Infrared Transmittance as an Alternative Thermal Strategy in the Desert Beetle *Onymacris plana*

Abstract. *Elevated elytral transmittance to shortwave infrared radiation is used by the black diurnal desert beetle* Onymacris plana *to increase heat gain at the beginning and end of the day. Near-infrared transmittance increases the percentage of radiation absorptance at times of low sun angle as a result of the relatively greater attenuation of visible to shortwave infrared radiation by longer atmospheric path lengths. Visible and ultraviolet radiation are absorbed by the insulated elytra, facilitating heat loss by convection at times of high sun angle.*

In the nearly vegetationless sand dunes of the Namib Desert in South West Africa several species of diurnal flightless tenebrionid beetles have developed behavior patterns and morphological adaptations enabling them to attain high and only slightly varying body temperatures during their activity periods. During March and April 1973 I measured beetle and microclimate parameters to develop a mathematical model of heat exchange for *Onymacris plana* (*1*). Dorsal surface reflectance and transmittance measurements were found to be abruptly elevated at near-infrared (NIR) wavelengths (800 to 2000 nm).

Elytral transmittance values in excess of 70 percent were measured around 1200 to 1300 nm. Reflectance values were 10 to 12 percent at the same wavelengths. Thus only about 20 percent of the incident solar radiation is absorbed by the elytra. This contrasts with the situation at visible and shorter wavelengths (<700 nm), where this visibly black beetle transmits no energy while reflecting 3 to 5 percent and absorbing 95 percent of the incident energy in the elytra.

A spectrophotometer (Beckman DK-2A) was used to determine the transmittance and reflectance between 290 and 2500 nm for three live specimens of *O. plana* (two males, one female) and four dead specimens (two males, two females) collected in spring 1973. This wavelength range includes more than 90 percent of the total incoming solar radiant energy (*2*). Before each measurement a standard MgO blank was used to calibrate the spectrophotometer and establish a 100 percent reflectance level. Figure 1 shows the dorsal reflectance and transmittance values for the elytra of *O. plana* and for the whole body.

This pattern of reflectance and transmittance can best be explained in relation to the thermal ecology of these insects and the temporal characteristics of the radiation regime to which they are exposed. *Onymacris plana* is a large beetle (0.75 to 1.5 g) exhibiting a distinct sexual dimorphism. Males have a broader, more fluted abdomen. Both sexes, like many other flightless desert tenebrionids, possess an air-filled subelytral cavity (*3*). This species is found in sparsely vegetated sand dunes; shaded resting places are available that the beetle uses between periods of activity in the direct sunlight. During the study period the *O. plana* population showed a bimodal activity rhythm characteristic of several Namib Desert tenebrionid beetles for much of the year (*4*).

The bimodal activity rhythm is part of a thermal strategy that results in a rapid rise in body temperature in the morning to levels near 40°C after the beetles emerge from below ground. This body temperature is maintained by behavioral thermoregulation until close to midday when the beetles are forced by high radiation levels and elevated air temperatures to seek thermal refuge underground. Surface activity resumes around midafternoon, again at body temperatures near 40°C. The beetles cool gradually until sundown when they once again retire underground for the night. Hamilton (*5*) has called this type of thermal strategy in poikilotherms "maxithermic" in that the preferred body temperature is maintained within a very few degrees of the insect's upper lethal limit for as much of the diurnal cycle as possible. Manipulation of the radiative input appears to be an important mechanism employed by *O. plana* in maintaining high and constant body temperatures.

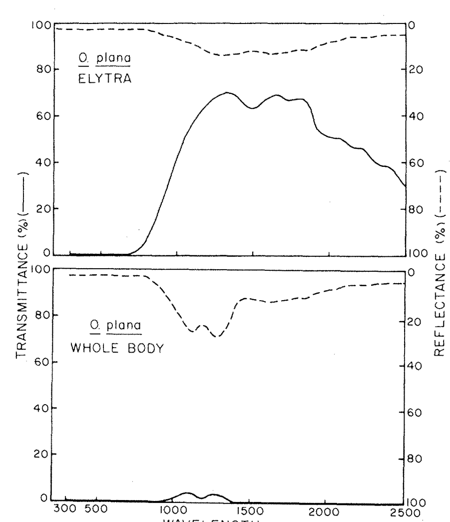

Fig. 1. Spectral distribution of average transmittance and reflectance for the dorsal surface of *O. plana*. Curves are shown for the elytra alone and for the whole body.

The band-pass filter characteristics of the elytra appear to be well suited to utilizing temporal changes in the character of the solar radiation regime relative to this thermal strategy. This is possible because there is a greater percentage attenuation of irradiance in the visible and short wavelengths at lower sun angles. For an air mass of 1 (sun directly overhead), with low amounts of atmospheric dust and water vapor, about 50 percent of the incoming radiation is in wavelengths longer than 700 nm (*6*). However, when the sun's rays have traversed 5 air masses [early morning (0700 to 0730 hours) or late afternoon] 60 percent of the incoming energy is contained in wavelengths longer than 700 nm, approximately the end of the visible spectrum. With longer path lengths in clear dry atmospheres there is a shift in the distribution of energy toward the longer wavelengths as well as a diminution in the total amount of energy available. With increased NIR transmittances this radiant energy is better able to pass through the shielding elytra to the abdomen, thus enhancing the insect's ability to remain warm at the beginning and end of the day.

At the beginning of the morning activity period with a relatively low sun angle, the major proportion of the incident radiant energy is in wavelengths greater than 700 nm. In these wavelengths *O. plana*'s elytral transmittance reaches a maximum (Fig. 1), and, as a result, this radiant energy passes directly through to the membrane-covered abdomen. By late morning with ever shorter atmospheric path lengths to traverse, incoming radiation in the visible and ultraviolet wavelengths (where *O. plana* is both opaque and black) approaches its daily maximum. For an air mass of 1 about 78 percent of the total incident energy is absorbed by the elytra and 14 percent passes through to the abdomen. High elytral surface temperatures [temperatures in excess of 60°C have been measured (*7*) on the backs of active individuals] can facilitate heat loss by convection during these thermally stressful hours, and thus the beetles are able to remain active for longer into the midday period before having to retreat underground.

When the beetles emerge in the midafternoon, an analogous situation prevails with a relatively high sun angle and solar radiant energy split approximately evenly between the visible to shorter wavelengths and the NIR wavelengths. Lower sun angles and attenuation of radiation occur in the cooling environment of late afternoon. A greater percentage of the available radiant energy again shifts to the NIR portion of the spectrum and is augmented by longwavelength thermal radiation from the warm sand and warm mass of air above the desert surface. With the sun's rays traversing 5 air masses, the available energy is reduced to about half of its noontime maximum but the percentage passing through to the abdomen has risen to 20 percent while the amount absorbed by the elytra has decreased to 73.6 percent.

The thermal strategy of maximum surface absorptance in visible wavelengths and selectively elevated transmittances in NIR wavelengths is an alternative to the thermal strategy of color change as shown by the desert iguana (*Dipsosaurus dorsalis*) (*8*). This pattern is one of several adaptations of these beetles enhancing thermoregulatory efficiency. Behavioral thermoregulatory actions contribute quantitatively greater absolute value to the maintenance of thermal equilibria, but the combination of physical and behavioral adaptations establishes the potential for thermal optimization. The adaptive nature of NIR transmittance in *O. plana* could be an accident of the beetle's elytral morphology or the result of positive selection. However, when considered in terms of the solar radiation regime to which these arthropods are exposed, the differential transmittance shown in the NIR seems to be the least costly alternative for the utilization of the given environmental regime to produce maximum sublethal body temperatures for the greatest period of time each day.

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References and Notes

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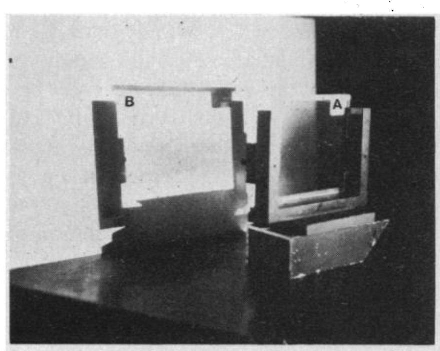
Optical Holographic Three-Dimensional Ultrasonography

Abstract. *Three-dimensional ultrasonograms prepared by superposition optical holography improves anatomical orientation and reduces the volume of data needed to study parenchymal organs such as breast, liver, kidney, spleen, and others. An optical hologram makes it possible to simultaneously view multiple planes of observations and see through and around structures without the superimposition of overlying structures. The use of pulse echo ultrasonograms results in better resolution and gray scale and permits multiplane viewing and eliminates the geometric distortions present in acoustical holography.*

Ultrasonography, a painless, apparently harmless, noninvasive modality, enables physicians to observe structural features that were previously only visible upon surgical exploration. One of the impediments to broader application of this technique is that B-mode pulse echo ultrasonographic systems produce planigrams of the examined tissue. An ultrasonographic planigram is a scan of tissue about 0.5 mm thick. The tissue above and below the level of the acoustic scan (planigram) is therefore invisible. To adequately visualize a three-dimensional organ, it is necessary to serially scan the organ at an arbitrary interval. Thus, to detect lesions as small as 0.5 cm in size, serial scanning at 3-mm intervals must be performed. Such scanning of organs, for example, the breast, liver, and spleen, result in the accumulation of a vast amount of data which must be studied in detail to arrive at a diagnosis.

This volume of data may be effectively reduced by forming a three-dimensional ultrasonogram from the individual serial ultrasonograms by optical holographic techniques.

As in all optical holograms, there is no superimposition of structures, so that it is possible to observe structures from different viewing angles as they are oriented in vivo. In addition, the optical hologram absorbs so little light that it remains transparent even at high information densities. Figure 1 is an optical holographic reconstruction of 2.1 cm of breast tissue which demonstrates the minimal absorption of such a hologram. Prior three-dimensional



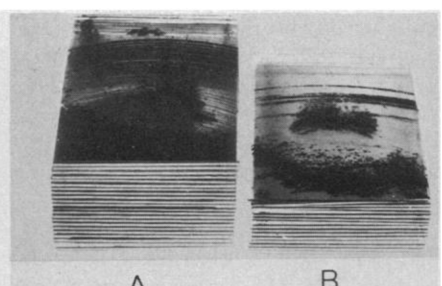
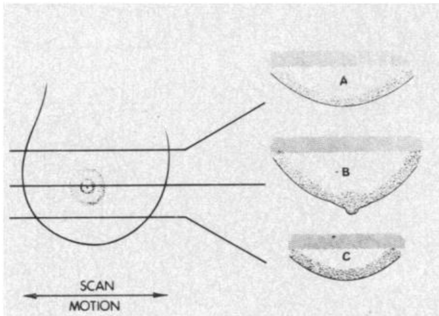


Fig. 1 (left). An optical hologram of a three-dimensional ultrasonogram. This optical hologram is composed of six ultrasound tomograms. This represents a 2.1-cm-thick slab of breast tissue. The optical hologram (A) absorbs so little light that it produces only minimal shadowing (B). Fig. 2 (right). A three-dimensional ultrasonogram of an eye prepared by the glass plate technique is shown for comparison. (A) The three-dimensional ultrasonogram is light-opaque at high information densities and (B) becomes transparent as the information densities decreased.



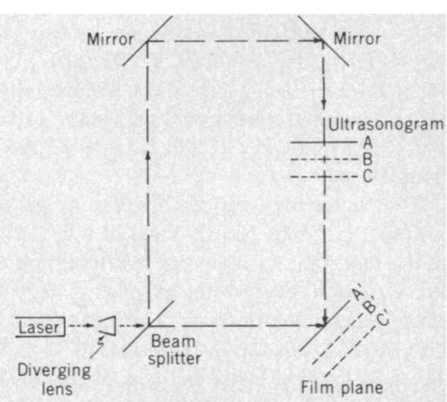


Fig. 3 (left). A diagrammatic representation of the appearance of an ultrasound mammogram through different levels of scan. (A) Ultrasonogram representing a section taken above the nipple. (B) A section through the nipple. (C) a section below the nipple. In practice, serial scans are taken at 3-mm intervals to detect lesions 0.5 cm in size. Fig. 4 (right). Formation of a superimposition optical hologram of serially scanned ultrasonograms.