Biological Journal of the Linnean Society, 2006, **89**, 397–406. With 3 figures

Extreme ultraviolet sexual dimorphism in jumping spiders (Araneae: Salticidae)

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Received 28 April 2005; accepted for publication 4 October 2005

Jumping spiders (Salticidae) have acute vision with some cells in the retina that are sensitive to ultraviolet (UV) spectra (< 400 nm). However, no study has documented the use of UV signals in salticids. To appreciate the function of UV vision, it is necessary to characterize the UV colours of salticids. In the present study, the UV and human-visible wavelengths of a tropical ornate salticid spider, *Cosmophasis umbratica*, were analysed using reflectance spectrometry to obtain evidence of sex-specific UV colours. An absolute sexual dimorphism in the UV colours of this salticid species was found. All of the body parts of adult males that are displayed to conspecifics during intra-specific interactions reflected UV (300–400 nm) light, whereas the adult females and juveniles did not reflect UV light from any body part. A great deal of variation was also found in the UV wavebands among males. This is the first full UV characterization of a salticid spider and the first study to demonstrate an extreme sexual UV dimorphism in jumping spiders. The findings obtained provide evidence that UV reflectance may comprise important sexual signals in jumping spiders.

ADDITIONAL KEYWORDS: animal communication – colour signalling – *Cosmophasis umbratica* – spectral reflectance – ultraviolet vision.

INTRODUCTION

There is a growing interest in the importance of ultraviolet (UV) reflectance (wavelengths between 300 and 400 nm) in animals that have UV vision (Jacob, 1992; Bennett & Cuthill, 1994; Tovée, 1995; Cuthill *et al*., 2000b; Briscoe & Chittka, 2001). The majority of studies on the functional significance of UV reflectance and UV vision have focused on insects (Silberglied, 1979; Goldsmith, 1994; Tovée, 1995) and vertebrates, including birds (Bennett *et al*., 1996, 1997; Andersson, Örnborg & Andersson, 1998; Hunt *et al*., 1998, 1999; Johnsen *et al*., 1998; Maddocks *et al*., 2001), fish (Smith *et al*., 2002), and reptiles (Fleishman, Lowe & Leal, 1993). These studies provide strong evidence of the use of UV cues in female mate choice (Cuthill *et al*., 2000b; Cuthill, Partridge & Bennett, 2000a) and male–male interactions (Alonso-Alvarez, Doutrelant & Sorci, 2004). However, the adaptive significance of UV signalling in other invertebrates is relatively poorly understood. To appreciate the role of UV signalling in other invertebrates, it is necessary to characterize the UV colours that are employed and to specify the tasks that are performed.

Many jumping spiders (Araneae: Salticidae), which is the largest family of spiders, have bright colours and elaborate ornamentation, and show sexual colour dimorphism in that males are generally brighter than females (Oxford & Gillespie, 1998). The coloration of salticids has engendered much supposition but, compared to butterflies, for example, has been the subject of surprisingly few studies. As a result, the question of why many jumping spiders are colourful remains largely unanswered. One problem with this question is that, as humans are primarily visual animals, there is a tendency to assume that animals view colours in the same way as humans. However, it is certain that no jumping spider sees itself, its conspecifics, or its neighbours in the way humans do. This assumption has led to a great deal of erroneous concepts and some

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serious implications for many previous studies on colour in birds (Bennett, Cuthill & Norris, 1994; Cuthill *et al*., 2000b). To avoid such mistakes, a non-subjective measure of colours is essential, and one of the objectives of the present study is to present such data in jumping spiders.

Jumping spiders have complex eyes and acute vision (Land, 1969, 1985; Blest, O'Carroll & Carter, 1990; Land & Nilsson, 2002) that facilitate numerous visually-mediated behavioural activities, such as elaborate mating and threat displays (Peckham & Peckham, 1889, 1890, 1894; Crane, 1949a, b; Drees, 1952; Forster, 1982; Jackson & Blest, 1982; Li & Jackson, 1996). They not only have green cells, and possibly blue and even red cells, but are also known to have UV cells in the retina of their principal (anterior median) eyes (Land, 1969; DeVoe, 1975; Yamashita & Tateda, 1976; Blest *et al*., 1981; Peaslee & Wilson, 1989). It is this colour visual system that allows salticids to discriminate between colours (Nakamura & Yamashita, 2000). As has been outlined, it is not unreasonable to predict that salticids reflect UV light, and may use UV reflectance as visual signals in both inter- and intraspecific communication. However, no study has investigated whether salticids are UV reflecting and the function of this attribute, if it exists, in salticid communication.

In an attempt to understand the uses of UV reflectance in salticid spiders, the present study analysed the UV and visible colours of a highly active and ornate iridescent jumping spider, *Cosmophasis umbratica*, by measuring the reflectance spectra of the body parts that are involved in courtship and agonistic displays (Lim & Li, 2004). If UV colours in *C. umbratica* function as sexual signals, then a significant difference in UV reflectance between and within the sexes would be expected, as well as a lack of UV colours in juveniles.

MATERIAL AND METHODS

Study animals

Juvenile and adult (male and female) *C. umbratica* were collected during periods when spiders are more active and commonly spotted (in the morning between 08.30 h and 11.00 h) (Lim & Li, 2004). The maintenance and cage design were the same as those used in earlier salticid studies (Jackson & Hallas, 1986; Lim & Li, 2004), and only the essential details are given here. The spiders were kept individually in cylindrical cages (diameter 6.5 cm; height 8.5 cm) in a laboratory in which the environmental conditions were controlled (relative humidity 80–85%; temperature 25 ± 1 °C; 12 : 12 h light/dark cycle, lights on 08.00 h). Additional lights (Arcadia Natural Sunlight Lamp) were used to illuminate the cages for 4 h daily (09.00–11.00 h; 16.00–18.00 h) to provide a light spectrum that simulates natural sunlight because the spiders are most frequently spotted on plants that are exposed to sunlight during late morning and early afternoon (personal observations). Water and sugar water were provided *ad libitum* through dental rolls. The spiders were maintained on a diet of houseflies (*Musca domestica*), fruit flies (*Drosophila melanogaster*), and small instars of crickets (*Gryllidae* sp.) twice a week, as described in a previous study (Lim & Li, 2004). The adults were differentiated based on morphological differences: the males have complex iridescent markings on the dorsal and lateral cephalothorax and on the lateral femora of all legs, and silvery white lines on the abdomen (Fig. 1A), whereas adult females are green on the cephalothorax and have a mixture of brown, white, and black coloration on the abdomen (Fig. 1B; Lim & Li, 2004). The spectral reflectance of each spider was measured a maximum of 10 days after the small juveniles had moulted to become older juveniles or adults (males and females).

Reflectance spectrometry

The reflectance spectra of live juveniles, adult males, and the females of *C. umbratica* were measured using the same protocols as in numerous previous studies (Endler, 1990; Andersson, 1996; Endler & Thery, 1996; Andersson & Amundsen, 1997; Cuthill *et al*., 1999), and only the essential details are given here. To facilitate the accurate measurement of reflectance spectra, the spiders were mildly anaesthetized (using carbon dioxide) for 5 min before measurements. All of the reflected spectra were measured with a USB2000 UV/VIS miniature fibre-optic spectrometer (Ocean Optic Inc.). A DH-2000 deuterium tungsten halogen light source (Ocean Optics Inc.) was used to provide a stable and continuous source of full spectrum light (215–1700 nm) in a single optical path that illuminated an area approximately 1 mm in diameter at a distance of 2 mm from the reflection probe to the body part. A reflection probe that recorded reflected light through a single-read fibre that was surrounded by six hexagonally arranged illuminating fibres was held firmly by a vertical adjustable translation stage (Creative Stars Electro-Optics, Inc.). This stage was designed to enable the accurate determination of the distance (2 mm) between the tip of the probe and the area of the spider body part upon which the reflectance spectra were being measured (up to an accuracy of 0.01 mm), and to maintain a perpendicular angle between the probe and the plane of the area to be measured. The raw data were processed using OOIBase32 spectrometer operating software (version 2.0.1.3). All of the spectral readings that were obtained were relative to a Spectralon white standard (Labsphere), an almost

Figure 1. Female and male *Cosmophasis umbratica* and the seven body regions that were measured for sexual colour dimorphism. A, adult male. B, adult female. C, clypeus (top) and palps (bottom). D, legs I (top) and femur (bottom). E, dorsal (top) and lateral carapace (bottom). F, dorsal (top) and lateral abdomen (bottom). Figures on the left belong to males, except in (D) where legs I belong to a male, and those on the right belong to females.

perfect diffuser (> 95% reflectance from 250–2000 nm), and a dark reference (lights off in a dark room).

Seven body parts were identified based on the body postures that are used during intraspecific interactions (left or right chosen randomly, where applicable) (Lim & Li, 2004): palps, clypeus, legs I, dorsal and lateral carapace, and dorsal and lateral abdomen (Fig. 1C, D, E, F). Due to the relatively small size of the juveniles, only the reflectance spectra of the dorsal carapace and the dorsal abdomen were measured. Because of different degrees of morphological complexity, several reflectance spectra of certain body parts (the dorsal carapace, dorsal abdomen, and legs I) were initially measured from anterior to posterior to determine the specific area of highest reflectance within these body parts. Once the area was determined, five reflectance spectra (300–700 nm) were obtained randomly at each body part for each individual, with the distance of 2 mm being reconfirmed before saving each reflectance spectrum. Overall, approximately 800 spectra were obtained from 30 individuals (ten male and ten female adults, and ten juveniles).

Data analysis

We performed principal components analysis (PCA) on the spectral data of *C. umbratica* because this analysis is able to summarize otherwise complex reflectance spectra into a few orthogonal variables (the principal components, PCs) (Endler, 1990; Cuthill *et al*., 1999), and allows multivariate analysis to be performed on the principal component scores that were derived from the spectral readings obtained from each body region. Because the significant features of a reflectance spectrum are the positions of the peaks, steepest slopes, and cutoffs, which are variables that correlate with psychometric colour measurements (Endler, 1990), a reliable statistical analysis of colours based on these factors may work on relatively simple reflectance spectra (e.g. a single-peak spectrum with a clear slope) but not on complex spectra (Cuthill *et al*., 1999), such as the reflectance spectra that are recorded in the males of *C. umbratica* that have more than one peak and multiple slopes. Before performing PCAs, each original reflectance spectrum of more than 2000 data points (from 180–860 nm at 0.36-nm intervals) was reduced to 21 data points from 300–700 nm at 20-nm intervals, which is the expected spectral sensitivity range of jumping spiders (Land, 1969; DeVoe, 1975; Yamashita & Tateda, 1976; Blest *et al*., 1981; Peaslee & Wilson, 1989). Separate PCAs were then performed for intersexual (between adult males and females) and for age (between males and juveniles and between females and juvenile) comparisons. The first principal component (PC1) describes the variation in mean reflectance (brightness) because this forms most of the between-spectra variation (typically greater than 90%; cf. Endler & Thery, 1996; Cuthill *et al*., 1999). The subsequent principal components (PC2 and PC3) represent the variation in spectral shape in terms of hue and chroma, respectively (Endler, 1990; Endler & Thery, 1996; Cuthill *et al*., 1999). The PCs are orthogonal by definition, and conclusions about the differences in PC1 are independent of those in PC2 (Heindl & Winkler, 2003). Once the PCs (PC 1, PC2 and PC3) were obtained for each individual spider, two separate repeated-measures multivariate analysis of variance (MANOVAS) (in SPSS, version 11.5) were then performed to compare the age and between-sex differences in PC scores. The individual PCs were then analysed by analysis of varianace only if the MANOVA was significant. The mean PC scores (PC1 vs. PC2, and PC3 vs. PC2) of the adults (males and females) were then plotted against each other to compare the relative variations in reflectance spectra between the sexes.

RESULTS

Inter- and intra-sexual variations

The mean spectral reflectance of the seven body parts of the adult male and female spiders are presented in Figure 2. All seven of the measured body parts of the adult males reflected UV light, but adult females did not reflect UV from any body part (Table 1). There were significant differences in brightness (PC1) between the sexes for all body parts except for the lateral abdomen, which indicates that males have brighter palps, clypeus, legs I, carapaces, and dorsal abdomens than females. The reflectance spectra of all the body parts except for the lateral abdomen and legs I differed significantly in hue (PC2) between both sexes. Apart from the dorsal abdomen, the colours of all the other body parts were more saturated (PC3) in males than in females (Table 1). Among the body parts that were sampled, the highest *F*-ratios were recorded for the clypeus (all of the PCs) followed by the palps (PC1 and PC3) and the dorsal carapace (PC2), which implies that colour variations differ most between the sexes in these body parts (Table 1).

In comparing the intrasexual colour variations among males and among females, the plots of PC1 (brightness) against PC2 (hue) and PC3 (chroma) against PC2 (hue) indicate greater differences in spectra reflectance among individual males (the filled circles that represent the individual PCs are more scattered) than among individual females (the unfilled circles are more clustered) (Fig. 2). The among-male differences in the spectral reflectance of the carapace

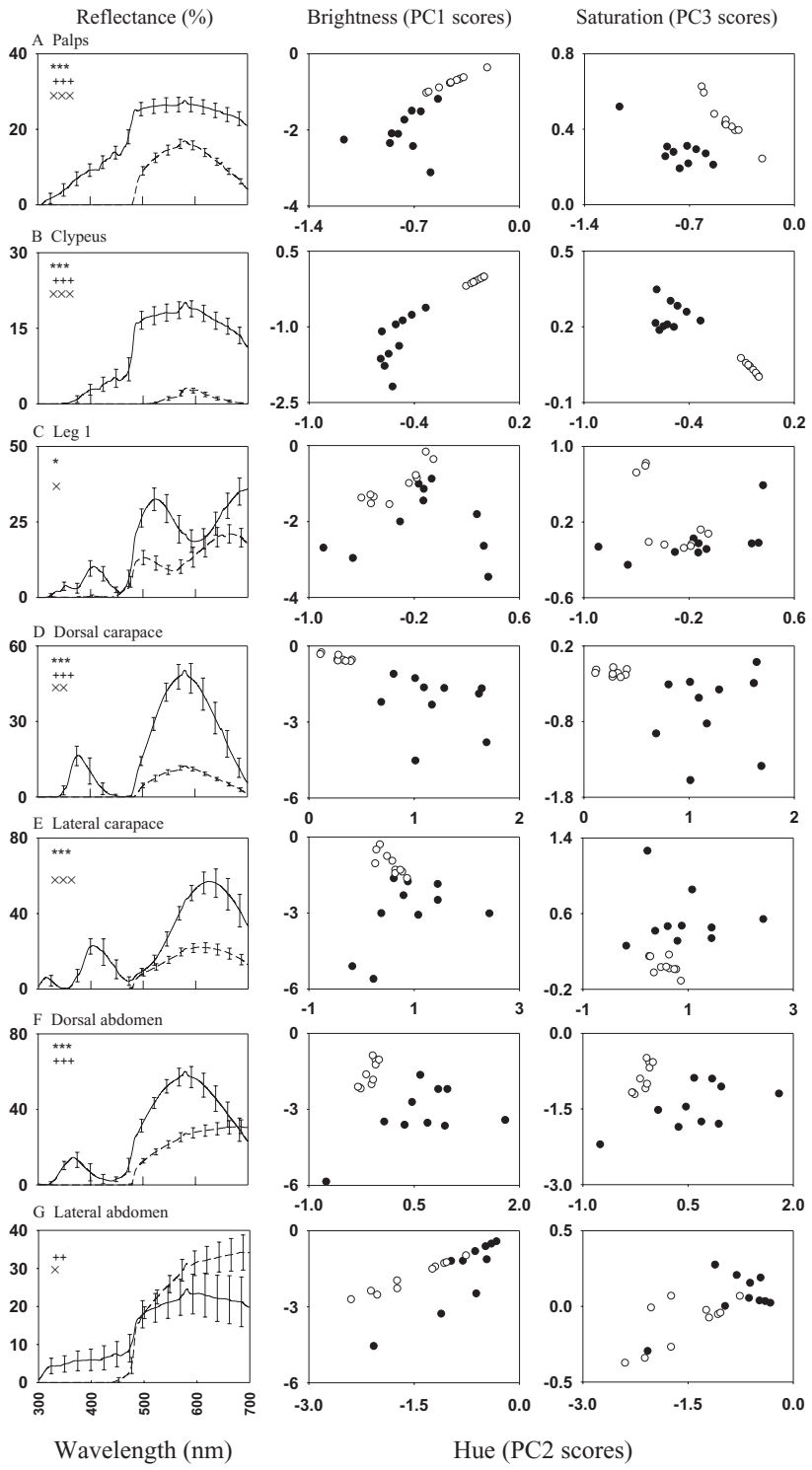

Figure 2. Reflectance spectra of seven body parts of *Cosmophasis umbratica* (left), along with the corresponding plotted PC scores that represent brightness (PC1) and hue (PC2) (middle), and chroma (PC3) and hue (PC2). The reflectance curves are the means of five measurements from ten males (continuous lines) and ten females (broken lines), and each dot represents the means of five PC scores (from five spectra readings per individual per region) for each male (filled circle) or female (unfilled circle). The asterisks and the two different types of crosses indicate the significant difference in the PC scores that represent brightness (*), hue (+), and chroma (×). *, + or ×: $P < 0.05$; **, ++ or ××: $P < 0.01$; ***, +++ or ×××: $P < 0.001$); see also Table 1.

Table 1. Intersexual differences in the spectral reflectance of *Cosmophasis umbratica*

Body region	Wilks's λ	*F*-ratios			Notes
		Brightness (PC1)	Hue (PC2)	Chroma (PC3)	
Palps	0.067***	47.306 (86.9)***	19.292 (8.4)***	20.021 (2.6)***	Males brighter and more saturated; UV present only in males;
Clypeus	0.047***	53.913 (81.4)***	200.711 (11.7)***	258.860 (4.5)***	Males brighter and more saturated; UV present only in males
Leg 1	0.439**	9.480 (65.3)*	0.666 (14.0)	4.430 (9.1)*	Males brighter and more saturated; UV present only in males; more peaks in males than females
Dorsal carapace	0.181***	23.592 (66.0)***	49.209 (19.5)***	16.104 (8.4)**	Males brighter and more saturated; UV present only in males
Lateral carapace	0.326***	17.193 (57.4)***	2.134 (23.4)	19.699 (8.9)***	Males brighter and more saturated
Dorsal abdomen	0.179***	15.535 (59.7)***	17.515 (22.2)***	3.040 (7.4)	Males brighter; UV present only in males
Lateral abdomen	0.383***	0.199 (74.0)	9.945 (19.8)**	6.880 (3.7)*	Males more saturated; UV present only in males

The values shown are *F*-ratios for the factor individual for each of the three variables, of brightness (PC1), hue (PC2), and chroma (PC3). The value in brackets after each principal component *F*-ratio value represents the proportion of between-spectra variations that are explained by that principal component. The analysis of each body region was performed separately.
UV, ultraviolet.
*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

and abdomen were greater than those of the other body parts.

Age variation (comparison of juveniles with adults)

Overall, there were significant differences in the spectral reflectance of both the dorsal carapace and the dorsal abdomen between juveniles and adults (Fig. 3). Although the females and the juveniles did not reflect any UV light, there was a significant difference in brightness (PC1) of the dorsal carapace and the dorsal abdomen between juveniles and females (Table 2). The juvenile carapace was significantly brighter than the female carapace, and the female abdomen was brighter than the juvenile abdomen. Significant differences in PC2 indicate the differences in the positions of the spectral peak in the visible (VIS) spectra (400–700 nm) of both the carapace and the abdomen of the juveniles and females (Table 2). The abdomen colours of the females were significantly more saturated (PC3) than those of the juveniles, but the differences in PC3 were not significant for the carapace. A comparison of the PCs between the adult males and juveniles shows that the male colours were significantly more intense and saturated, and were different in hue from those of the juveniles due to the absence of UV reflectance in the latter, with the only exception being the carapace chroma, for which there was no difference (Table 2).

DISCUSSION

The jumping spider *C. umbratica* is extremely sexually dimorphic in UV reflectance for all of the seven body parts that are displayed during the intraspecific communication, in that adult males are UV reflecting whereas juveniles and adult females are not. This is the first full UV characterization of a jumping spider and the first report of an absolute UV sexual dimorphism in jumping spiders. The findings from the present study are also consistent with the prediction that there are significant differences in UV reflectance

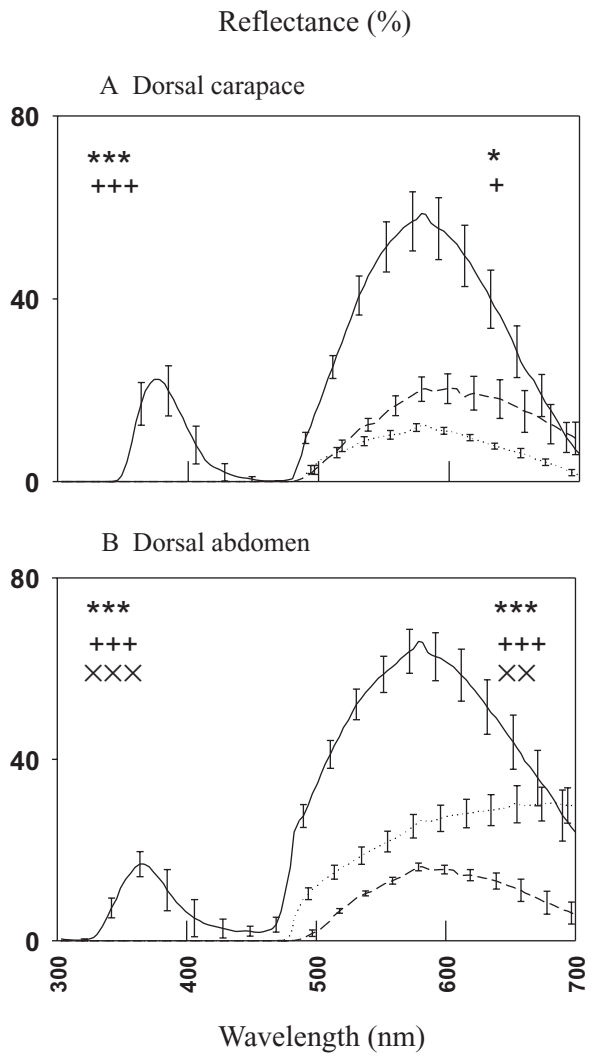

Figure 3. Reflectance spectra of two body parts for male, female and juvenile *Cosmophasis umbratica*. The reflectance curves are the means of five measurements from 10 sexually mature males (continuous lines), 10 females (dotted lines), and 10 juveniles ($N = 10$) (broken lines). The asterisks and the two different types of crosses indicate the significant difference in brightness (*), hue (+), and chroma (×) between the adult males (top left in the reflectance graphs) or females (top right in the reflectance graphs) and the juveniles. *, + or ×: $P < 0.05$; **, ++ or ××: $P < 0.01$; ***, +++ or ×××: $P < 0.001$); see also Table 2.

between the sexes when UV signals are used in sexual signalling.

The absolute sexual dimorphism in UV, in which only one sex but not the other is UV reflecting, has also been reported in several species of butterflies of the genera *Colias*, *Gonepteryx*, and *Pieris* (Silberglied & Taylor, 1973, 1978; Silberglied, 1979; Brunton &

Table 2. Age-specific (male, female and juvenile) difference in the spectral reflectance of *Cosmophasis umbratica*

		F-ratios				
Intraspecific comparisons	Body region	Wilks's λ	Brightness (PC1)	Hue (PC2)	Chroma (PC3)	Notes
Female vs. juvenile	Dorsal carapace	0.572*	5.816 (81.8)*	9.566 (10.3)**	0.134 (7.2)	Juveniles brighter; marginal difference in spectra positions (peaks and maximum slope)
	Dorsal abdomen	0.364***	27.255 (88.4)***	21.302 (6.2)***	14.193 (3.5)**	Females brighter and more saturated; difference in spectra positions (peaks and maximum slope)
Male vs. juvenile	Dorsal carapace	0.300***	17.529 (57.2)***	37.574 (25.5)***	0.006 (9.5)	Males brighter; UV present only in males
	Dorsal abdomen	0.095***	62.642 (65.3)***	51.089 (18.5)***	20.797 (6.7)***	Males brighter and more saturated; UV present only in males

The values shown are *F*-ratios for the individual factors of each of the three variables of brightness (PC1), hue (PC2), and chroma (PC3). The value in brackets after each principal component *F*-ratio value represents the proportion of between-spectra variations that are explained by that principal component. The analysis of each body region was performed separately.
UV, ultraviolet.
*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

Majerus, 1995). Similar to the salticid spider *C. umbratica*, the male wings of *Colias* and *Gonepteryx* butterflies have brilliant UV reflection, but those of females do not (Silberglied, 1979; Brunton & Majerus, 1995). However, the females of many *Pieris* butterflies are UV reflecting, whereas the wings of males are strongly UV absorbing due to the presence of pigments in the wing scales (Descimon, 1976). Because these spiders and butterflies are sexually dimorphic in their UV reflectance, a potential function of these patterns may be sexual recognition. However, the degree of such UV sexual dimorphism that is reported in the invertebrates studied (butterflies, and salticids spider in the present study) is different from that which has been reported in vertebrates. In vertebrates, particularly avian species that show UV sexual dimorphism (Cuthill *et al*., 2000; Cuthill, Partridge & Bennett, 2000), even though males generally reflect more UV light than females, UV colours are still predominant in both sexes.

Taking the well-known conspicuous colour patterns (Oxford & Gillespie, 1998) and UV spectral sensitivity of some cells in the retina of salticids (Land, 1969; DeVoe, 1975; Yamashita & Tateda, 1976; Blest *et al*., 1981; Peaslee & Wilson, 1989) as a starting point, the present study provides evidence that UV reflectance may be important in sexual signalling, and that UV sexual dimorphism may be widespread in jumping spiders. There are three distinct, but not necessarily mutually exclusive, reasons for UV reflectance in any animal. UV reflectance may be non-adaptive, a by-product of some other aspect of the animal's life; it may be cryptic, mimic or aposematic; or may be adaptive to convey information, such as a signal to a con-specific, a predator, or prey. If UV reflectance is non-adaptive, then it should present (or absent) at all life stages and in both sexes. It appears that this may not be the case for *C. umbratica* because only adult males reflect UV light. If UV reflectance serves as a cryptic, mimetic, or apothematic function, then the spiders of any age and sex reported here should be expected to reflect UV light. The results obtained in the present study otherwise indicate that UV reflectance is unlikely to be involved in crypsis, mimicry, or aposematism in this species. If UV reflectance is adapted to convey information to a con-specific, and plays a role in sexual selection, then a lack of UV reflectance in juveniles but a greater sex-specific and within-sex UV reflectance overall would be expected. The findings from the present study (Fig. 2) are consistent with this prediction and suggest that males may use differences in UV reflectance to assess opponents during male–male contests, and that females may use difference in UV reflectance between males for mate choice. The results from the laboratory experiments also demonstrate the importance of UV reflectance in the sexual selection of *C. umbratica*, which will be reported elsewhere (M. L. M. Lim & D. Li, unpubl. data).

The fact that the among-male variation in spectral reflectance varies with the body parts that are displayed during agonistic and courtship interactions reveals the relative importance or 'signalling tasks' of different body parts during intraspecific communication. For example, the low among-male variation in the palps may suggest a limited role in sexual signalling because males seek the attention of females through the vigorous up and down vibration of the fully extended palps during courtship (Lim & Li, 2004). By contrast, the greater colour variations in both the carapace and abdomen suggest the involvement of these parts in more complex roles during courtship and contests because both body parts are actively displayed to males or females, in particular the 'flexing-up' of the abdomen during courtship (Lim & Li, 2004). Therefore, both the varying degrees of among-male variations in all of the body parts that are involved during intraspecific displays and the different body postures that are adopted by male *C. umbratica* during courtship and conflicts (Lim & Li, 2004) strongly suggest that UV colours are involved in sexual signalling, and that different body parts may play different roles during such interactions.

The observed UV spectral reflectance variation between the sexes, between adults and juveniles and, among individuals, could not have been due to errors in measuring techniques because the reflectance spectra were measured following a strict and standardized methodology. The incident light (or probe) was kept perpendicular to the sampling area, which was followed by a precise vertical transition of 2 mm. The specific area of maximum reflectance was identified by minute horizontal transitions, and the reflected spectrum was then recorded. The area of the body part with the highest reflectance was measured by placing the spider (ventral side) onto a platform that allowed for fine tilting in the horizontal plane to ensure the maximum reading of reflected light by keeping the sampling area horizontal. Statistical tests (repeated measures MANOVA) showed no significant differences among the repeated measures of any of the specific body parts in all of the spiders measured. Finally, the variations among the male *C. umbratica* could not have been due to the age of the adult males or their reproductive status (virgin or nonvirgin) because all of the individuals were measured 10 days after they had moulted and become adults, and they were not mated before the reflectance measurements were carried out. Therefore, the among-male variation in UV reflectance is a naturally occurring phenomenon, and was not due to measuring procedures. If it had been, then the females would have displayed similar variations to the males.

All of the previous studies on salticid species that deal with visual receptor type (DeVoe, 1975; Yamashita & Tateda, 1976; Blest *et al*., 1981; Peaslee & Wilson, 1989) have found that there are some receptor cells in the retina that are highly sensitive to UV light, regardless of whether salticids are dichromatic, trichromatic, or tetrachromatic. However, the presence of a colour receptor in the eyes does not automatically imply a discriminatory colour capacity in that part of the spectrum. Interestingly, the reflectance spectra that underlie the colour of the body parts of the male spider (specifically, the carapace and abdomen) have a peak around 350–380 nm in UV (Fig. 3), which matches with the peak spectral sensitivity of the corresponding UV cells in the eyes of other salticids studied (365–380 nm) (DeVoe, 1975; Yamashita & Tateda, 1976). This indirectly suggests that salticids may be capable of discriminating the UV colours, but direct behavioural tests are needed to establish the use of UV vision in salticid communication.

In conclusion, the greater intrasexual variation in the UV reflectance of males, the different degrees of variations among the body parts, and the existence of extreme UV dimorphism between the sexes are consistent with both intrasexual and inter-sexual interactions. Thus, UV colorations in *C. umbratica* may have evolved through intersexual or intrasexual selection. To separate these hypotheses, detailed and intense behavioural tests of UV colour quality on the outcome of male-male contests and female mate choice in salticids are needed. The present study has implications for studies of sexual selection in jumping spiders and other animals, especially those that exhibit sexual differences in UV colours and show a preference for specific light environments or periods that enhances their UV colours (Endler, 1987, 1993; Endler & Thery, 1996). In particular, when studying salticid colours, it would be wise to investigate colour signalling from the perspective of the salticid rather than from the visual perspective of humans.

ACKNOWLEDGEMENTS

We are grateful to Poh Moi Goh for rearing the houseflies and to Chun Hong Cheong for providing the fruit flies. We thank En-Cheng Yang for help with the spectrometer and measurement techniques. Comments and suggestions from Lian Pin Koh, Robert R. Jackson, Tien Ming Lee, Jeremy R. W. Woon, and Karen S. L. Lee greatly improved the manuscript. We also thank the Singapore National Parks Board for the research permit (NP/RP104). This work was supported by generous grants (R-154-000-140-112) to D. Li from the National University of Singapore Academic Research Fund.

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