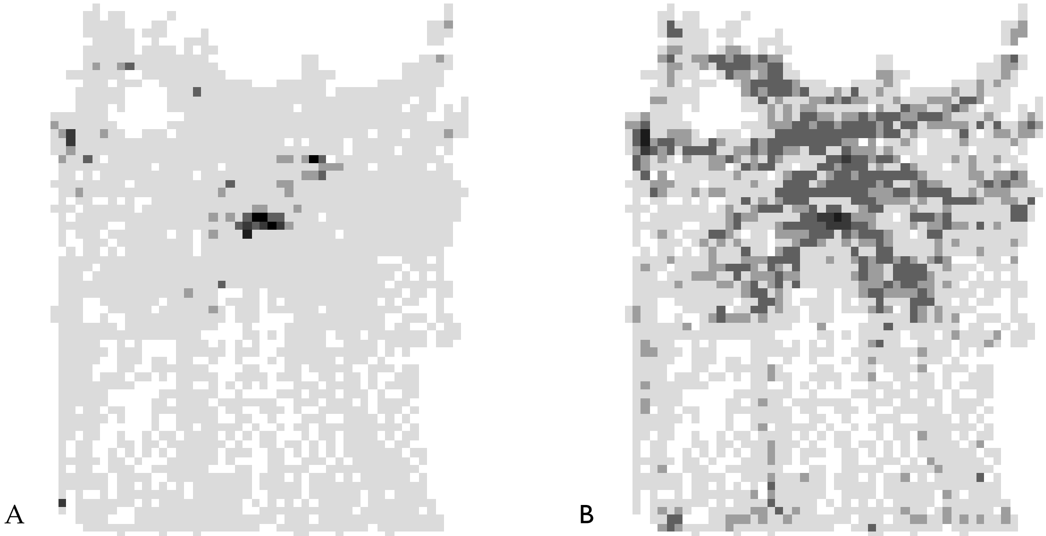

Fig. 5. Position patterns of the web construction shown in Fig. 3. **(A)** shows where the spider spent most of the time during the construction of its web, darkness proportional to the cumulated time spent in each square. **(B)** shows where the spider was most active, darkness proportional to the number of visits to each square.

will then display various data (like position or speed) pertaining to the selected element.

CONCLUSIONS

Our computerised observation method requires high contrast between the spider and background. This makes it difficult to offer the spider a structured environment. It also limits operation of the system in the field. This is not unique to our system but is a general problem in automated vision systems (Bakchine-Huber et al. 1992; Baatrup & Bayley 1993; Zschokke 1994). Nevertheless, due to the inaccuracy of human observation of long chains of behavioural events and the stereotypic nature of web building behaviour, computerised observation systems are preferable.

Since the observation method determines the sequence of spider positions in two dimensions only, all movements in the third direction are ignored.

This observation method and data analysis enable detailed study of the behaviour of nocturnal animals and eliminates most constraints encountered to date. Although this observation method was developed for the observation of spider web building behaviour, its use is not limited to the study of spiders. It is also ideal for the recording and analysis of movement patterns of any nocturnal animal or animals that are disturbed by the presence of visible light, provided that they can be studied under laboratory conditions.

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