Rapid adaptive camouflage and signaling by cephalopods

Part 2: Experimental approaches to explore visual perception of prey & predators

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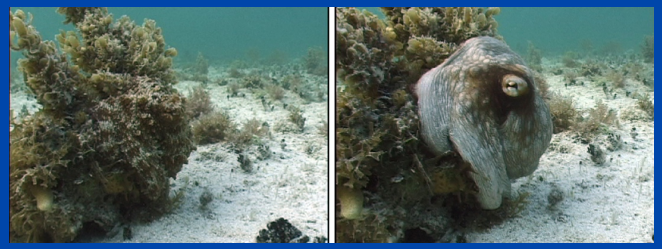
Dynamic general resemblance



How do they do this?

Some fundamental questions

Pattern: what elicits each of the 3 types?

Do they prefer certain substrates?

What about “conflicting” info for each eye?

Are 3D background objects more important than 2D?

Can they tailor camou at night?

How is the morphing 3D skin controlled?

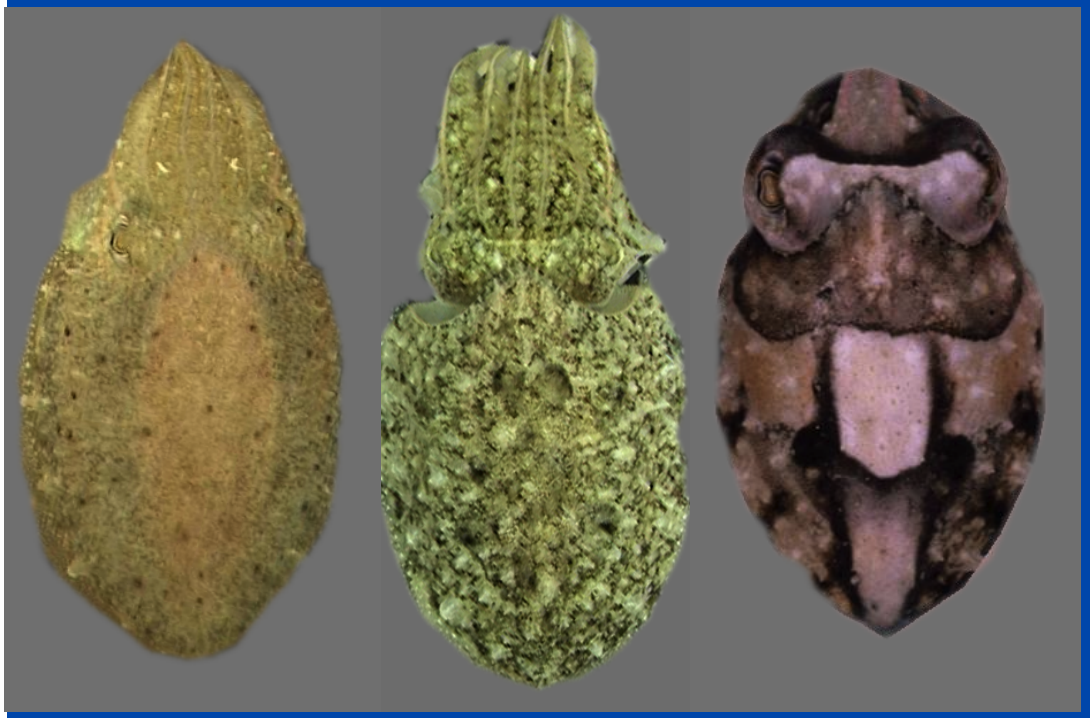
How is posture controlled?

How do they achieve color-blind camou?

Is motion camouflage possible?

Can visual predators detect color patterns?

CHIEF CHARACTERISTICS OF THE 3 BASIC CAMOU PATTERNS



Uniform	Mottled	Disruptive
no contrast	small-scale light and dark patches; moderate contrast, some repetition of general shapes	large-scale light and dark shapes of multiple contrast, orientations and scales

How is the background <u>rapidly</u> sensed to achieve adaptive camouflage?

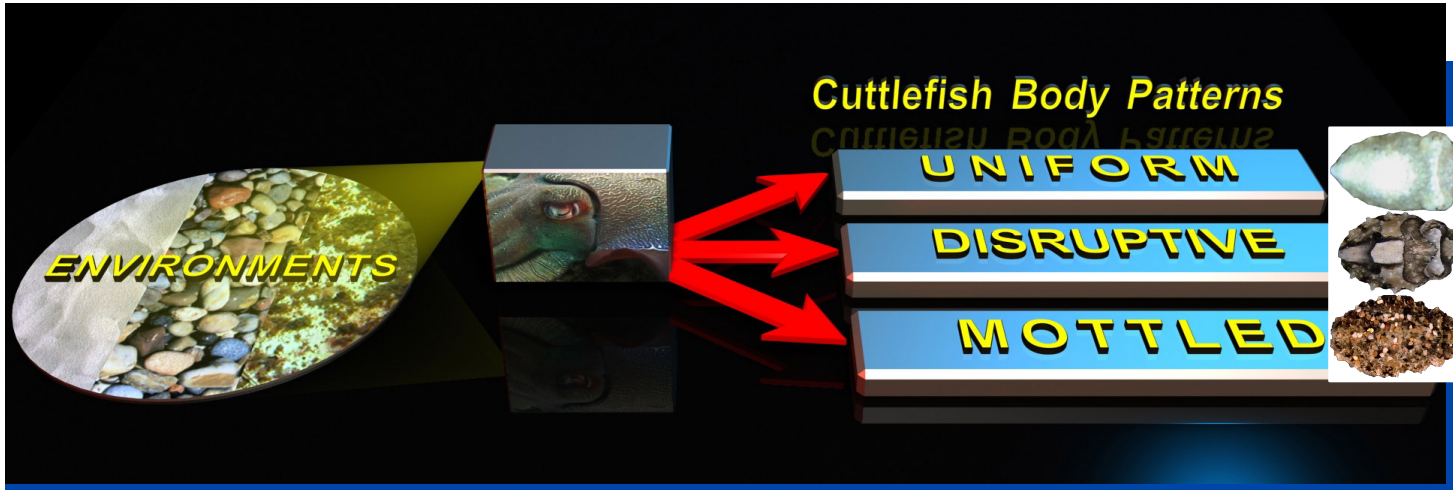
Key attribute:

Cephalopods are genetically driven to camouflage themselves on any background - a primary defense that is visually guided

CONCEPT:

3 Pattern templates

3 Visual sampling rules



Basic experimental approach

Basic approach

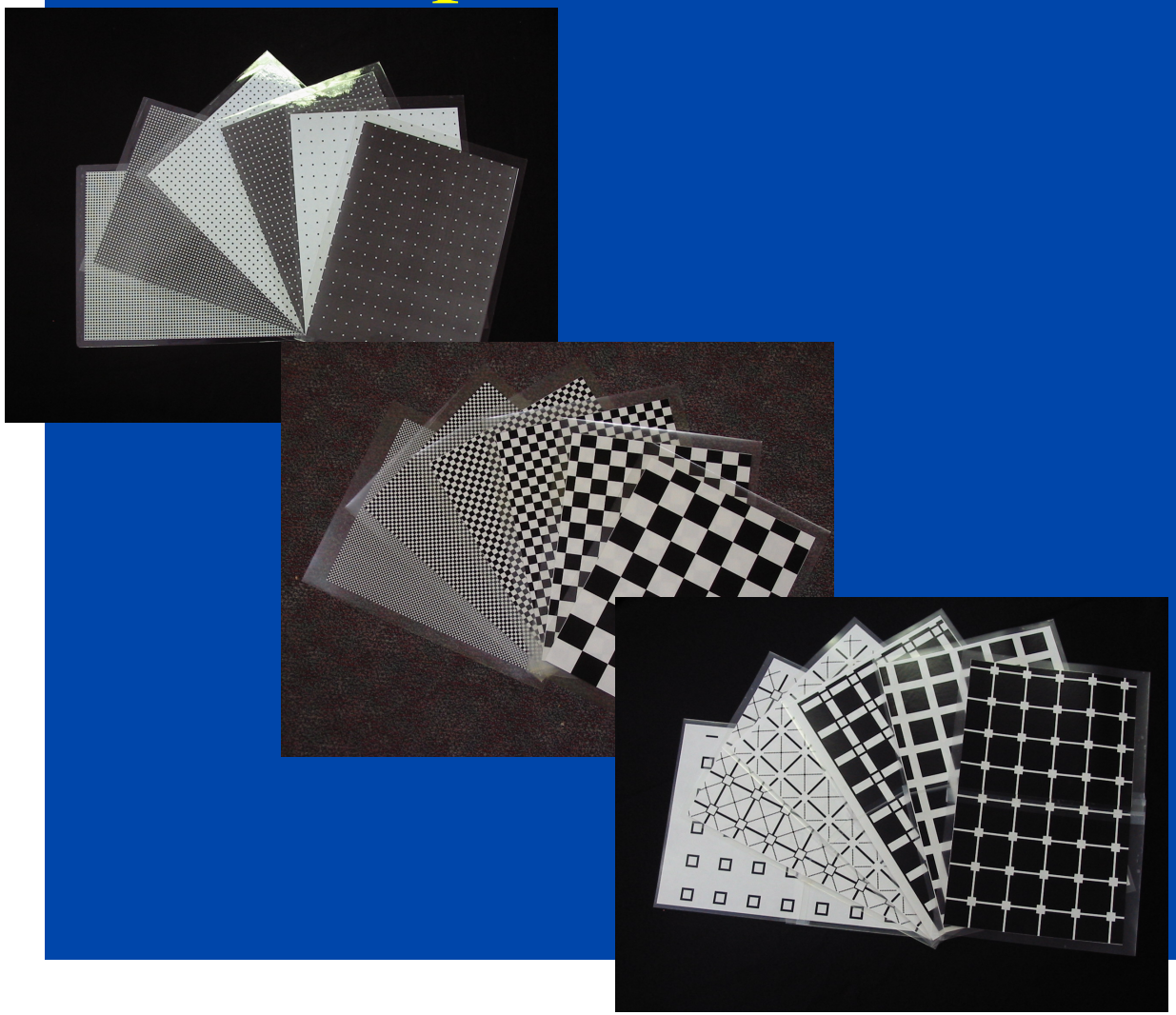
-Study range of natural marine patterns (make use of extensive video/still library)

-Extract and measure salient background features

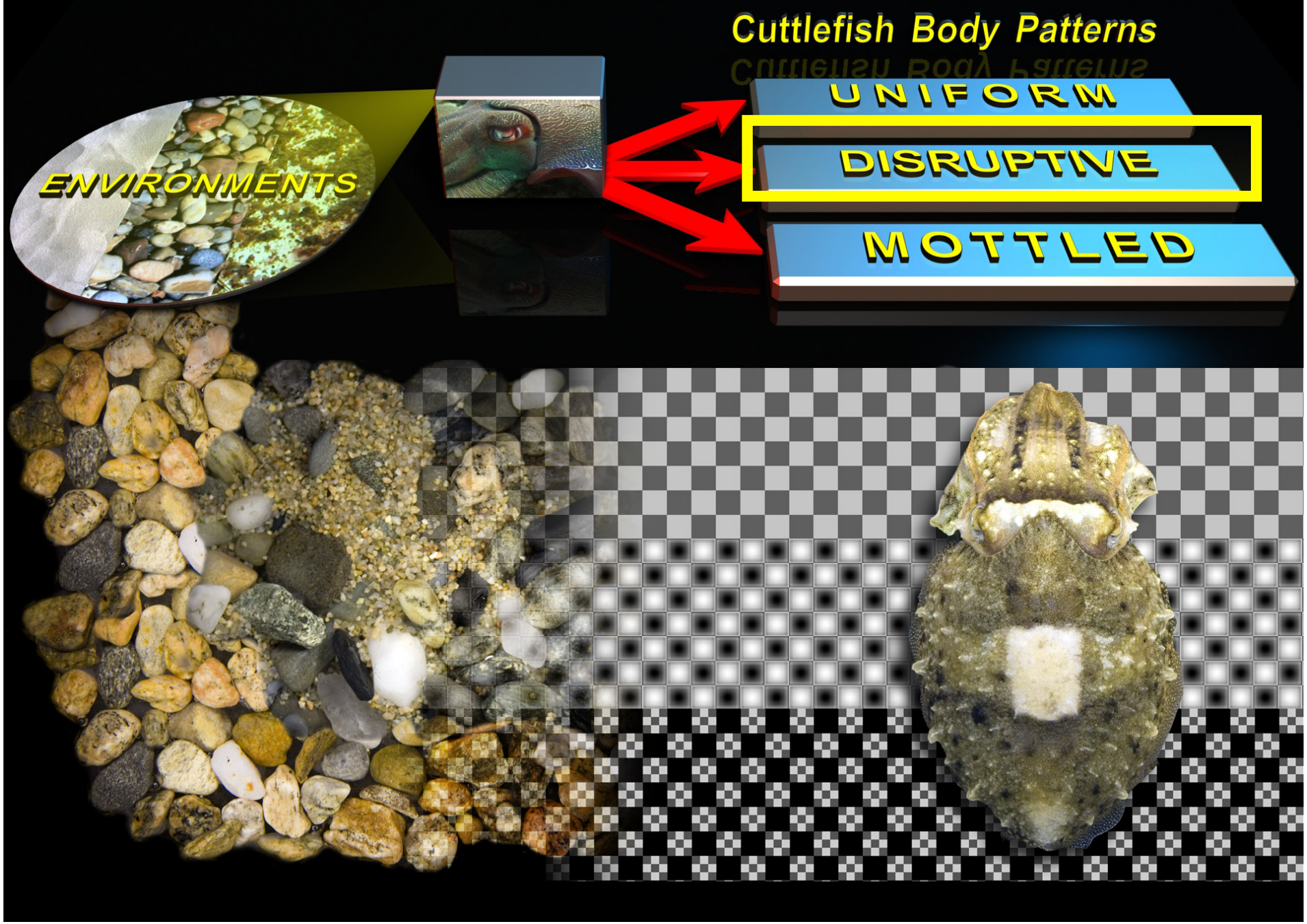
-Imitate these in their simplest form with computer-generated patterns

-Test multiple computer-generated patterns on many cuttlefish (psychophysics approach)

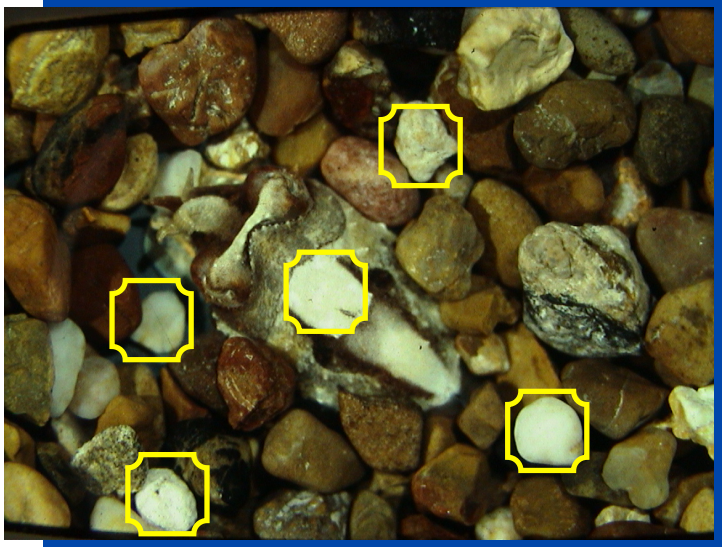
Robust bio-assay to test visual perception (seek simple rules)

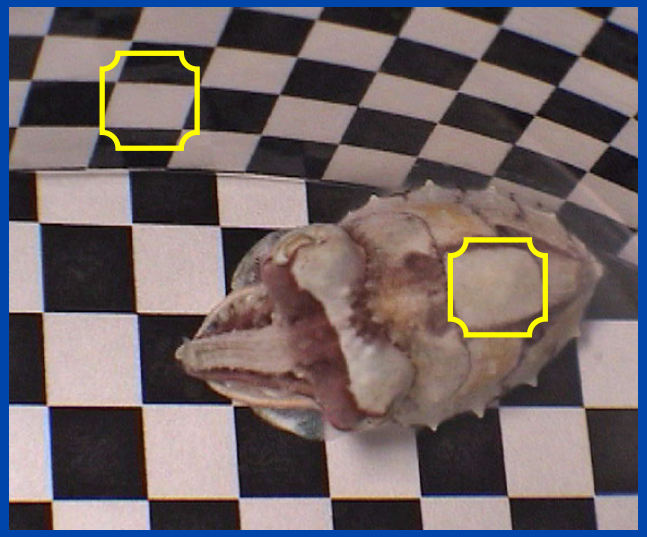


When is disruptive patterning turned on?



Both backgrounds elicit disruptive patterns: what do they have in common?

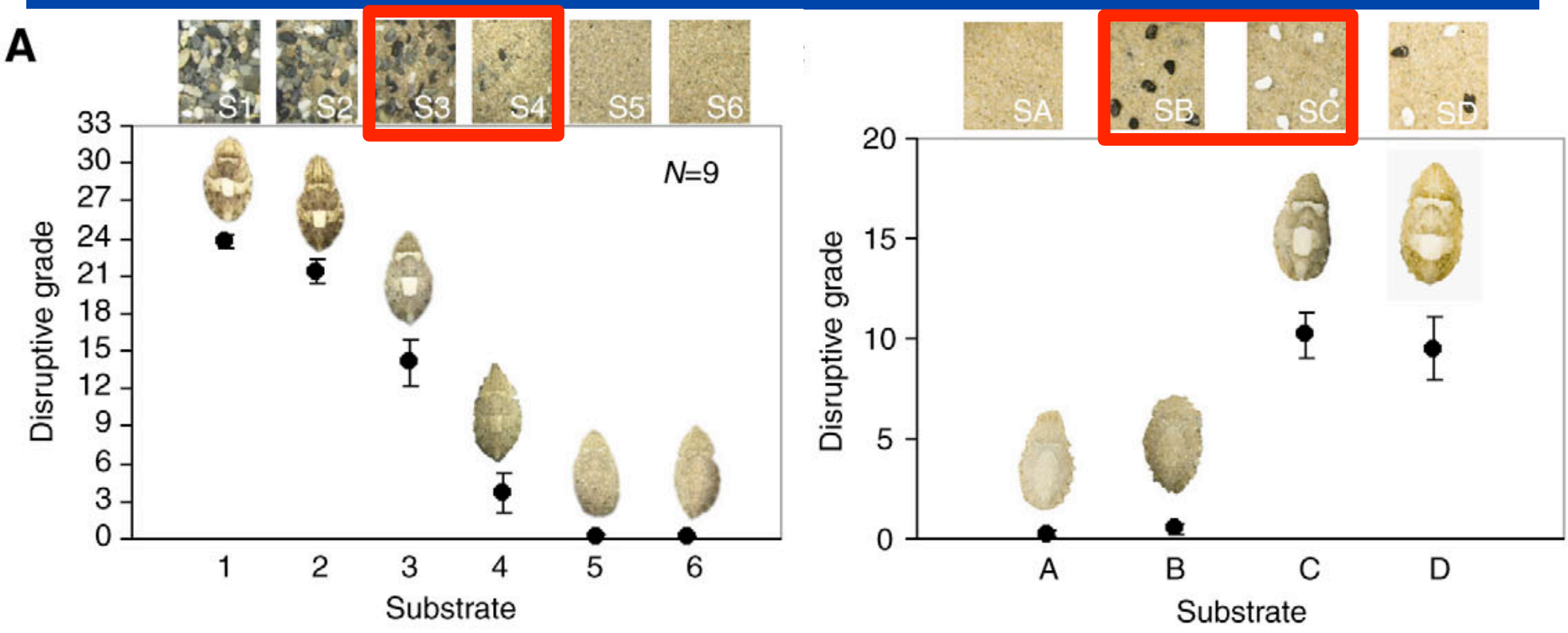




large light areas in each background

Controlled natural substrates that elicit Disruptive coloration

same contrast



Synopsis: only the WHITE objects elicit disruptive patterns

Mathger, *et al*. 2007. J Exp Biol 210: 2657-2666

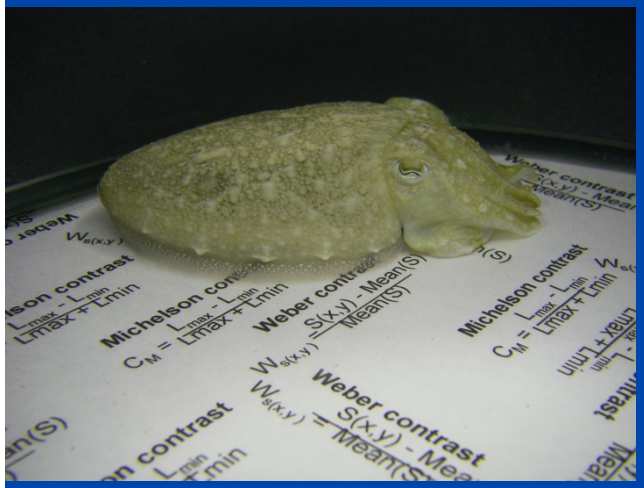
Algorithm development: aspects of light background objects studied in detail (disruptive)

AREA

NUMBER & DENSITY

CONTRAST

BRIGHTNESS

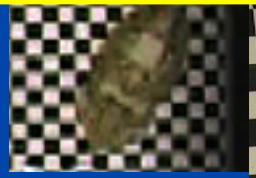
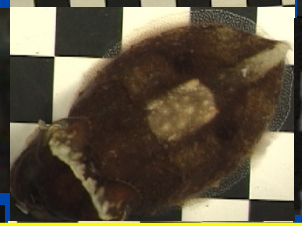
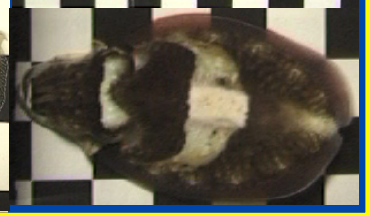
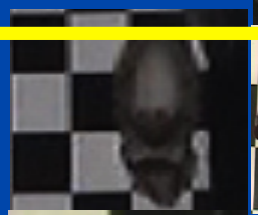
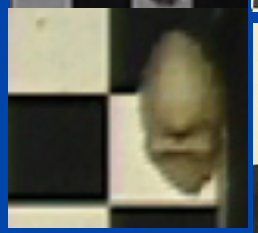
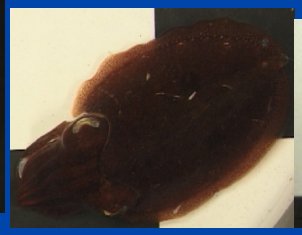


EDGE characteristics

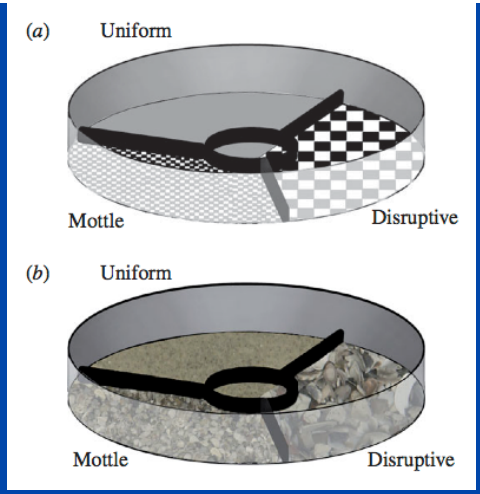
SPATIAL FREQUENCIES

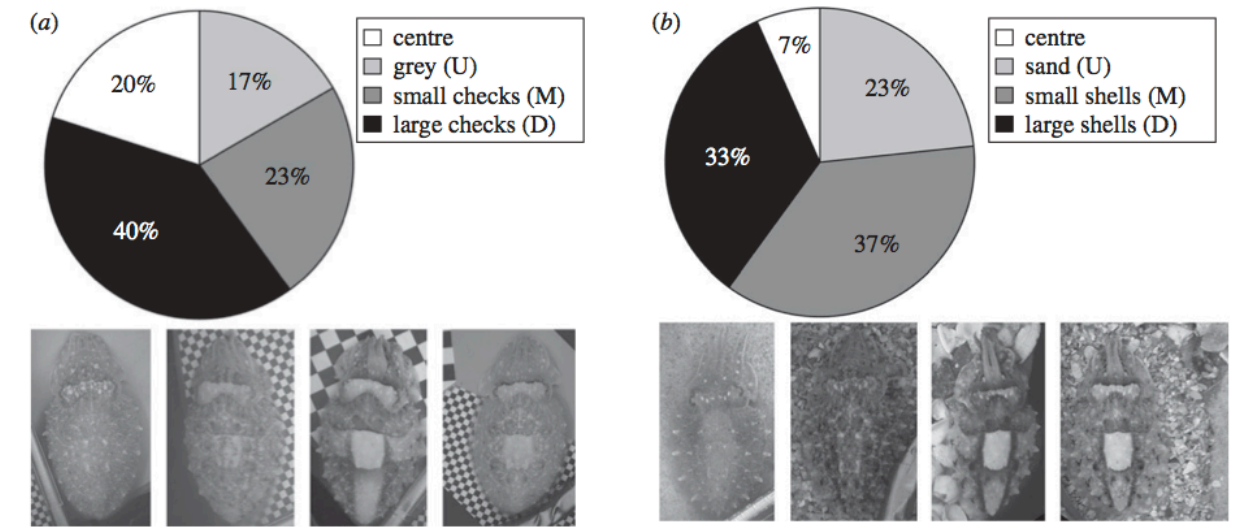
GLOBAL CONTEXT

Ontogeny

	Exp. 2	Exp. 4	Exp. 6
	ML 1.65cm	10.41 cm	19.04 cm
Checker area 4% WS			
12% WS			
40% WS			
120% WS			
400% WS			
1200% WS			

Do cuttlefish prefer certain substrates?



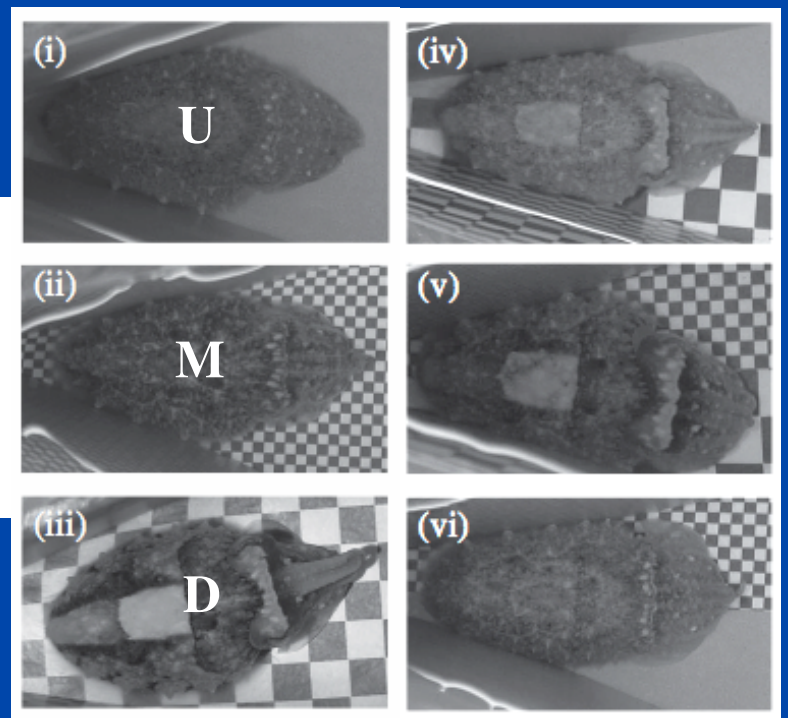


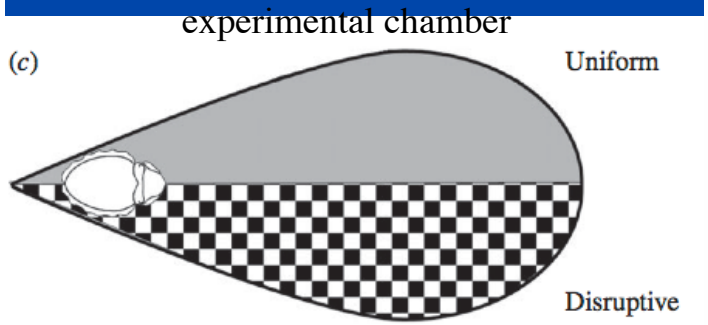
Cuttlefish show **NO** PREFERENCE for different substrates

Allen *et al*. Proc. Roy. Soc.B 2010

What happens when left eye senses one substrate and right eye another?

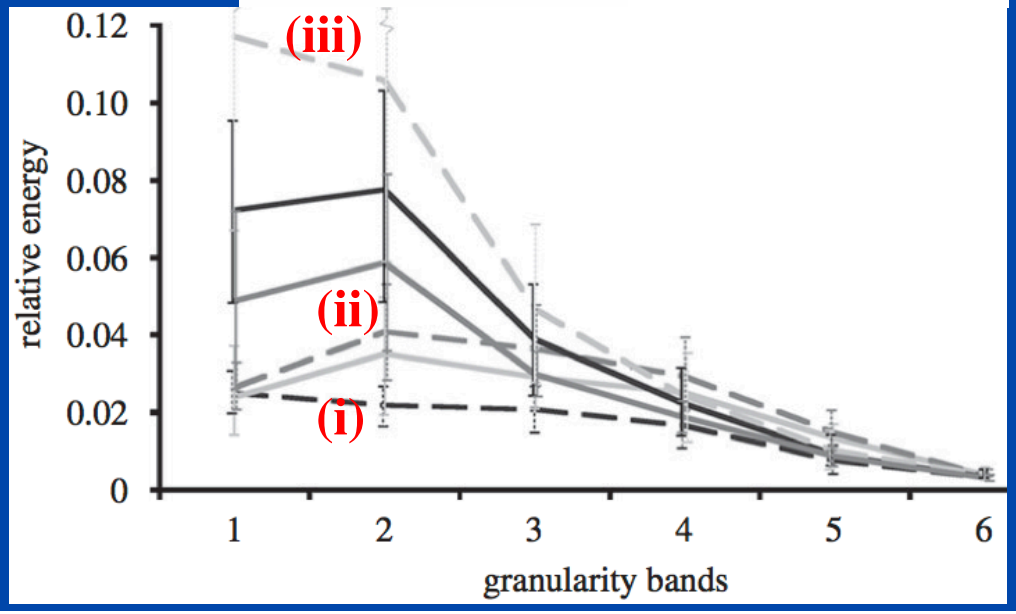
controls:





Cuttlefish respond to cues from **each half** of the split substrate

(no bilateral patterns)

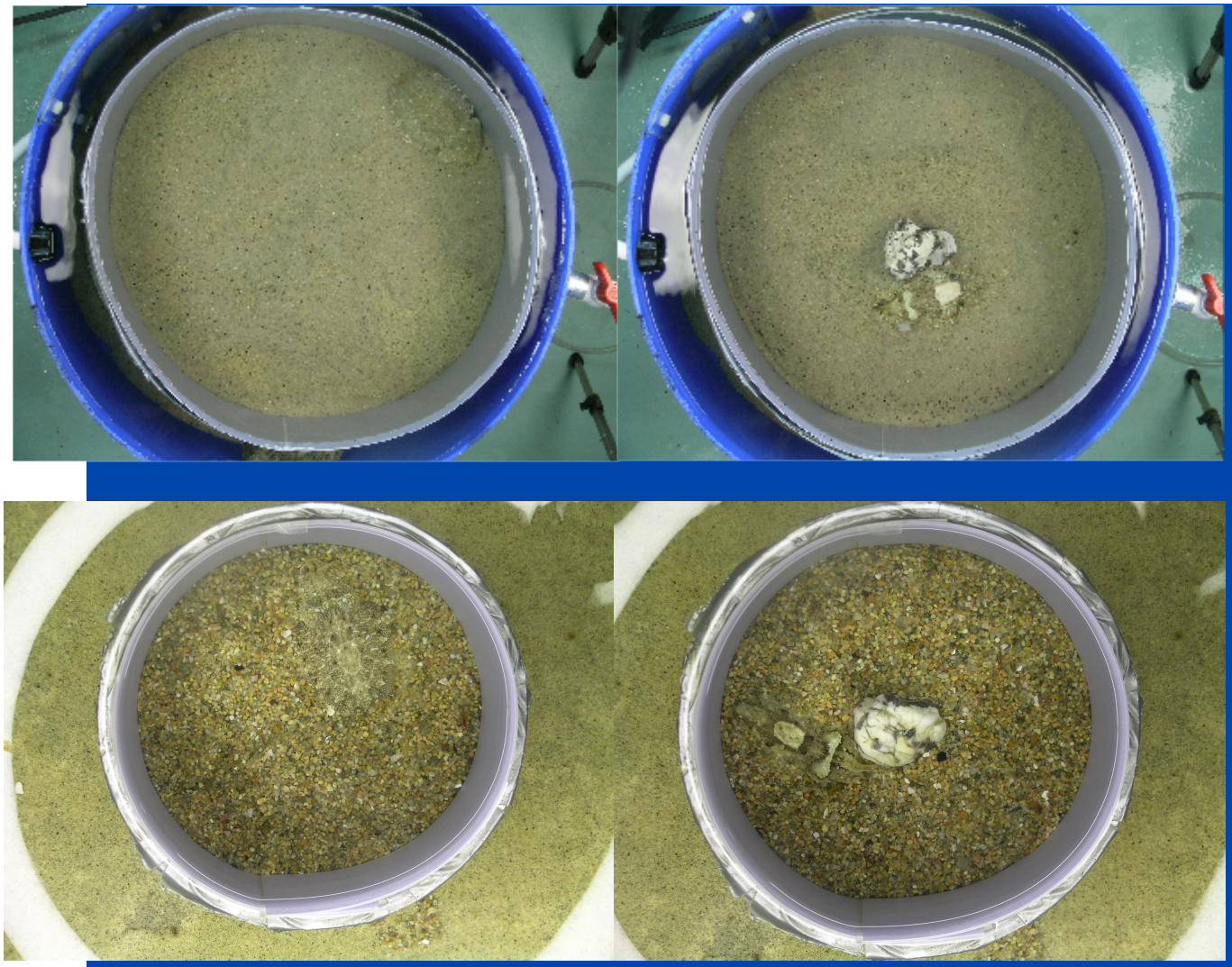


Allen *et al*.
Proc. Roy. Soc.B 2010

Experimental luck:

The Magic Rock

2D vs 3D perception

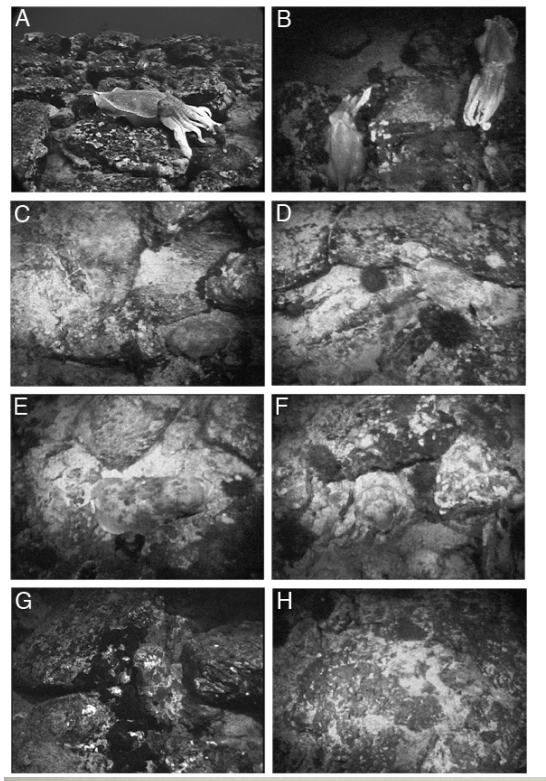


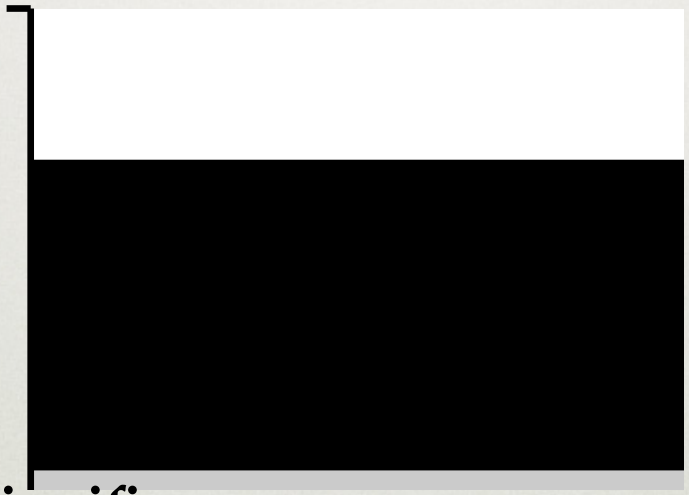
-Attracted to 3D rock
-Rock elicits different pattern

magic rock psychophysics

3D priority over 2D?

Adaptable Night Camouflage by Cuttlefish





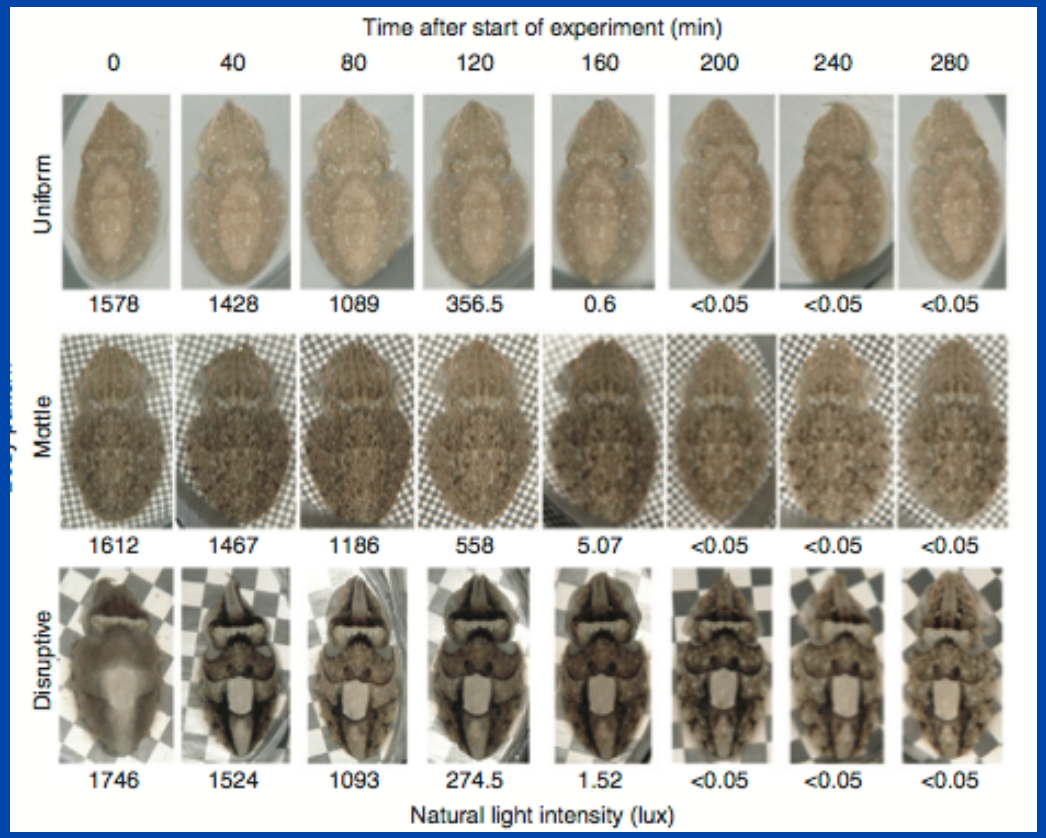
Significance:
-UMD for each microhabitat
-Ceph vision/ predator vision at night are excellent

But can they **CHANGE** at night?

Hanlon et al. 2007. American Naturalist 169 (4): 543-551

Are cuttlefish camouflage patterns adaptable at night?

No change during day to night transition

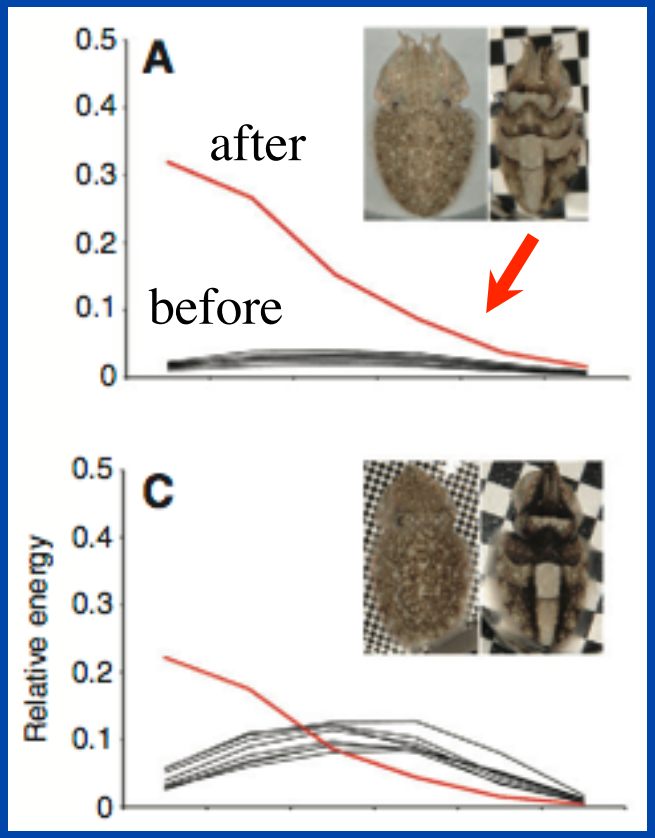


But this does not prove perception under starlight conditions .....

Allen *et al*. J Exp Biol 2010

Are cuttlefish camouflage patterns adaptable at night?

Cuttlefish change at 0.003 lux

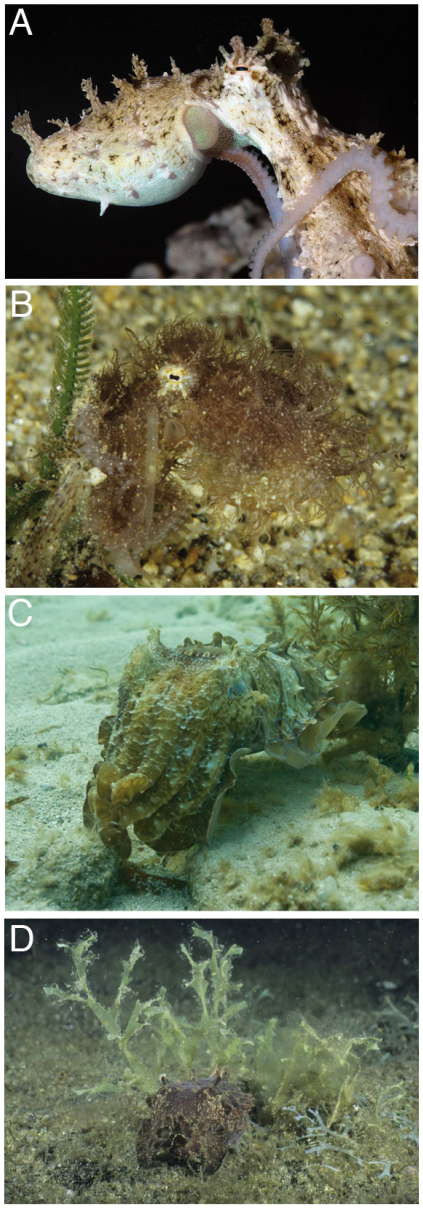


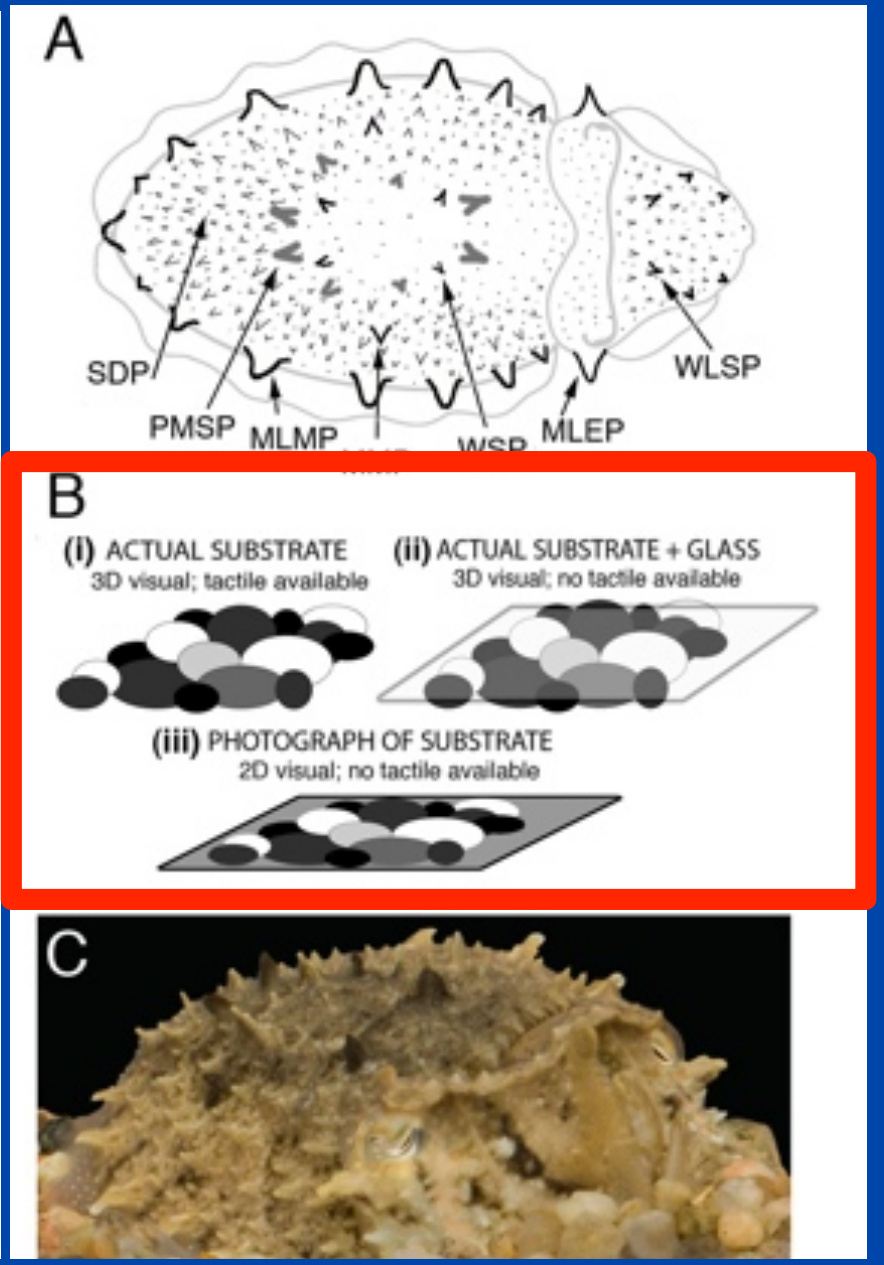
YES cuttlefish can change under starlight levels; they can see at night

Allen *et al*. J Exp Biol 2010

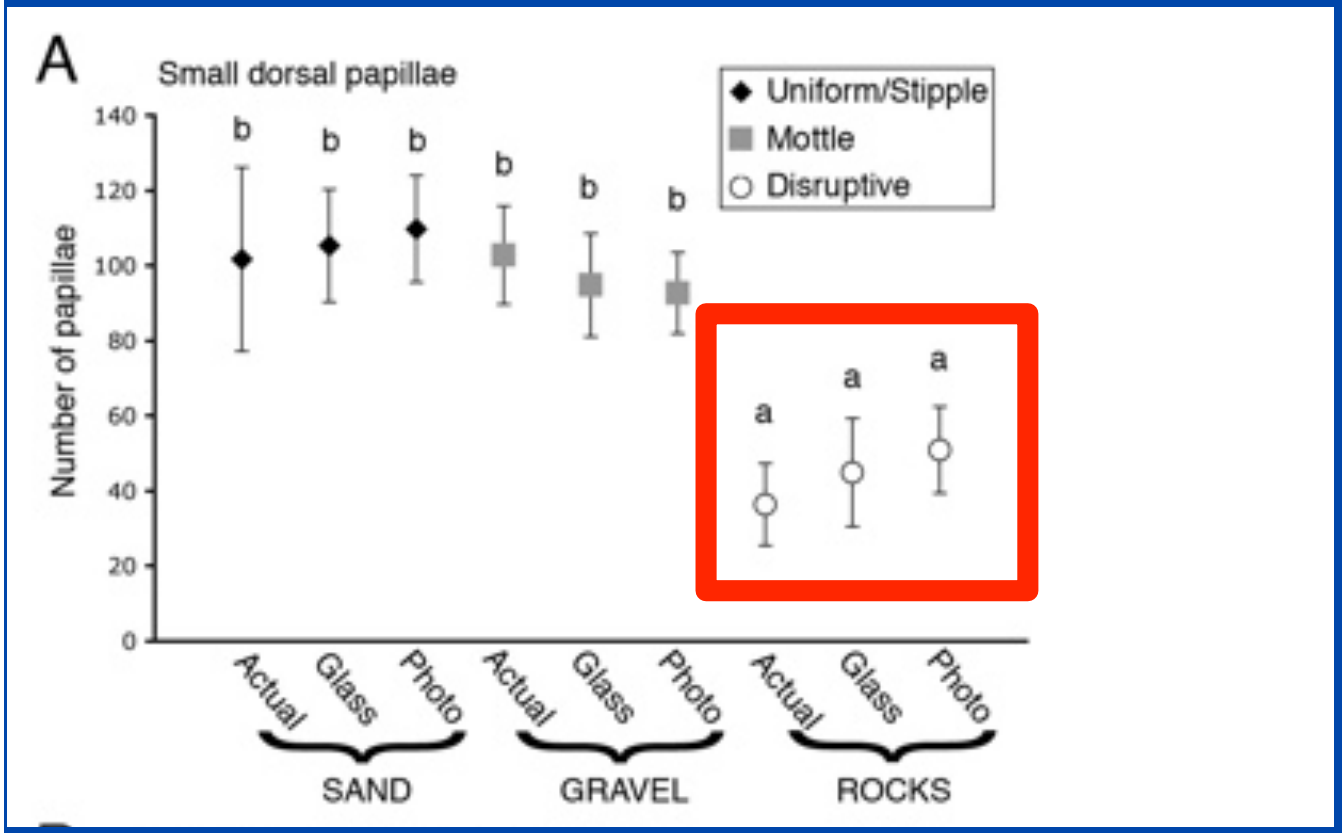
Dynamic 3D change in texture

Are papillae controlled visually or by touch?





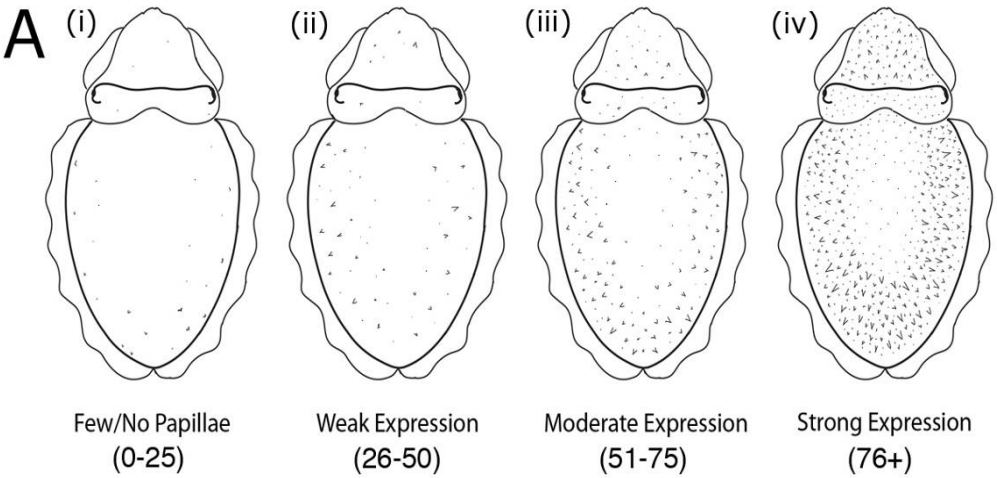
RESULTS



Allen JJ, Mathger LM, Barbosa A, Hanlon RT. 2009. J. Comparative Physiology A **195**: 547-555

Library images: approx 5000 images

Analysis: Subset of 60 (20 uniform, 20 mottle, 20 disruptive)



Surprise finding: there are 9 sets of independently controlled papillae

How does an octopus/cuttlefish view the background **monocularly** to assess and reproduce 3D texture in the skin?

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papillae gone-
no evidence of their presence

June 2009

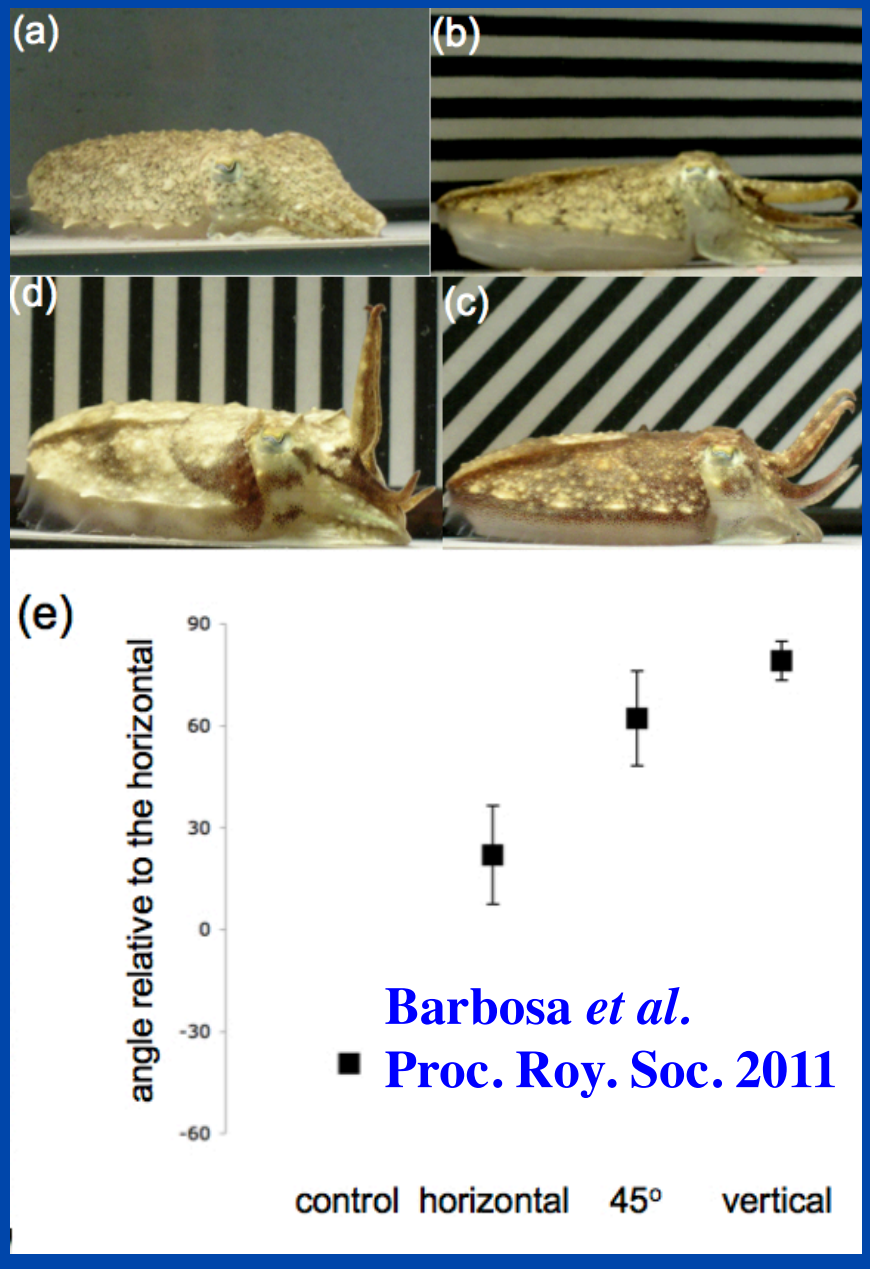
How are arm postures controlled?

arms up with
only a picture
of algae

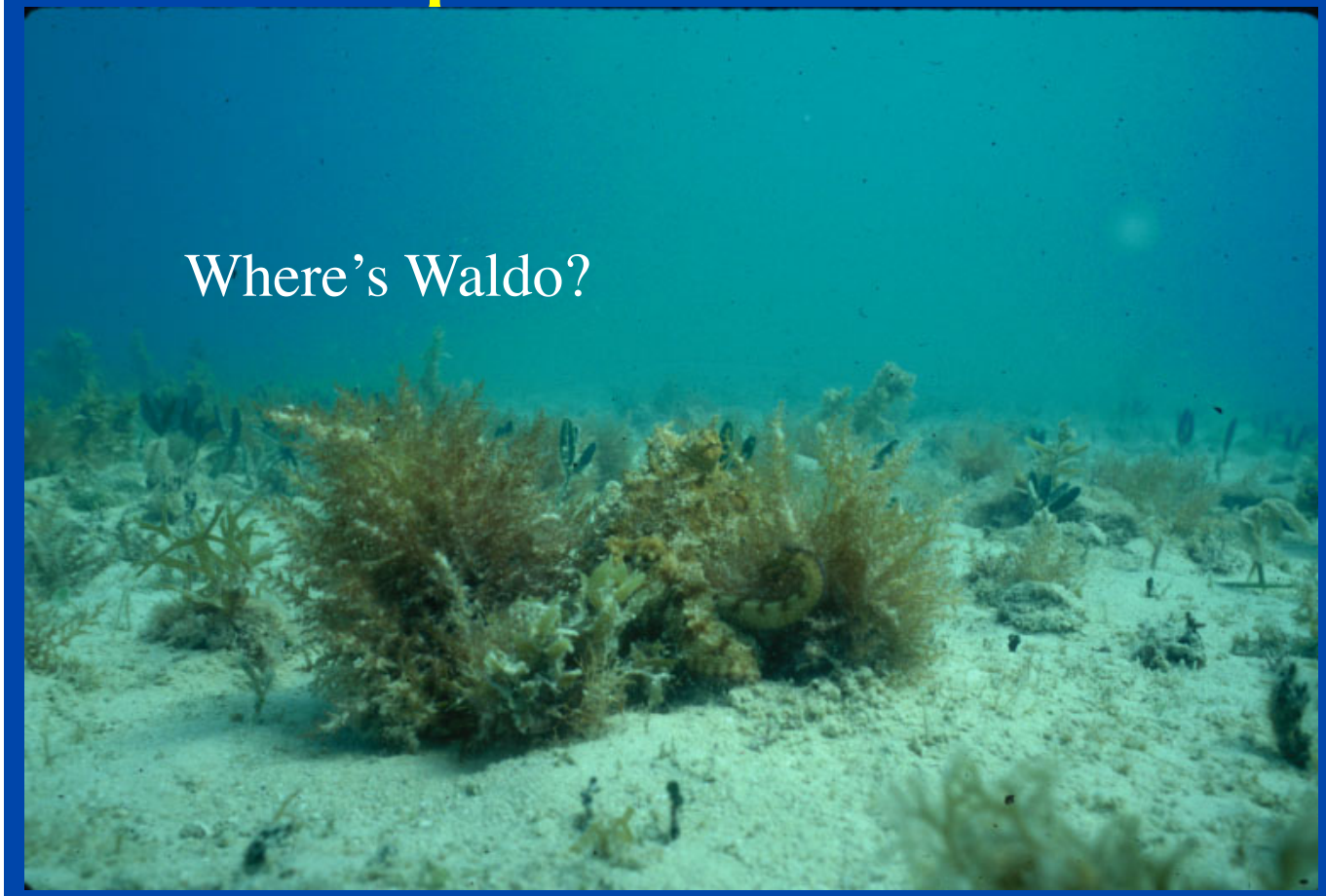
How are postures controlled?

Visually -guided Arm Postures

Experimental data
9 cuttlefish; 36 trials total



Is color-blind camouflage really possible?



Evidence of color blindness

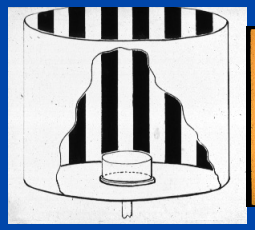
-biochemical: 1 pigment - rhodopsin

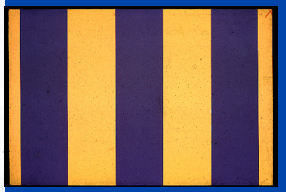
-morphological: 1cell type - rhabdomere

(no rods or cones)

-physiological: ERG - no Purkinje shift

-behavioral:





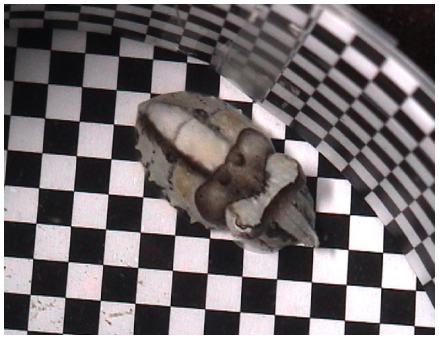
optomotor

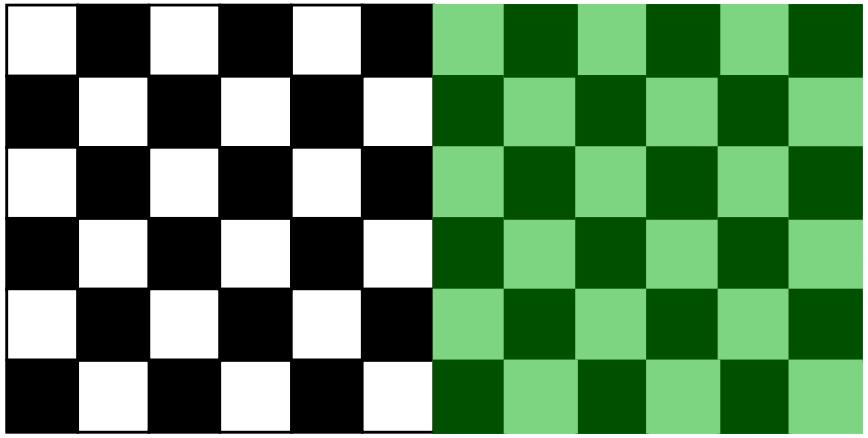
learning (vertical rectangle discrim.)

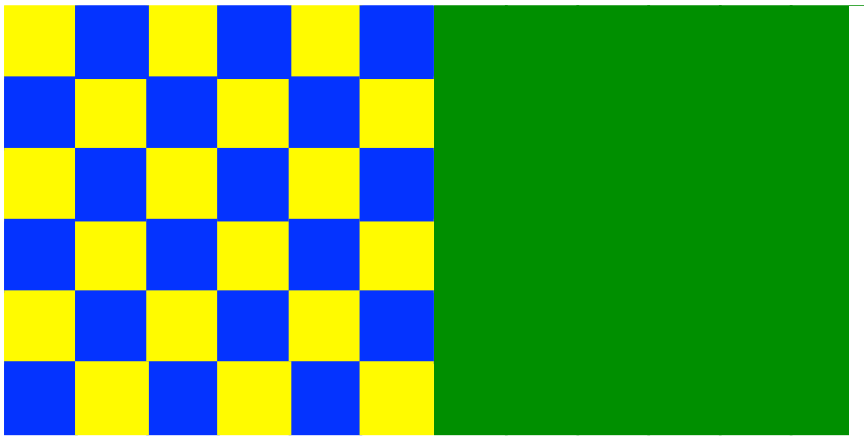
substrate matching

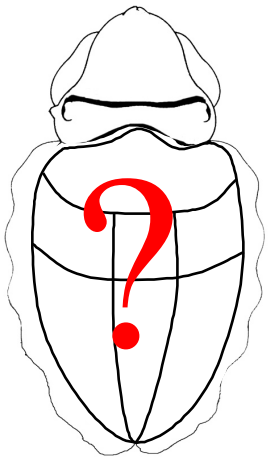
(review: Hanlon & Messenger 1996 Ceph Behaviour, CUP)

Color blind Experiment 1
Blue and yellow checkerboard

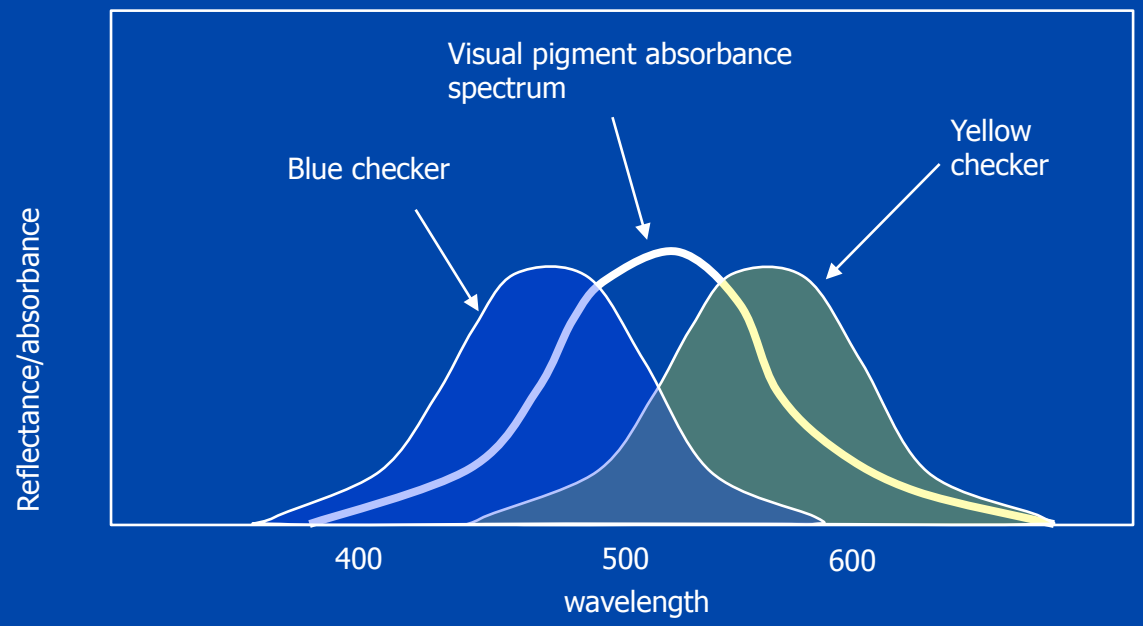




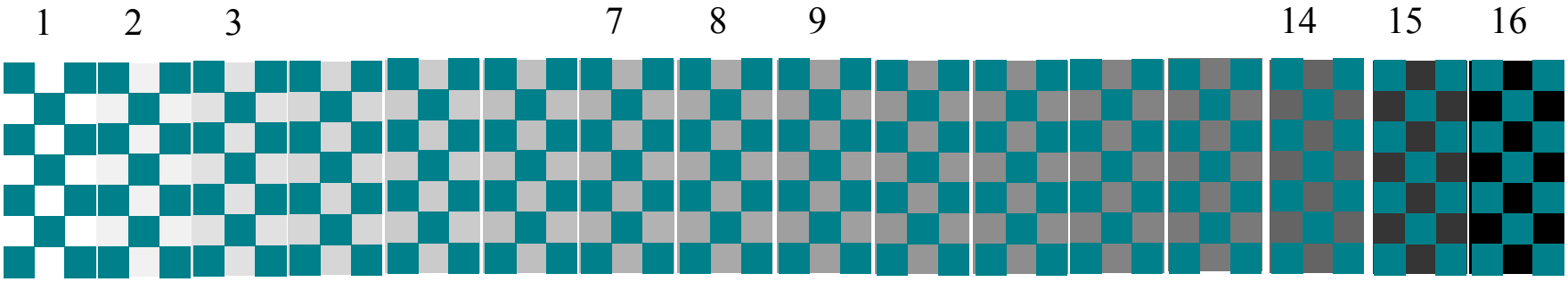




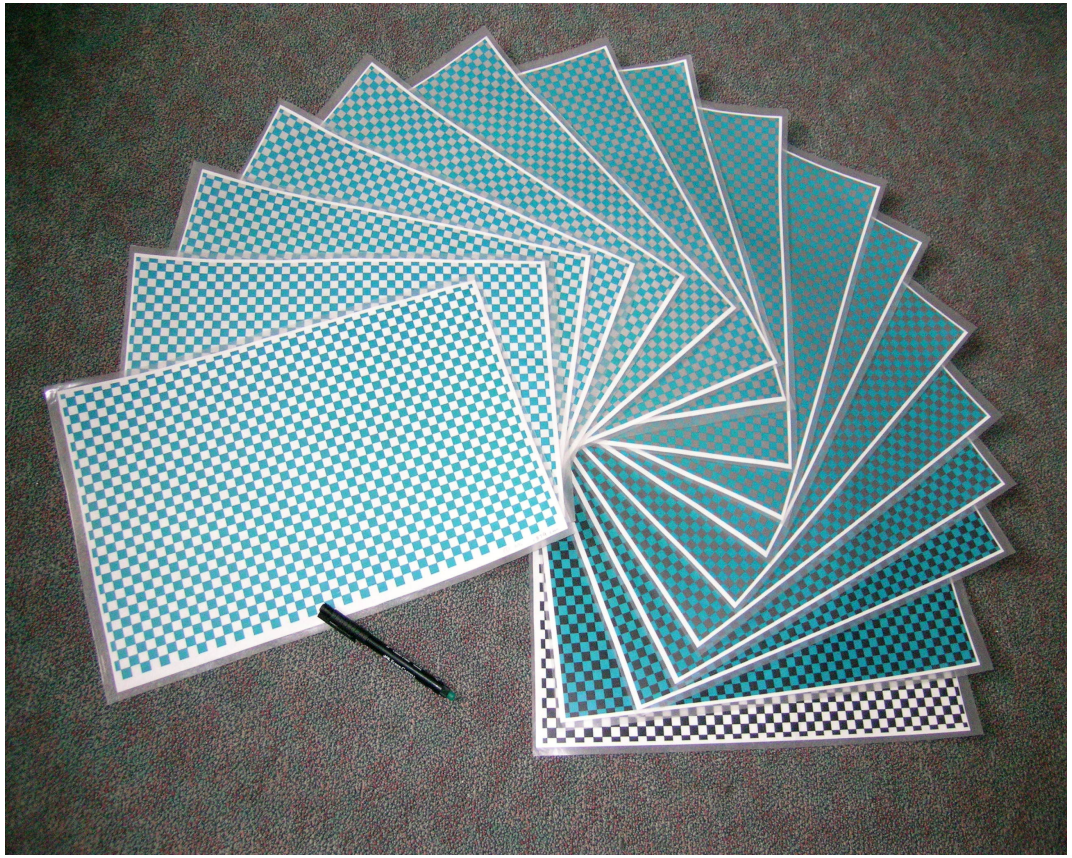
Blue and yellow checkerboard



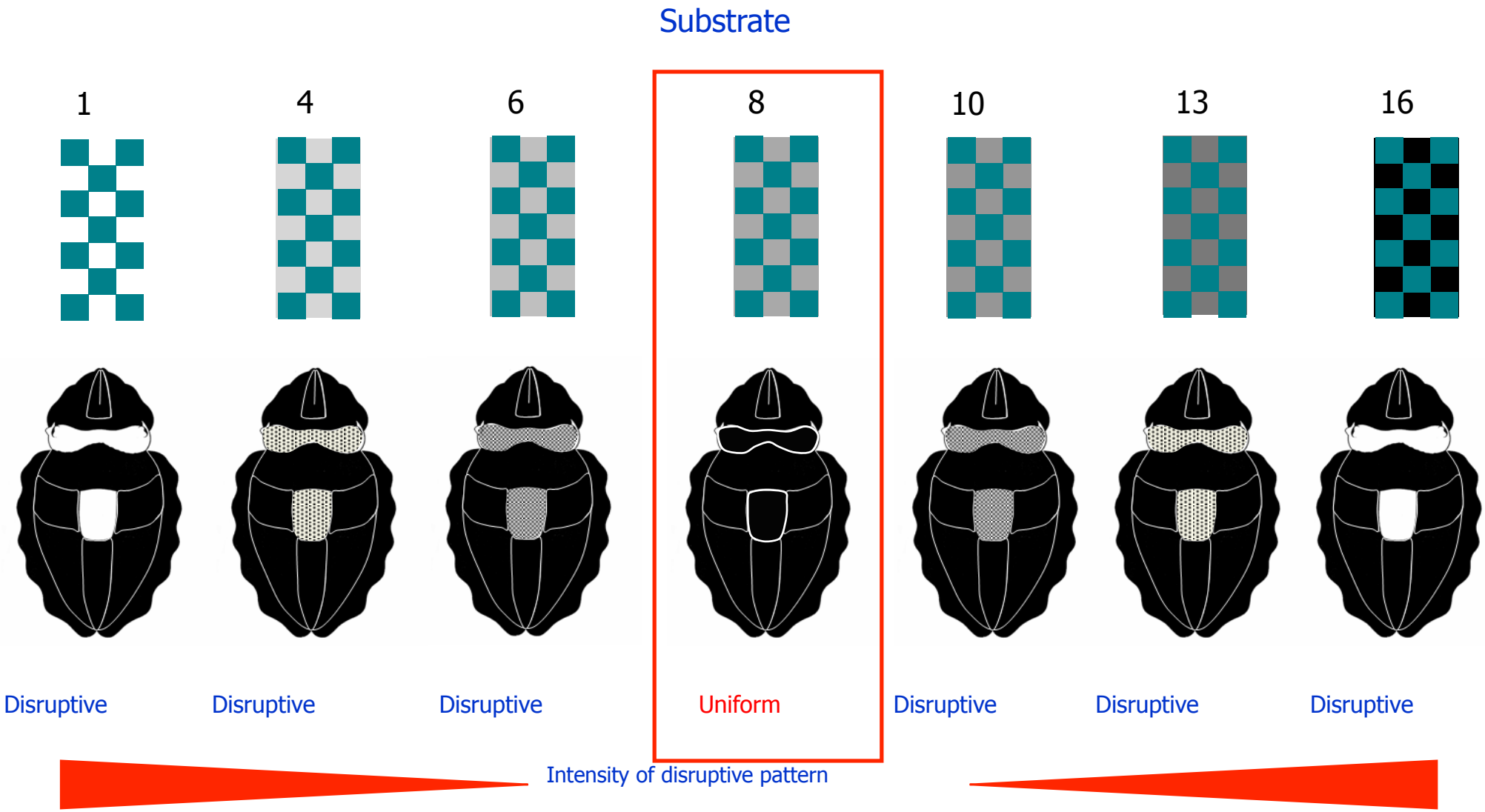
Cuttlefish sees this
as a UNIFORM substrate



Experiment 2:
Sixteen gray scale checkerboards



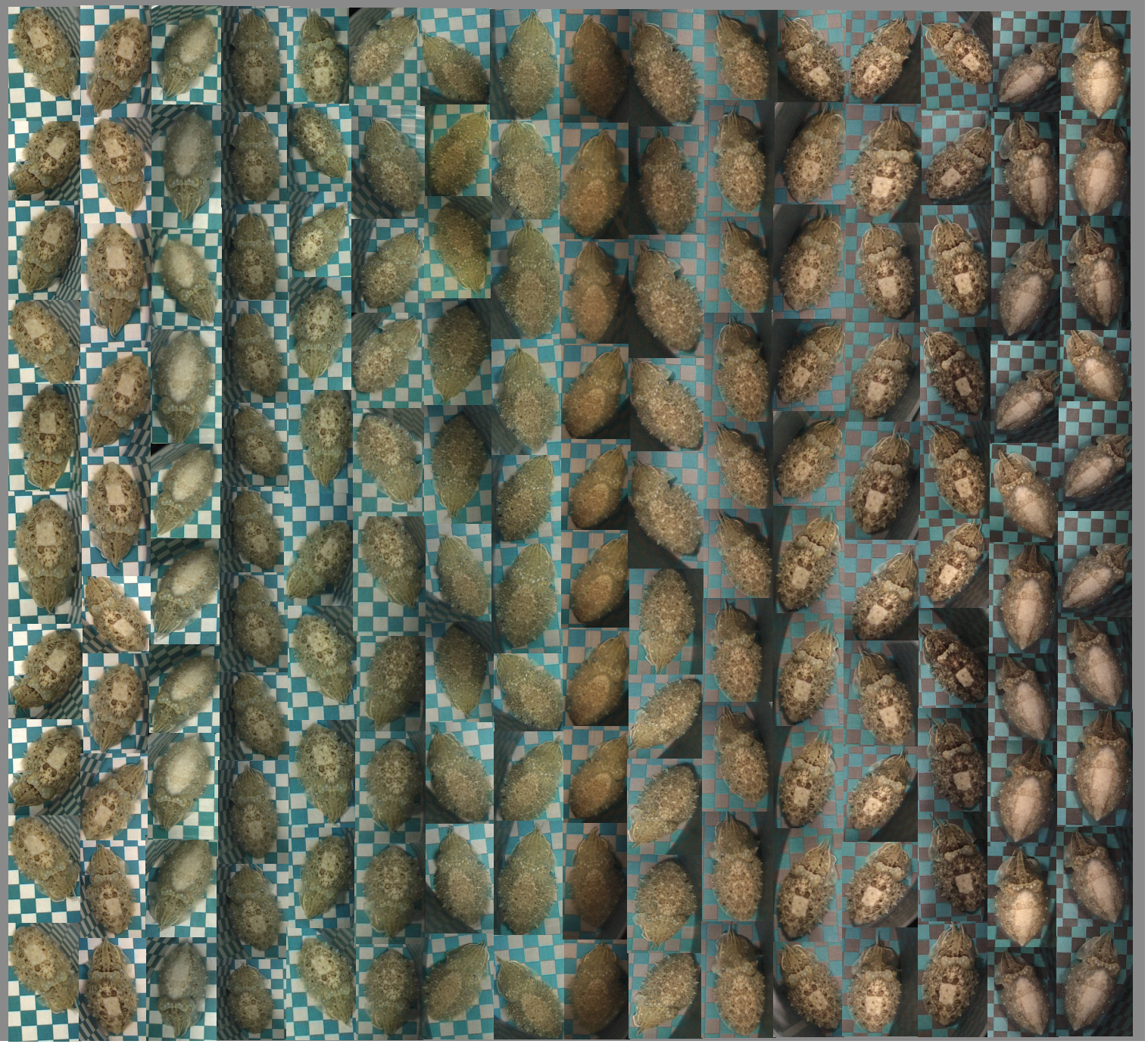
Predictions



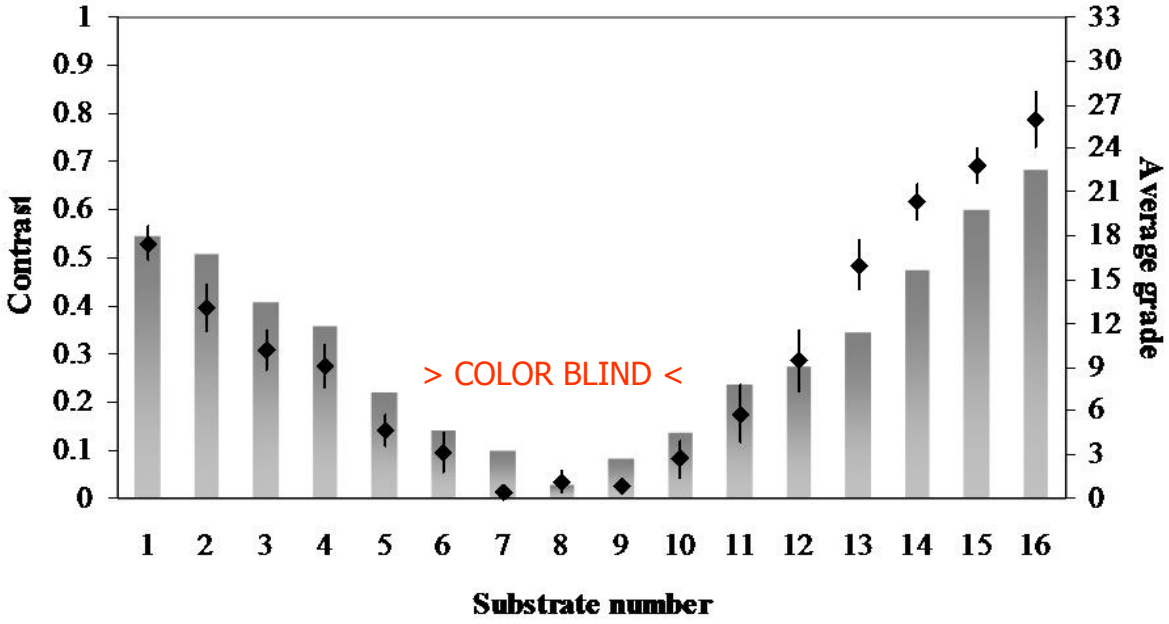
Expected body pattern = uniform

Animal 9

10 images per substrate are graded



Results color-blind Experiment 2



Uniform shown on the substrate on which the grey and green are matched in intensity to the cuttlefish eye.

- Mäthger, Barbosa, Miner, Hanlon. 2006 Vision Research 46

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Not bad for a “color blind” animal

Could there be other light sensors outside the eye?

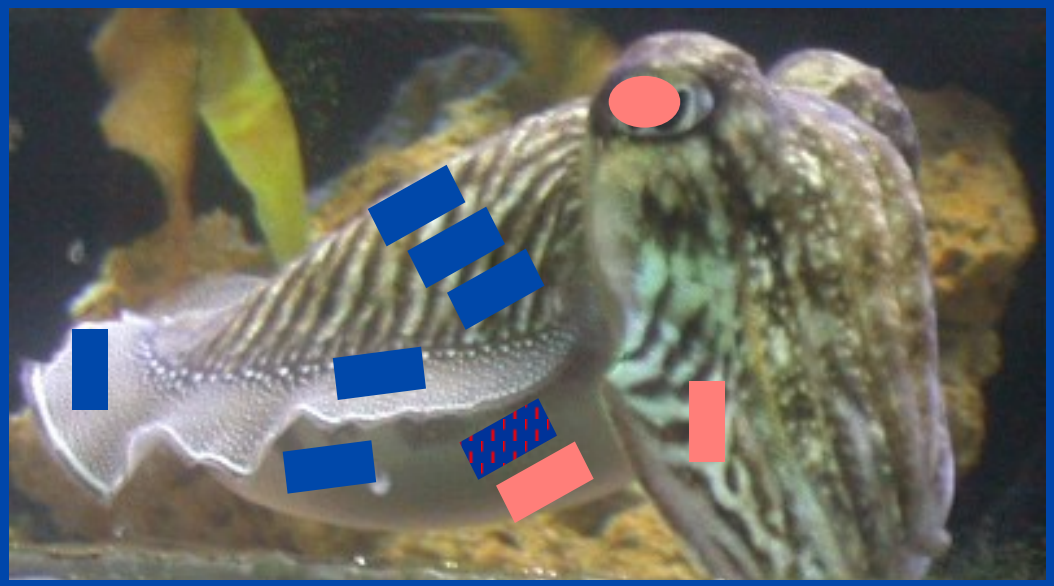
biology letters 2010
Biol. Lett.
doi:10.1098/rsbl.2010.0223
Published online
Animal behaviour

Evidence for distributed light sensing in the skin of cuttlefish, *Sepia officinalis*

Lydia M. Mäthger[1,*], Steven B. Roberts[1,2] and Roger T. Hanlon[1]

Single retinal pigment: 492nm

Opsin expressed in skin

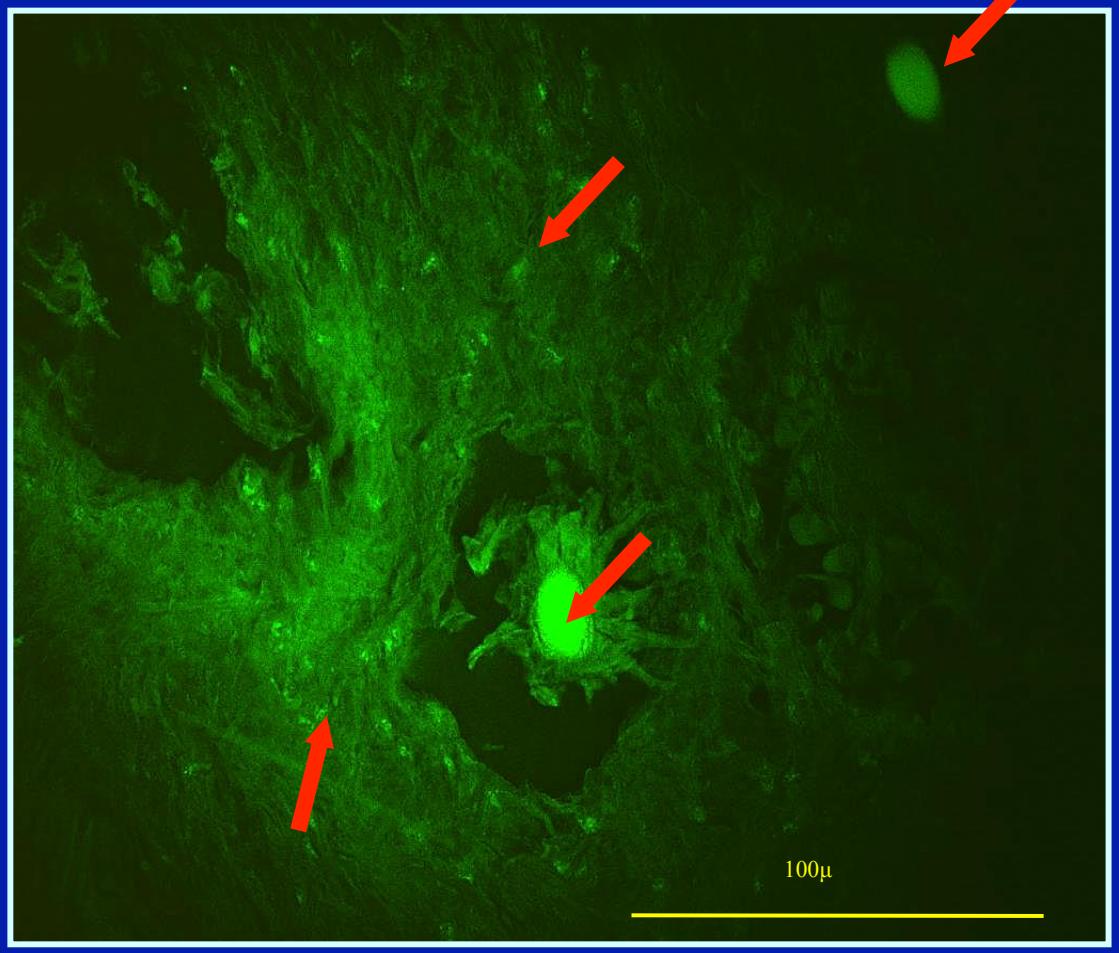


OPSIN NO OPSIN

Squid skin - opsin distribution

Concentration of immunofluorescent cells

surrounding a yellow chromatophore.



What can it mean?

Motion camouflage video ……

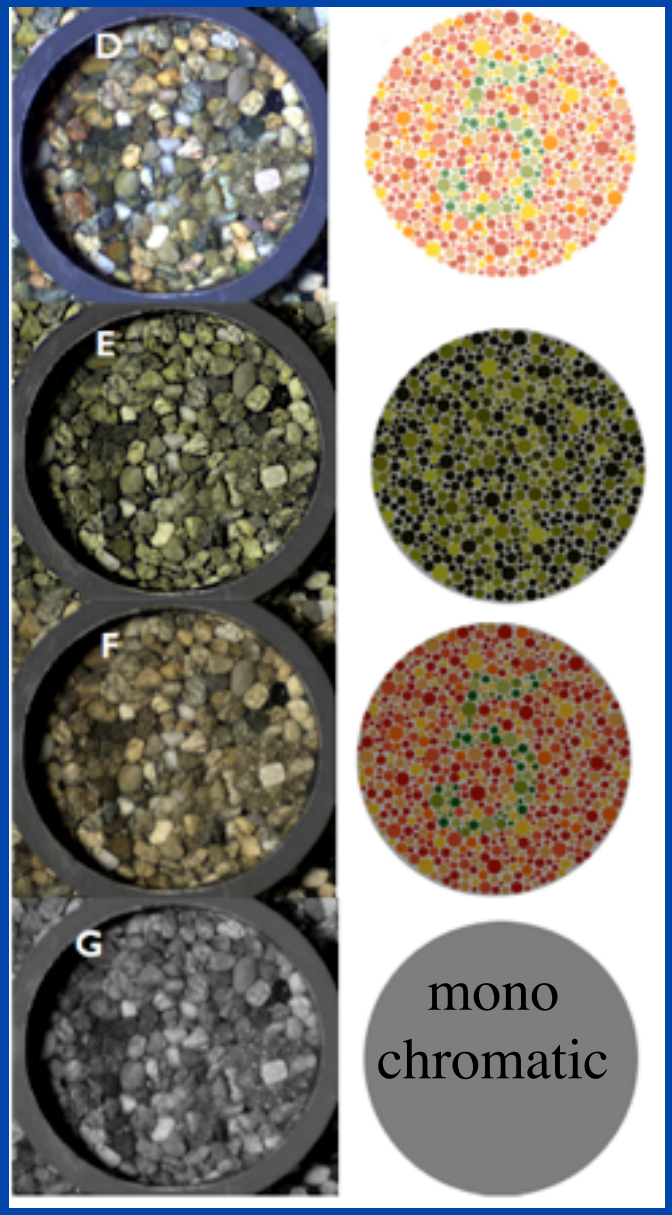
"moving rock" trick

Roger T. Hanlon

ULTIMATE GOAL:

View a background and PREDICT the correct camouflage pattern, color, posture and skin texture for an animal of any shape and size

Can visual predators detect color patterns?



pseudocolor
(RGB camera)

di chromatic
model predator

This fish is color blind
to **this** cuttlefish,
even with color vision !

tri chromatic
model predator

Chiao *et al*. PNAS 2011

Concluding thoughts

Dynamic camouflage is controlled visually

Although cephalopod eyes LOOK like human eyes,
they are different in perceptual capabilities

Experiments with a Visual Sensorimotor Assay (live, healthy, untethered cuttlefish) indicate that they do indeed use “simple” cues to turn on 3 basic camou pattern templates

Concluding thoughts

Future experiments need to decipher fine control of the variations on these 3 patterns

Mechanisms of “color blind camouflage” and “skin 3D texture control” are potentially exciting areas of future study

Study nature, not books

L. Agassiz ca. 1890

Thank you

Video:
lembeh cuttle 0:08
papillae 1:39
vigo color 0:22
moving rock 0:22
NEED MORE