ELECTRICAL CONDUCTIVITY OF *SCYLIORHINUS CANICULA* EGG CAPSULES

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Nico Pals earned a PhD on dogfish electro-orientation at Utrecht University in 1982. During his research, some eggs of the study object, the dogfish *Scyliorhinus canicula,* developed into embryos. The embryos reacted surprisingly well with a freeze response to electrical stimulation, still inside their egg capsules (Peters & Evers 1985). The present paper shows the results of an unpublished 'Blitz'-experiment in 1983 to assess the electrical conductivity of the egg capsules.

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Materials & Methods, Results, Conclusions, References, Ackowledgements

Summary

The electrical conductivities of capsules of embryos of the dogfish *Scyliorhinus canicula* were measured, in order to investigate to which extent external electrical fields are attenuated before detection by the embryos inside. The resistivity of the capsules measured at a test current of 0.1 mA at 50 Hz was 231 Ohm.cm. A first estimation based on this figure shows that about 90% of the external field strength might be felt inside the capsule.

Keywords

Dogfish - egg capsule - electric field – electrical conductivity – electrical resistivity - electroreception – embryo - S*cyliorhinus canicula* - resistance.

Introduction

Egg capsules of sharks, skates, rays, and cuttlefish offer a considerable amount of protection to the encapsulated embryos. Apparently, the protection is effective during the several months lasting development to hatched individuals. Egg capsules do not only offer mechanical protection, they also allow extrusion of various metabolic waste products, as has been demonstrated in shark eggs (Lombardi & Files 1993), and are permeable to oxygen, as was demonstrated in for instance cuttlefish (Cronin & Seymour 2000). Since dogfish embryos are already sensitive to electrical stimulation inside their egg capsules - an observation by A.A.C. Schönhage (Peters & Evers 1985) - the question arose to what extent the egg capsules affect externally applied electrical fields. To answer this question I made some preliminary measurements of the electrical resistance of the egg capsules, and, in addition estimated their effect on external electrical stimuli.

Materials and Methods

Capsule holder. To measure the electrical resistance of the capsules of the dogfish embryos, circular discs were cut from the empty capsules when the embryos had hatched. The capsule samples were mounted in a segmented perspex tube with an inner diameter of 11 mm, corresponding roughly to 0.95 cm² cross-section (fig 1). The perspex tube was designed earlier for measurements of skin impedance and potentials in catfish (Schouten 1977; Schouten & Bretschneider 1980). At both ends of the tube silver plate electrodes were mounted for generation of the test current. The sample of the egg capsule was rigidly clamped between the segments of the tube at various distances from the reference electrode (fig 2). Along the tube, small holes were drilled into the wall as to pass electrodes to measure the potential drop over a length of tube, *i.e.* either a column of seawater or a column of seawater containing the egg capsule sample.

Test current and resistance measurement. The resistance of the egg capsule sample was determined by passing a constant current through the seawater column with and without egg capsule sample, and measuring the potential drop over the column, which with the help of Ohm's law yields the resistance of the egg capsule (Bretschneider & de Weille 2006). The experimental protocol, dated 831220-PETR[1], is incomplete. The description of the recording electrodes is missing. In retrospect, the use of a test current of 50 Hz square wave suggests that I tried to measure at various frequencies including dc, but decided to switch to 50 Hz ac, as soon as I discovered that the measured signal was too noisy to read from the oscilloscope. Both recording electrodes were via custom built Gain 1 followers connected to a Princeton Applied Research 113 differential preamplifier, with Gain 10 and bandwidth dc<f<1 kHz. Most likely the recording electrodes were AgAg/Cl with seawater filled salt bridges, because the available alternatives, silver wires or stainless steel injection needles, were less suitable. Apparently the test was done in a hurry, which would explain why eventually I used an ordinary voltmeter with pointer to measure the potential drop over the seawater column. The test current of about 0.1 mA effectively was provided by a custom built current source. The temperature of the seawater was 17.5 º C; the specific resistance was 30 Ohm.cm.

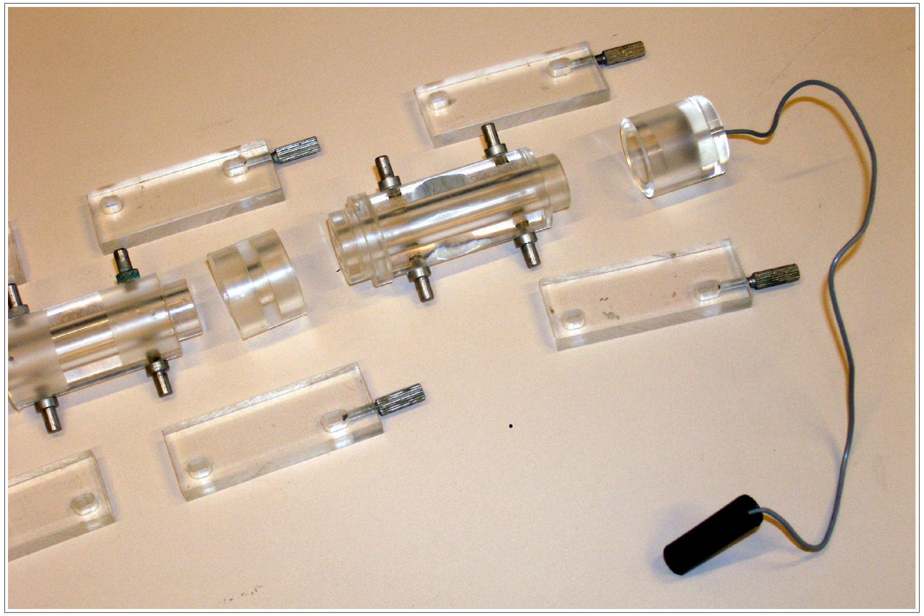

Fig 1. Photograph of the segmented measuring tube. Both end sections contained silver plate electrodes to generate the test current. The circular sample of the egg capsule could be clamped between two tube segments, and pressed firmly to prevent current shunting. Holes of 1 mm diameter were drilled in the tube wall every 5 cm to insert electrolyte cannulae or silver wire electrodes to measure the potential drop over the water column inside, with or without egg capsule sample. Inner diameter of the tube 11 mm. Originally designed for Schouten (1977) and Schouten & Bretschneider (1980).

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[1] 831220 means December 20, 1983. PETR is the code used at the time by the Academic Computer center for the author.

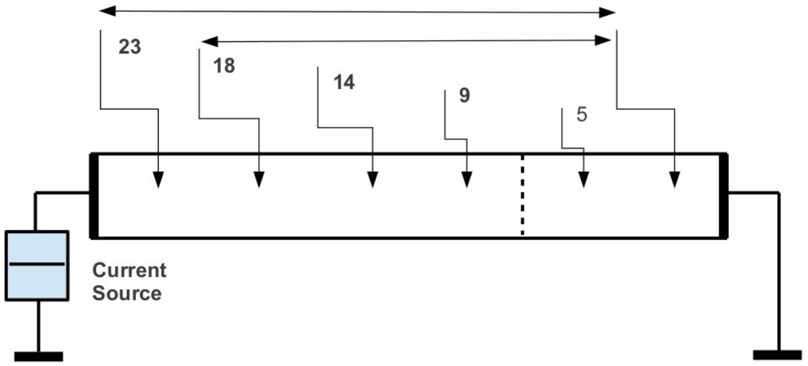

Fig 2. Schematic diagram of the tube, current source, and measuring sites. Black ends silver plate constant current source electrodes. Dotted line: egg capsule sample. Arrows: measuring sites. Numbers: distance to the reference electrode in cm. The measuring electrodes connect to a differential amplifier; the most right electrode is the reference electrode.

Results

The average thickness of the wet egg capsules, measured with a marking gauge, was 0.35 mm. The capacitive reactance of 1 cm² of egg capsule at 50 Hz is in the MOhm range and its shunting of the test current can apparently be neglected hereafter. Only the resistive component of the egg capsule impedance determines the current flow. The measured potential differences over the resistance of the seawater column with egg capsule and without capsule are given in table 1.

To avoid systematic errors, and since systematic errors of the test current disappear from the calculations, the test current (I) was calculated from the voltage drop over the seawater column, divided by the calculated resistance of the column according to I = V / R, where V is the measured voltage drop over the column in mV, R is the calculated resistance according to R= rho * L/O, where rho is the specificresistance of seawater in Ohm.cm, L is the length of the water column in cm, and O is the cross-section of the tube in cm² (*cf* Bretschneider & de Weille 2006). Comparison of the voltage drops over the columns of various lengths gave an average value of I = 0.135 mA effectively.

cm									Row average mV	ΔV mV
23	100.0	98.3	99.0	99.5	99.2	98.0	99.2	99.0	**99.0**	
18	80.0	78.2	78.5	78.9	78.8	78.0	79.2	78.5	**78.7**	
14	63.0	60.7	61.2	61.2	61.3	60.2	61.8	61.0	**61.3**	
9	40.0	39.6	40.0	40.0	40.0	40.0	40.8	39.9	**40.0**	
5	21.0	21.2	21.0	21.0	21.0	20.3	21.0	21.0	**20.9**	
23	98.0	98.3	98.5		99.0	96.5	98.0	99.0	**98.2**	**0.8**
18	77.5	78.0	78.0		78.5	76.0	77.5	78.4	**77.7**	**1.1**
14	60.0	60.6	60.6		60.3	59.0	60.2	61.0	**60.2**	**1.1**
9	39.0	39.0	39.1		39.0	38.0	39.1	40.0	**39.0**	**1.0**
5	21.0	21.0	21.0		21.0	20.3	21.0	21.0	**20.9**	0.0
								Difference average:		**1.0**

Table 1. Potential drop over the seawater column. Left column: distance between the measuring electrodes. The rows marked light blue represent potential drops over the seawater column with egg capsule. The rows marked yellow represent potential drops over columns of seawater only. The white column represents a missing data series. Last column: potential change due to presence of egg capsule.

From the values of table 1 can be inferred that the average potential difference ΔV between the seawater column with and without egg capsule is 1.0 mV. The increase in resistance ΔR due to the presence of the egg capsule is therefore

$$\Delta R = \Delta V / I = 1.0/0.135 = 7.4 \text{ Ohm}$$

Calculation of the increase of specific resistance of the egg capsule by
$\Delta rho = \Delta R * O/L$, where L is the thickness of the egg capsule, and O is the cross-section of the tube yields
$\Delta rho = 7.4 * 0.95 / 0.035 = 201$ Ohm.cm.
Because the specific resistance rho of seawater replacing the egg capsule was already 30 Ohm.cm, the resistivity of the egg capsule is 201 + 30 = 231 Ohm.cm.

Effect of capsule on external electric fields

Earlier tests (Peters 1979, unpublished) suggested that embryos inside their capsules were slightly less sensitive to electrical currents that small dogfish of roughly the same size outside the capsules. In order to estimate the effect of the egg capsule on the electric fields inside the capsule, one of Holzer's formulae (Holzer 1933) can be used to describe the effective stimulation of eggs in a bath. As a first approximation the dogfish embryo capsule can be considered as a sphere with an inner radius of 1 cm, and an outer radius of 1.035 cm, filled with seawater. According to Holzer the current density J_k inside such a sphere can be calculated by

$J_b / J_k = k_b * A + B$ (Holzer 1933, page 824, formula 8)
where
k_b is the specific conductivity of the bath medium in $Ohm^{-1}.cm^{-1}$
$A = (2/9) * (1/k_m) * [(2n + 1) + d * (n-1)]$
$B = (1/9) * [(2n + 1) - 2 d * (n-1)]$
and
k_m = specific conductivity of egg capsule in $Ohm^{-1}.cm^{-1}$
n = (k_m / k_k), where k_m = specific conductivity of egg capsule, en k_k specific conductivity of egg interior, in this example seawater.
d = $(b/a)^3$, where b inner radius of egg capsule, a outer radius of egg capsule.

For $k_k = k_b = 0.033$ $Ohm^{-1}.cm^{-1}$, $k_m = 0.0049726$ $Ohm^{-1}.cm^{-1}$, b = 1 cm, and a = 1.035 cm, it follows that $J_b / J_k = 1.1$, implying that the current density inside the egg capsule is 90 %f the external current density, the current density in the surrounding bath.

Discussion

Although the measurements and calculations presented above must be considered as a rough first approach – not having enough weight to submit these findings as a manuscript to the demanding editor of a scientific periodical – they nevertheless give a fair estimate of the electrical properties of the egg capsule. Egg capsules, whether of sharks, skates, rays or cuttlefish protect the eggs against a number of disadvantageous external influences by giving mechanical protection. Still the embryo should have access to oxygen, and metabolic waist products should be expelled. That this is the case has been demonstrated (e.g. Cronin & Seymour 2000, Lombardi & Files 1993). Apparently the permeability of the egg capsule also extends to electrical currents, allowing the embryo in the early stages of development to experience the presence of external electrical stimuli. A possible profit of this sensitivity has been discussed by Kempster *et al* (2013). See for an overview of detection thresholds Elasmobranch fish Peters *et al.* (2007).

Conclusions

Dogfish embryo's can feel external electrical fields because the electrical resistance of the egg capsule is sufficiently low lo have the current pass.

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The reader is invited to check and recalculate the presented findings.

Appendix

Fig 3. Photograph (2013) of the dried egg capsule samples on blotting paper, still kept in the author's experimental archive. Scale in cm.