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THE USE OF ELECTRONARCOSIS AS ANAESTHETIC IN THE CICHLID, *OREOCHROMIS MOSSAMBICUS* (PETERS). II. THE EFFECTS OF CHANGING PHYSICAL AND ELECTRICAL PARAMETERS ON THE NARCOTIZING ABILITY OF ALTERNATING CURRENT

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ABSTRACT

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The effects of wave form, voltage, frequency and current as well as application time on the narcotizing ability of alternating current were investigated. A 60 Vrms, 50 Hz sine wave current applied for 30 s produced narcosis of sufficient duration to enable handling and blood sampling. A triangle wave form was inferior in narcotizing ability to both sine wave and square wave forms.

Duration of narcosis increased with increasing water conductivity but was reduced by increasing water temperatures.

INTRODUCTION

There is a general lack of conformity in the combination of electrical parameters employed to electronarcotize fishes (Kynard & Lonsdale, 1975; Madden & Houston, 1976). In order to develop practical standardized procedures for fresh water fish, attention was given, in the present study, to the possible effects of changes in particular electrical and related physical water parameters on the narcotizing ability of electronarcosis.

According to the literature (Scheminzky & Bukatsch, 1941; Meyer-Waarden, 1957), fishes respond differently to alternating and direct currents. The question, however, is not just whether there is a difference between the effects on fish of alternating and direct currents *per se*, but of the quality of narcosis induced by different alternating or direct current configurations. Only after this has been established can recommendation be made regarding the most suitable combinations to use. Ideally, a suitable narcotizing current must induce deep anaesthesia with little or no physical and physiological stress to the fish. In evaluating this problem, due consideration must be given not only to the electrical parameters involved but also to water quality and temperature, as well as to factors such as size of fish and species specific responses.

The effects of changing physical and electrical parameters on the narcotizing ability of direct current will be dealt with in Part III.

MATERIALS AND METHODS

For materials and procedures used in this investigation readers are referred to Part I of the series (Barham, Schoonbee & Visser, 1987a). In this study the experimental groups consisted of 8 acclimated fish each. Unless otherwise stated, the wave form used for electronarcosis was a 50 Hz sine wave at 60 Vrms.

Aquaria were 60 cm long and water temperture was 20 °C unless otherwise stated.

RESULTS

Effects of wave form and voltage

Three alternating current wave forms, square, sine and triangle were evaluated at a frequency of 50 Hz at 3 different potentials and the results are recorded in Tables 1–3. A comparison of the effects of different wave forms at a potential of 60 Vrms (Table 3) shows that, although a square wave produced the longest enduring narcosis, this was not significantly longer ($P>0,1$) than the narcosis time induced by a sine wave. Square wave narcosis, however, was statistically significantly longer ($P=0,02$) than that produced by a triangle wave. This situation was also observed for opercular recovery times and narcosis coefficients (Table 3).

At a potential of 45 Vrms the picture changes and a sine wave induces the longest narcosis time which statistically is significantly longer ($P=0,01$) than the narcosis time induced by a square wave (Table 2). The mean narcosis time of 62,4 s for a sine wave, however, was not significantly longer than the mean time induced by a triangle wave. Mean opercular times and mean narcosis coefficients also reflected this pattern, but recovery times did not differ significantly from one wave form to another (Table 2). In contrast, there were no significant differences in narcosis times between any of the 3 wave forms at 30 Vrms.

The effects of different electrical potentials on the duration of narcosis induced by a particular wave form are recorded in Tables 4–6. A comparison of the results obtained clearly shows that for all 3 wave forms investigated mean narcosis times were positively related to increasing eletrical potentials (voltage), with distinct increases at 60 Vrms for all 3 waves (compare Tables 4–6). The same was generally true for both opercular recovery times and narcosis coefficients. Square wave recovery times increased consistently with increasing voltage but these differences were not significant.

The same was true for both opercular recovery times and narcosis coefficients. Only square wave recovery times increased with increasing voltage, but these differences were not significant. Both triangle and sine wave recovery times were depressed at 45 volts, although differences ranging from significant to very significant were only apparent between the different voltages in the case of triangle waves (Table 6).

When considering the effect of different potentials, it is important to appreciate that, if the conductivity of the circuit remains constant, decreasing potentials result in decreased current flow, i.e., a drop in amperage. Thus changes in observed times may also be attributed to changes in current flow (see below for an elaboration of this point). Since the electrical main supply in South Africa is a sine wave current it was decided to use this wave form to evaluate the other electrical and physical parameters.

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TABLE 1 A comparison of the effects of electronarcosis by different a.c. wave forms at 30 Vrms on opercular recovery time, narcosis time and recovery time

		Length (cm)	Mass (g)	Opercular recovery time (s)	Narcosis time (s)	Recovery time (s)	Narcosis coefficient (s cm^{-1})
Square wave	n =	8	8	8	8	8	8
	Minimum	21,3	162,8	3,0	11,2	3,9	0,4
	Maximum	27,7	337,2	41,3	75,4	85,4	2,7
	Range	6,4	174,4	38,3	64,2	81,5	2,3
	Mean	24,4	242,7	9,1	29,9	54,8	1,2
	Standard dev.	2,0	57,2	13,1	23,0	26,7	0,9
	Standard err.	0,7	20,2	4,6	8,1	9,4	0,3
Sine wave	n =	8	8	8	8	8	8
	Minimum	22,6	185,6	2,3	2,3	18,8	0,1
	Maximum	28,0	319,9	38,8	47,6	155,5	1,8
	Range	5,4	134,3	36,5	45,3	136,7	1,7
	Mean	25,0	260,9	21,5	30,2	74,9	1,2
	Standard dev.	1,7	41,3	13,1	14,9	42,2	0,6
	Standard err.	0,6	15,6	5,0	5,6	16,0	0,2
Triangle wave	n =	8	8	8	8	8	8
	Minimum	22,4	187,9	20,1	28,6	33,4	1,1
	Maximum	27,9	346,0	33,2	70,1	82,5	2,5
	Range	5,5	158,1	13,1	41,5	49,1	1,4
	Mean	25,8	283,4	27,6	39,6	64,7	1,5
	Standard dev.	1,8	51,0	4,8	13,0	19,1	0,4
	Standard err.	0,6	18,0	1,7	4,6	6,8	0,1
	't' Values (df)						
	Sq/Sin (14)	NS	NS	1,901 (P=0,1)	NS	NS	NS
	Sq/Tri (14)	NS	NS	3,770 (P=0,01)	NS	NS	NS
	Sin/Tri (14)	NS	NS	NS	NS	NS	NS

df = degree of freedom; P = two-tailed probability; NS = not significant

TABLE 2 A comparison of the effects of electronarcosis by different a.c. wave forms at 45 Vrms on opercular recovery time, narcosis time and recovery time

		Length (cm)	Mass (g)	Opercular recovery time (s)	Narcosis time (s)	Recovery time (s)	Narcosis coefficient (s cm^{-1})
Square wave	n =	8	8	8	8	8	8
	Minimum	21,4	166,6	15,1	26,1	30,2	1,1
	Maximum	27,7	338,4	35,0	55,7	192,6	2,2
	Range	6,3	171,8	19,9	29,6	162,4	1,1
	Mean	24,3	245,6	28,4	46,8	84,9	1,9
	Standard dev.	2,0	56,7	6,0	9,6	49,8	0,3
	Standard err.	0,7	20,0	2,1	3,4	17,6	0,1
Sine wave	n =	8	8	8	8	8	8
	Minimum	22,5	186,0	21,6	53,4	32,9	2,1
	Maximum	27,9	322,7	43,1	87,8	123,3	3,5
	Range	5,4	136,7	21,5	34,4	90,4	1,4
	Mean	25,0	264,3	34,6	62,4	63,5	2,5
	Standard dev.	1,6	38,5	6,8	10,8	32,7	0,4
	Standard err.	0,5	14,0	2,4	3,8	11,6	0,2
Triangle wave	n =	8	8	8	8	8	8
	Minimum	22,4	187,4	30,4	51,6	16,6	2,0
	Maximum	27,8	349,2	47,2	62,5	120,2	2,6
	Range	5,4	161,8	16,8	10,9	103,6	0,6
	Mean	25,7	286,0	37,8	57,3	50,1	2,2
	Standard dev.	1,8	51,4	6,0	3,2	31,4	0,2
	Standard err.	0,6	18,2	2,1	1,1	11,1	0,1
	't' Values (df)						
	Sq/Sin (14)	NS	NS	1,931 (P=0,1)	3,040 (P=0,01)	NS	2,990 (P=0,01)
	Sq/Tri (14)	NS	NS	3,131 (P=0,01)	2,933 (P=0,02)	NS	2,345 (P=0,05)
	Sin/Tri (14)	NS	NS	NS	NS	NS	NS

df = degree of freedom; P = two-tailed probability; NS = not significant

Effects of frequency

The physical effects of electronarcosis at 3 different frequencies on the tilapia are recorded in Table 7. Although mean narcosis time at 100 Hz was somewhat higher than at lower frequencies, there were no significant differences between the 3 frequencies tested. The significant differences between recovery times at 25 Hz and 50 Hz (P=0,05) and between 50 Hz and 100 Hz (P=0,01) must be viewed in terms of the subjectivity inherent in the determination of recovery time.

Effects of water condictivity and current

The effects of 3 water conductivities, 100, 250 and 430 $\mu S\ cm^{-1}$, on tilapia, using 50 Hz alternating currents at 3 voltages, were investigated. The upper limit of 430 $\mu S\ cm^{-1}$ was chosen as this represented the maximum

TABLE 3 A comparison of the effects of electronarcosis by different a.c. wave forms at 60 Vrms on opercular recovery time, narcosis time and recovery time

		Length (cm)	Mass (g)	Opercular recovery time (s)	Narcosis time (s)	Recovery time (s)	Narcosis coefficient (s cm^{-1})
Square wave	n =	8	8	8	8	8	8
	Minimum	21,5	164,1	16,4	81,9	5,0	3,5
	Maximum	27,7	346,2	57,3	247,2	426,4	10,3
	Range	6,2	182,1	40,9	165,3	421,4	6,8
	Mean	24,4	245,8	35,0	174,3	94,0	7,2
	Standard dev.	1,9	59,8	12,6	48,6	147,7	2,1
	Standard err.	0,7	21,1	4,4	17,2	52,2	0,7
Sine wave	n =	8	8	8	8	8	8
	Minimum	22,5	185,9	24,3	60,2	38,7	2,4
	Maximum	28,2	325,7	99,7	243,9	190,4	10,8
	Range	5,7	139,8	75,4	183,7	151,7	8,4
	Mean	25,2	267,4	51,1	156,8	95,4	6,3
	Standard dev.	1,6	40,4	25,1	70,8	50,1	3,1
	Standard err.	0,6	14,3	8,9	25,0	17,7	1,1
Triangle wave	n =	8	8	8	8	8	8
	Minimum	22,5	198,4	25,4	50,3	15,8	2,1
	Maximum	28,0	350,7	67,1	197,0	139,9	7,0
	Range	5,5	152,3	41,7	146,7	124,1	4,9
	Mean	25,8	287,1	47,2	112,3	91,2	4,3
	Standard dev.	1,8	48,3	13,8	45,7	42,2	1,7
	Standard err.	0,6	17,1	4,9	16,2	14,9	0,6
	't' Values (df)						
	Sq/Sin (14)	NS	NS	NS	NS	NS	NS
	Sq/Tri (14)	NS	NS	1,846 (P=0,1)	2,628 (P=0,02)	NS	3,000 (P=0,01)
	Sin/Tri (14)	NS	NS	NS	NS	NS	NS

df = degree of freedom; P = two-tailed probability; NS = not significant

TABLE 4 A comparison of the effects of square wave a.c. electronarcosis at 3 different potentials on opercular recovery time, narcosis time and recovery time

		Length (cm)	Mass (g)	Opercular recovery time (s)	Narcosis time (s)	Recovery time (s)	Narcosis coefficient (s cm^{-1})
30 volts	n =	8	8	8	8	8	8
	Minimum	21,3	162,8	3,0	11,2	3,9	0,4
	Maximum	27,7	337,2	41,3	75,4	85,4	2,7
	Range	6,4	174,4	38,3	64,2	81,5	2,3
	Mean	24,4	242,7	9,1	29,9	54,8	1,2
	Standard dev.	2,0	57,2	13,1	23,0	26,7	0,9
	Standard err.	0,7	20,2	4,6	8,1	9,4	0,3
45 volts	n =	8	8	8	8	8	8
	Minimum	21,4	166,6	15,1	26,1	30,2	1,1
	Maximum	27,7	338,4	35,0	55,7	192,6	2,2
	Range	6,3	11,8	19,9	29,6	162,4	1,1
	Mean	24,3	245,6	28,4	46,8	84,9	1,9
	Standard dev.	2,0	56,7	6,0	9,6	49,8	0,3
	Standard err.	0,7	20,0	2,1	3,4	17,6	0,1
60 volts	n =	8	8	8	8	8	8
	Minimum	21,5	164,1	16,4	81,9	5,0	3,5
	Maximum	27,7	346,2	57,3	247,2	426,4	10,3
	Range	6,2	182,1	40,9	165,3	421,4	6,8
	Mean	24,4	245,8	35,0	174,3	94,0	7,2
	Standard dev.	1,9	59,8	12,6	48,6	147,7	2,1
	Standard err.	0,7	21,1	4,4	17,2	52,2	0,7
	't' Values (df)						
	30/45 (14)	NS	NS	3,788 (P=0,01)	1,918 (P=0,1)	NS	2,087 (P=0,1)
	30/60 (14)	NS	NS	4,030 (P=0,001)	7,596 (P=0,001)	NS	7,428 (P=0,001)
	45/60 (14)	NS	NS	NS	7,279 (P=0,001)	NS	7,067 (P=0,001)

df = degree of freedom; P = two-tailed probability; NS = not significant

conductivity of the aquarium water. The lower values were selected to provide a spectrum of prevailing river water conductivities. Voltages selected were the same as before, namely, 30, 45 and 60 Vrms. This experiment also afforded the opportunity of studying the effects of current on the fish as, according to electrical theory, at a given conductivity, current flow is directly proportional to the applied potential (Malmstadt, Enke & Crouch, 1981). The following currents were observed for each conductivity and potential investigated:

Conductivity	100 $\mu S\ cm^{-1}$	250 $\mu S\ cm^{-1}$	430 $\mu S\ cm^{-1}$
Potential			
30 V	40 mA	90 mA	180 mA
45 V	60 mA	140 mA	260 mA
60 V	80 mA	200 mA	350 mA

In Tables 8–10 the analysis of physical effects on tilapia of changing water conductivities at 3, 50 Hz, alternating current narcotizing potentials of 30, 45, 60 Vrms

TABLE 5 A comparison of the effects of sine wave a.c. electronarcosis at 3 different potentials on opercular recovery time, narcosis time and recovery time

		Length (cm)	Mass (g)	Opercular recovery time (s)	Narcosis time (s)	Recovery time (s)	Narcosis coefficient (s cm^{-1})
30 volts	n =	8	8	8	8	8	8
	Minimum	22,6	185,6	2,3	2,3	18,8	0,1
	Maximum	28,0	319,9	38,8	47,6	155,5	1,8
	Range	5,4	134,3	36,5	45,3	136,7	1,7
	Mean	25,0	260,9	21,5	30,2	74,9	1,2
	Standard dev.	1,7	41,3	13,1	14,9	42,2	0,6
	Standard err.	0,6	15,6	5,0	5,6	16,0	0,2
45 volts	n =	8	8	8	8	8	8
	Minimum	22,5	186,0	21,6	53,4	32,9	2,1
	Maximum	27,9	322,7	43,1	87,8	123,3	3,5
	Range	5,4	136,7	21,5	34,4	90,4	1,4
	Mean	25,0	264,3	34,6	62,4	63,5	2,5
	Standard dev.	1,6	38,5	6,8	10,8	32,7	0,4
	Standard err.	0,5	14,0	2,4	3,8	11,6	0,2
60 volts	n =	8	8	8	8	8	8
	Minimum	22,5	185,9	24,3	60,2	38,7	2,4
	Maximum	28,2	325,7	99,7	243,9	190,4	10,8
	Range	5,7	139,8	75,4	183,7	151,7	8,4
	Mean	25,2	267,4	51,1	156,8	95,4	6,3
	Standard dev.	1,6	40,4	25,1	70,8	50,1	3,1
	Standard err.	0,6	14,3	8,9	25,0	17,7	1,1
	't' Values (df)						
	30/45 (14)	NS	NS	2,491 (P=0,05)	4,949 (P=0,001)	NS	5,099 (P=0,001)
	30/60 (14)	NS	NS	2,966 (P=0,01)	4,949 (P=0,001)	NS	4,568 (P=0,001)
	45/60 (14)	NS	NS	1,812 (P=0,1)	3,728 (P=0,01)	NS	3,439 (P=0,01)

df = degree of freedom; P = two-tailed probability; NS = not significant

TABLE 6 A comparison of the effects of triangle wave a.c. electronarcosis at 3 different potentials on opercular recovery time, narcosis time and recovery time

		Length (cm)	Mass (g)	Opercular recovery time (s)	Narcosis time (s)	Recovery time (s)	Narcosis coefficient (s cm^{-1})
30 volts	n =	8	8	8	8	8	8
	Minimum	22,4	187,9	20,1	28,6	33,4	1,1
	Maximum	27,9	346,0	33,2	70,1	82,5	2,5
	Range	5,5	158,1	13,1	41,5	49,1	1,4
	Mean	25,8	283,4	27,6	39,6	64,7	1,5
	Standard dev.	1,8	51,0	4,8	13,0	19,1	0,4
	Standard err.	0,6	18,0	1,7	4,6	6,8	0,1
45 volts	n =	8	8	8	8	8	8
	Minimum	22,4	187,4	30,4	51,6	16,6	2,0
	Maximum	27,8	349,2	47,2	62,5	120,2	2,6
	Range	5,4	161,8	16,8	10,9	103,6	0,6
	Mean	25,7	286,0	37,8	57,3	50,1	2,2
	Standard dev.	1,8	51,4	6,0	3,2	31,4	0,2
	Standard err.	0,6	18,2	2,1	1,1	11,1	0,1
60 volts	n =	8	8	8	8	8	8
	Minimum	22,5	198,4	25,4	50,3	15,8	2,1
	Maximum	28,0	350,7	67,1	197,0	139,9	7,0
	Range	5,5	152,3	41,7	146,7	124,1	4,9
	Mean	25,8	287,1	47,2	112,3	91,2	4,3
	Standard dev.	1,8	48,3	13,8	45,7	42,2	1,7
	Standard err.	0,6	17,1	4,9	16,2	14,9	0,6
	't' Values (df)						
	30/45 (14)	NS	NS	3,732 (P=0,01)	3,719 (P=0,01)	NS	4,060 (P=0,01)
	30/60 (14)	NS	NS	3,797 (P=0,01)	4,327 (P=0,001)	4,939 (P=0,001)	4,611 (P=0,001)
	45/60 (14)	NS	NS	1,775 (P=0,1)	3,394 (P=0,01)	2,215 (P=0,05)	3,549 (P=0,01)

df = degree of freedom; P = two-tailed probability; NS = not significant

is given. These clearly show that, in each case, increasing conductivities resulted in increasing mean opercular recovery times, increasing mean narcosis times and increasing mean narcosis coefficients. Most of these increases were statistically significant. It is also interesting to note that at the lowest voltage tested (30 Vrms) the only significant difference in mean nacrosis times was that between the lowest (100 μS cm^{-1}) and highest (430 μS cm^{-1}) condictivities (P=0,05). No consistent pattern was observed for recovery times, a phenomenon which generally occurred for this parameter.

An alternative method of analysis is to compare the effects of different applied potentials at a particular water conductivity. The patterns of effects achieved by this approach are recorded in Tables 11–13. This analysis shows that at a given water conductivity, increasing the electrical potential increases the physical effects on most parameters and that mean narcosis time is positively correlated with applied potential. An interesting exception is mean recovery times at 430 μS, which were not significantly different for any of the 3 voltages tested. A similar situation was found when an electrical potential

TABLE 7 The effects of a.c. electronarcosis at different frequencies on opercular recovery time, narcosis time and recovery time

		Length (cm)	Mass (g)	Opercular recovery time (s)	Narcosis time (s)	Recovery time (s)	Narcosis coefficient (s cm^{-1})
25 Hz	n =	8	8	8	8	8	8
	Minimum	22,9	206,2	34,5	106,4	11,6	3,9
	Maximum	28,1	355,7	55,3	269,6	93,4	11,0
	Range	5,2	149,5	20,8	163,2	81,8	7,1
	Mean	25,7	283,4	44,9	154,6	52,0	6,1
	Standard dev.	1,9	53,2	7,0	50,1	27,3	2,2
	Standard err.	0,7	18,8	2,5	17,7	9,6	0,8
50 Hz	n =	8	8	8	8	8	8
	Minimum	22,5	185,9	24,3	60,2	38,7	2,4
	Maximum	28,2	325,7	99,7	243,9	190,4	10,8
	Range	5,7	139,8	75,4	183,7	151,7	8,4
	Mean	25,2	267,4	51,1	156,8	95,4	6,3
	Standard dev.	1,6	40,3	25,0	70,8	50,1	3,1
	Standard err.	0,6	14,3	8,8	25,0	17,7	1,1
100 Hz	n =	8	8	8	8	8	8
	Minimum	23,2	200,1	31,0	121,2	3,7	4,6
	Maximum	27,3	329,2	61,8	303,7	97,3	12,8
	Range	4,1	129,1	30,8	182,5	93,6	8,2
	Mean	25,2	275,1	49,1	178,7	28,8	7,1
	Standard dev.	1,6	51,1	10,9	73,7	31,3	3,1
	Standard err.	0,6	18,1	3,9	26,1	11,1	1,1
	't' Values (df)						
	25/50 (14)	NS	NS	NS	NS	2,155 (P=0,05)	NS
	25/100 (14)	NS	NS	NS	NS	NS	NS
	50/100 (14)	NS	NS	NS	NS	3,189 (P=0,01)	NS

df = degree of freedom; P = two-tailed probability; NS = not significant

TABLE 8 A comparison of the effects of 30 Vrms a.c. electronarcosis at 3 different water conductivities on opercular recovery time, narcosis time and recovery time

		Length (cm)	Mass (g)	Opercular recovery time (s)	Narcosis time (s)	Recovery time (s)	Narcosis coefficient (s cm^{-1})
100 μS cm^{-1}	n =	8	8	8	8	8	8
	Minimum	20,3	136,9	2,6	4,6	8,2	0,2
	Maximum	24,1	259,7	24,2	34,1	62,9	1,7
	Range	3,8	122,8	21,6	29,5	54,7	1,5
	Mean	22,7	196,1	8,4	15,5	36,6	0,7
	Standard dev.	1,3	44,9	7,0	10,9	20,6	0,5
	Standard err.	0,5	15,9	2,5	3,8	7,3	0,2
250 μS cm^{-1}	n =	8	8	8	8	8	8
	Minimum	22,0	189,1	0,0	0,0	8,1	0,0
	Maximum	25,0	285,0	14,1	36,4	54,0	1,6
	Range	3,0	95,9	14,1	36,4	45,9	1,6
	Mean	23,4	222,7	9,0	20,8	29,1	0,9
	Standard dev.	1,1	35,4	4,5	12,5	16,8	0,5
	Standard err.	0,4	12,5	1,6	4,4	5,9	0,2
430 μS cm^{-1}	n =	8	8	8	8	8	8
	Minimum	22,6	185,6	2,3	2,3	18,8	0,1
	Maximum	28,0	319,9	38,8	47,6	155,5	1,8
	Range	5,4	134,3	36,5	45,3	136,7	1,7
	Mean	25,0	260,9	21,5	30,2	74,9	1,2
	Standard dev.	1,7	41,3	13,1	14,9	42,2	0,6
	Standard err.	0,6	15,6	5,0	5,6	16,0	0,2
	't' Values (df)						
	100/250 (14)	NS	NS	NS	NS	NS	NS
	100/430 (14)	3,039 (P=0,01)	3,004 (P=0,01)	2,494 (P=0,05)	2,252 (P=0,05)	2,306 (P=0,05)	1,810 (P=0,1)
	250/430 (14)	2,234 (P=0,05)	1,986 (P=0,1)	2,552 (P=0,05)	NS	2,852 (P=0,02)	NS

df = degree of freedom; P = two-tailed probability; NS = not significant

of 60 Vrms was applied at 3 different water conductivities (Table 10).

As already mentioned, this particular investigation afforded the opportunity to evaluate the effects on *O. mossambicus* of different alternating currents as well as the effects of different currents on mean narcosis times. It is clear that although the effect is subject to some variation there is a clear positive correlation between current and narcosis time (r=0,7836).

The effects, at 3 voltages, on mean nacrosis time of increasing currents are illustrated in Fig. 7. It is clear from the graph that the effect is greatest at the maximum voltage tested (60 V). A similar pattern is evident for mean narcosis coefficients (Fig. 2). These patterns show that 60 Vrms is clearly superior to the lower voltages.

Effects of water temperature

As is shown in Table 14, increasing water temperature clearly reduces both opercular recovery time and narcosis time, and, at 25 °C, mean narcosis time is very significantly shorter (P=0,001) than at 15 °C. Although the mean narcosis time is clearly shorter at 25 °C than at 20

TABLE 9 A comparison of the effects of 45 Vrms a.c. electronarcosis at 3 different water conductivities on opercular recovery time, narcosis time and recovery time

		Length (cm)	Mass (g)	Opercular recovery time (s)	Narcosis time (s)	Recovery time (s)	Narcosis coefficient (s cm^{-1})
100 $\mu S\ cm^{-1}$	n =	8	8	8	8	8	8
	Minimum	21,2	162,5	12,7	27,0	20,8	1,1
	Maximum	27,4	315,2	37,6	45,1	88,2	1,8
	Range	6,2	152,7	24,9	18,1	67,4	0,7
	Mean	24,5	235,6	23,9	36,8	42,9	1,5
	Standard dev.	2,0	54,3	8,8	6,2	21,5	0,3
	Standard err.	0,7	19,2	3,1	2,2	7,6	0,1
250 $\mu S\ cm^{-1}$	n =	8	8	8	8	8	8
	Minimum	21,1	160,0	16,2	34,8	41,4	1,6
	Maximum	26,9	313,0	34,6	70,2	74,3	2,9
	Range	5,8	153,0	18,4	35,4	32,9	1,3
	Mean	23,7	235,4	27,0	51,2	58,5	2,1
	Standard dev.	1,8	49,4	6,3	13,2	10,3	0,5
	Standard err.	0,6	17,5	2,2	4,6	3,6	0,2
430 $\mu S\ cm^{-1}$	n =	8	8	8	8	8	8
	Minimum	22,5	186,0	21,6	53,5	32,9	2,1
	Maximum	27,9	322,6	43,1	87,8	123,3	3,5
	Range	5,4	136,6	21,5	34,3	90,4	1,4
	Mean	25,0	264,3	34,5	62,4	63,5	2,5
	Standard dev.	1,6	39,5	6,8	10,8	32,7	0,4
	Standard err.	0,5	14,0	2,4	3,8	11,6	0,2
	't' Values (df)						
	100/250 (14)	NS	NS	NS	2,792 (P=0,02)	1,850 (P=0,1)	2,910 (P=0,01)
	100/430 (14)	NS	NS	2,695 (P=0,02)	5,814 (P=0,001)	NS	5,656 (P=0,001)
	250/430 (14)	NS	NS	2,288 (P=0,05)	1,857 (P=0,1)	NS	1,766 (P=0,1)

df = degree of freedom; P = two-tailed probability; NS = not significant

TABLE 10 A comparison of the effects of 60 Vrms a.c. electronarcosis at 3 different water conductivities on opercular recovery time, narcosis time and recovery time

		Length (cm)	Mass (g)	Opercular recovery time (s)	Narcosis time (s)	Recovery time (s)	Narcosis coefficient (s cm^{-1})
100 $\mu S\ cm^{-1}$	n =	8	8	8	8	8	8
	Minimum	20,8	150,6	20,2	52,8	25,7	2,0
	Maximum	28,2	403,9	44,8	96,1	133,2	4,0
	Range	7,4	253,3	24,6	43,3	107,5	2,0
	Mean	24,4	255,8	33,4	74,3	65,2	3,0
	Standard dev.	3,1	92,1	8,7	17,2	34,9	0,6
	Standard err.	1,1	32,6	3,1	6,1	12,3	0,2
250 $\mu S\ cm^{-1}$	n =	8	8	8	8	8	8
	Minimum	20,7	167,5	31,5	80,3	33,1	3,2
	Maximum	27,6	324,0	47,0	158,5	110,9	7,3
	Range	6,9	156,5	15,5	78,2	77,8	4,1
	Mean	23,3	221,4	37,5	106,7	62,4	4,6
	Standard dev.	2,4	57,9	5,8	24,8	30,9	1,3
	Standard err.	0,8	20,4	2,0	8,7	10,9	0,4
430 $\mu S\ cm^{-1}$	n =	8	8	8	8	8	8
	Minimum	22,5	185,9	24,3	60,2	38,7	2,4
	Maximum	28,2	325,7	99,7	243,9	190,4	10,8
	Range	5,7	139,8	75,4	183,7	151,7	8,4
	Mean	25,2	267,4	51,1	156,8	95,4	6,3
	Standard dev.	1,6	40,3	25,0	70,8	50,1	3,1
	Standard err.	0,6	14,3	8,8	25,0	17,7	1,1
	't' Values (df)						
	100/250 (14)	NS	NS	NS	3,036 P=0,01)	NS	3,160 (P=0,01)
	100/430 (14)	NS	NS	1,891 (P=0,1)	3,202 (P=0,01)	NS	2,956 (P=0,01)
	250/430 (14)	1,863 (P=0,1)	1,844 (P=0,1)	NS	1,888 (P=0,1)	NS	NS

df = degree of freedom; P = two-tailed probability; NS = not significant

°C, there is no significant difference between times at 15 °C and at 20 °C. These relationships are repeated for mean narcosis coefficients, and mean recovery times appear to continue this trend (Table 14).

Effect of duration of current flow

The physical effect of the duration of current flow on *O. mossambicus* at an alternating current potential of 60 volts and a frequency of 50 Hz is recorded in Table 15.

Opercular recovery times showed a general trend of increase with increasing duration of current flow with the exception of a 75 s application time. Although increasing the duration from 15 s to 30 s did not result in a significantly increased mean opercular recovery time, further increases in duration of current flow resulted in mean opercular recovery times significantly longer ($P<0,1$) than that at 15 s. It is clear from Table 15, however, that the increases are not consistent.

In contrast to the opercular recovery pattern, mean narcosis times increased significantly and consistently as the duration of current flow was increased from 15 s through 30 s to 45 s (Table 15 & Fig. 3). Extending the

TABLE 11 A comparison of the effects of a.c. electronarcosis at 3 different potentials on opercular recovery time, narcosis time and recovery time in water with a conditivity of 100 μS

		Length (cm)	Mass (g)	Opercular recovery time (s)	Narcosis time (s)	Recovery time (s)	Narcosis coefficient (s cm^{-1})
30 volts	n =	8	8	8	8	8	8
	Minimum	20,3	136,9	2,6	4,6	8,2	0,2
	Maximum	24,1	259,7	24,2	34,1	62,9	1,7
	Range	3,8	122,8	21,6	29,5	54,7	1,5
	Mean	22,7	196,1	8,4	15,5	36,6	0,7
	Standard dev.	1,3	44,9	7,0	10,9	20,6	0,5
	Standard err.	0,5	15,9	2,5	3,8	7,3	0,2
45 volts	n =	8	8	8	8	8	8
	Minimum	21,2	162,5	12,7	27,0	20,8	1,1
	Maximum	27,4	315,2	37,6	45,1	88,2	1,8
	Range	6,2	152,7	24,9	18,1	67,4	0,7
	Mean	24,5	235,6	23,9	36,8	42,9	1,5
	Standard dev.	2,0	54,3	8,8	6,2	21,5	0,3
	Standard err.	0,7	19,2	3,1	2,2	7,6	0,1
60 volts	n =	8	8	8	8	8	8
	Minimum	20,8	150,6	20,2	52,8	25,7	2,0
	Maximum	28,2	403,9	44,8	96,1	133,2	4,0
	Range	7,4	253,3	24,6	43,3	107,5	2,0
	Mean	24,4	255,8	33,4	74,3	65,2	3,0
	Standard dev.	3,1	92,1	8,7	17,2	34,9	0,6
	Standard err.	1,1	32,6	3,1	6,1	12,3	0,2
	't' Values (df)						
	30/45 (14)	2,134 (P=0,05)	NS	3,899 (P=0,01)	4,804 (P=0,001)	NS	3,880 (P=0,01)
	30/60 (14)	NS	NS	6,332 (P=0,001)	8,167 (P=0,001)	1,996 (P=0,1)	8,329 (P=0,001)
	45/60 (14)	NS	NS	2,171 (P=0,05)	5,801 (P=0,001)	NS	6,324 (P=0,001)

df = degree of freedom; P = two-tailed probability; NS = not significant

TABLE 12 A comparison of the effects of a.c. electronarcosis at 3 different potentials on opercular recovery time, narcosis time and recovery time in water with a conductivity of 250 μS

		Length (cm)	Mass (g)	Opercular recovery time (s)	Narcosis time (s)	Recovery time (s)	Narcosis coefficient (s cm^{-1})
30 volts	n =	8	8	8	8	8	8
	Minimum	22,0	189,1	0,0	0,0	8,1	0,0
	Maximum	25,0	285,0	14,1	36,4	54,0	1,6
	Range	3,0	95,9	14,1	36,4	45,9	1,6
	Mean	23,4	222,7	9,0	20,8	29,1	0,9
	Standard dev.	1,1	35,4	4,5	12,5	16,8	0,5
	Standard err.	0,4	12,5	1,6	4,4	5,9	0,2
45 volts	n =	8	8	8	8	8	8
	Minimum	21,1	160,0	16,2	34,8	41,4	1,6
	Maximum	26,9	313,0	34,6	70,2	74,3	2,9
	Range	5,8	153,0	18,4	35,4	32,9	1,3
	Mean	23,7	235,4	27,0	51,2	58,5	2,1
	Standard dev.	1,8	49,4	6,3	13,2	10,3	0,5
	Standard err.	0,6	17,5	2,2	4,6	3,6	0,2
60 volts	n =	8	8	8	8	8	8
	Minimum	20,7	167,5	31,5	80,3	33,1	3,2
	Maximum	27,6	324,0	47,0	158,5	110,9	7,3
	Range	6,9	156,5	15,5	78,2	77,8	4,1
	Mean	23,3	221,4	37,5	106,7	62,4	4,6
	Standard dev.	2,4	57,9	5,8	24,8	30,9	1,3
	Standard err.	0,8	20,4	2,0	8,7	10,9	0,4
	't' Values (df)						
	30/45 (14)	NS	NS	6,576 (P=0,001)	4,721 (P=0,001)	4,220 (P=0,001)	4,800 (P=0,001)
	30/60 (14)	NS	NS	10,981 (P=0,001)	8,748 (P=0,001)	2,678 (P=0,02)	7,513 (P=0,001)
	45/60 (14)	NS	NS	3,468 (P=0,01)	5,587 (P=0,001)	NS	5,077 (P=0,001)

df = degree of freedom; P = two-tailed probability; NS = not significant

duration of flow from 45 s to 60 s, however, resulted in a significant reduction (P=0,01) in mean narcosis time from 244,6 s to 158,6 s. Further increases in current duration, however, resulted in increased mean narcosis times and, at a duration of 90 s, the mean narcosis times was significantly longer (P=0,01) than at 60 s but was not significantly different from that produced by a current flowing for 45 s. This suggests that electronarcotizing currents need not be prolonged beyond 45 s for optimum results.

As was to the expected, mean narcosis coefficients showed a similar trend to that observed for narcosis times, with mean coefficients for current flows of 45 s and 90 s not differing significantly from each other.

As in most other cases, recovery times did not show a consistent pattern, even though very significant differences (P=0,001) did occur (Table 15).

Discussion

Because of the rapid induction of electronarcosis it is

TABLE 13 A comparison of the effects of a.c. electronarcosis at 3 different potentials on opercular recovery time, narcosis time and recovery time in water with a conductivity of 430 μS

		Length (cm)	Mass (g)	Opercular recovery time (s)	Narcosis time (s)	Recovery time (s)	Narcosis coefficient (s cm^{-1})
30 volts	n =	8	8	8	8	8	8
	Minimum	22,6	185,6	2,3	2,3	18,8	0,1
	Maximum	28,0	319,9	38,8	47,6	155,5	1,8
	Range	5,4	134,3	36,5	45,3	136,7	1,7
	Mean	25,0	260,9	21,5	30,2	74,9	1,2
	Standard dev.	1,7	41,3	13,1	14,9	42,2	0,6
	Standard err.	0,6	15,6	5,0	5,6	16,0	0,2
45 volts	n =	8	8	8	8	8	8
	Minimum	22,5	186,0	21,6	53,4	32,9	2,1
	Maximum	27,9	322,7	43,1	87,8	123,3	3,5
	Range	5,4	136,7	21,5	34,4	90,4	1,4
	Mean	25,0	264,3	34,6	62,4	63,5	2,5
	Standard dev.	1,6	38,5	6,8	10,8	3,27	0,4
	Standard err.	0,5	14,0	2,4	3,8	11,6	0,2
60 volts	n =	8	8	8	8	8	8
	Minimum	22,5	185,9	24,3	60,2	38,7	2,4
	Maximum	28,2	325,7	99,7	243,9	190,4	10,8
	Range	5,7	139,8	75,4	183,7	151,7	8,4
	Mean	25,2	267,4	51,1	156,8	95,4	6,3
	Standard dev.	1,6	40,4	25,1	70,8	50,1	3,1
	Standard err.	0,6	14,3	8,9	25,0	17,7	1,1
	't' Values (df)						
	30/45 (14)	NS	NS	2,491 (P=0,05)	4,949 (P=0,001)	NS	5,099 (P=0,001)
	30/60 (14)	NS	NS	2,966 (P=0,01)	4,949 (P=0,001)	NS	4,568 (P=0,001)
	45/60 (14)	NS	NS	1,812 (P=0,1)	3,728 (P=0,01)	NS	3,439 (P=0,01)

df = degree of freedom; P = two-tailed probability; NS = not significant

TABLE 14 The effects of different water temperatures on opercular recovery time, narcosis time and recovery time in *O. mossambicus* subjected to a.c. electronarcosis at 60 Vrms

		Length (cm)	Mass (g)	Opercular recovery time (s)	Narcosis time (s)	Recovery time (s)	Narcosis coefficient (s cm^{-1})
15 °C	n =	8	8	8	8	8	8
	Minimum	20,9	148,6	35,7	133,5	35,8	4,7
	Maximum	28,3	397,1	62,6	223,3	252,1	10,7
	Range	7,4	248,5	26,9	89,8	216,3	6,0
	Mean	24,4	256,8	55,4	185,9	104,1	7,8
	Standard dev.	3,1	96,7	10,1	36,9	77,5	2,0
	Standard err.	1,3	39,5	4,1	15,1	31,6	0,8
20 °C	n =	8	8	8	8	8	8
	Minimum	22,5	185,9	24,3	60,2	38,7	2,4
	Maximum	28,2	325,7	99,7	243,9	190,4	10,8
	Range	5,7	139,8	75,4	183,7	151,7	8,4
	Mean	25,2	267,4	51,1	156,8	95,4	6,3
	Standard dev.	1,6	40,3	25,0	70,8	50,1	3,1
	Standard err.	0,6	14,3	8,8	25,0	17,7	1,1
25 °C	n =	8	8	8	8	8	8
	Minimum	21,8	169,4	26,6	66,4	22,5	2,4
	Maximum	27,3	335,2	64,9	116,2	116,8	4,8
	Range	5,5	165,8	38,3	49,8	94,3	2,4
	Mean	24,7	260,3	40,5	92,0	52,4	3,7
	Standard dev.	2,0	59,6	11,5	16,8	31,5	0,8
	Standard err.	0,7	21,1	4,0	5,9	11,1	0,3
	't' Values (df)						
	15/20 (14)	NS	NS	NS	NS	NS	NS
	15/25 (14)	NS	NS	2,753 (P=0,2)	4,667 (P=0,001)	1,748 (P=0,1)	5,186 (P=0,001)
	20/25 (14)	NS	NS	NS	2,519 (P=0,05)	2,055 (P=0,1)	2,258 (P=0,05)

df = degree of freedom; P = two-tailed probability; NS = not significant

not feasible to document visible planes or stages of anaesthesia as described by McFarland (1959) for chemical anaesthesia. Recovery from an electrical induced unconsciousness in this study could be divided into a series of stages marked by particular events. In the species studied the following categories or phases could be discerned:

Phase 1: Resumption of opercular beat.

Phase 2: Response to stimulus.

Phase 3: Initial recovery phase.

Phase 4: Recovery.

Phase 1, although regarded as part of the recovery phase, is clearly initiated while the fish is still unconscious. The actual start of the process of returning to awareness of the environment appears to be *Phase 2*, when the fish will respond with a measure of muscle movement. This response is generally followed by a varying period of upside down and sideways swimming

TABLE 15 The effects of duration of current flow on opercular recovery time, narcosis time and recovery time in *O. mossambicus* subjected to a.c. electronarcosis at 60 Vrms

		Length (cm)	Mass (g)	Opercular recovery time (s)	Narcosis time (s)	Recovery time (s)	Narcosis coefficient (s cm^{-1})
15 s	n =	8	8	8	8	8	8
	Minimum	20,4	142,3	31,3	66,5	11,3	2,7
	Maximum	24,2	276,4	51,4	124,8	73,6	5,8
	Range	3,8	134,1	20,1	58,3	62,3	3,1
	Mean	22,4	210,7	39,7	100,3	35,0	4,5
	Standard dev.	1,4	43,4	6,8	22,0	19,5	1,0
	Standard err.	0,5	15,3	2,4	7,8	6,9	0,4
30 s	n =	8	8	8	8	8	8
	Minimum	22,5	185,9	24,3	60,2	38,7	2,4
	Maximum	28,2	325,7	99,7	243,9	190,4	10,8
	Range	5,7	139,8	75,4	183,7	151,7	8,4
	Mean	25,2	267,4	51,1	156,8	95,4	6,3
	Standard dev.	1,6	40,3	25,0	70,8	50,1	3,1
	Standard err.	0,6	14,3	8,8	25,0	17,7	1,1
45 s	n =	8	8	8	8	8	8
	Minimum	19,7	120,2	41,0	172,9	3,4	6,8
	Maximum	27,7	394,7	71,9	334,0	65,0	14,5
	Range	8,0	274,5	30,9	161,1	61,6	7,7
	Mean	23,3	228,5	52,3	244,6	26,0	10,6
	Standard dev.	2,4	82,9	10,7	57,6	24,9	2,9
	Standard err.	0,8	29,3	3,8	20,3	8,8	1,0
60 s	n =	8	8	8	8	8	8
	Minimum	23,0	196,7	44,5	128,7	7,9	4,5
	Maximum	28,3	360,9	96,9	217,0	249,8	6,5
	Range	5,3	164,2	52,4	88,3	241,9	2,0
	Mean	25,7	286,8	70,1	158,6	128,8	5,9
	Standard dev.	2,0	63,6	14,8	28,4	74,1	0,7
	Standard err.	0,7	22,5	5,2	10,0	26,2	0,2
75 s	n =	8	8	8	8	8	8
	Minimum	22,1	152,8	39,3	115,8	7,2	6,0
	Maximum	28,2	403,5	68,7	241,9	123,7	9,6
	Range	6,1	250,7	29,4	126,1	116,5	3,6
	Mean	25,0	264,4	57,6	178,8	37,1	7,6
	Standard dev.	2,0	78,7	11,2	38,8	39,8	1,1
	Standard err.	0,7	27,8	4,0	13,7	14,1	0,4
90 s	n =	8	8	8	8	8	8
	Minimum	20,9	169,0	59,4	176,4	71,1	7,8
	Maximum	25,5	260,7	99,3	261,2	146,5	11,0
	Range	4,6	91,7	39,9	84,8	75,4	3,2
	Mean	22,9	203,8	81,2	215,2	100,4	9,4
	Standard dev.	1,5	33,4	12,6	30,4	25,0	1,2
	Standard err.	0,5	11,8	4,5	10,7	8,8	0,4
	't' Values (df)						
	15/30 (df = 14)	3,725 (P=0,01)	2,708 (P=0,02)	NS	2,155 (P=0,05)	3,178 (P=0,01)	NS
	15/45 (df = 14)	NS	NS	2,811 (P=0,02)	6,620 (P=0,001)	NS	5,624 (P=0,001)
	15/60 (df = 14)	3,823 (P=0,01)	2,795 (P=0,02)	5,279 (P=0,001)	4,590 (P=0,001)	3,462 (P=0,01)	3,244 (P=0,01)
	15/75 (df = 14)	3,012 (P=0,01)	NS	3,864 (P=0,01)	4,978 (P=0,001)	NS	5,898 (P=0,001)
	15/90 (df = 14)	NS	NS	8,198 (P=0,001)	8,660 (P=0,001)	5,834 (P=0,001)	8,872 (P=0,001)
	30/45 (df = 14)	1,863 (P=0,1)	NS	NS	2,721 (P=0,02)	3,508 (P=0,01)	2,865 (P=0,02)
	30/60 (df = 14)	NS	NS	1,850 (P=0,1)	NS	NS	NS
	30/75 (df = 14)	NS	NS	NS	NS	2,577 (P=0,05)	NS
	30/90 (df = 14)	2,966 (P=0,01)	3,437 (P=0,01)	3,041 (P=0,01)	2,144 (P=0,05)	NS	2,638 (P=0,02)
	45/60 (df = 14)	2,173 (P=0,05)	NS	2,757 (P=0,02)	3,788 (P=0,01)	3,719 (P=0,01)	4,456 (P=0,001)
	45/75 (df = 14)	NS	NS	NS	2,680 (P=0,02)	NS	2,736 (P=0,02)
	45/90 (df = 14)	NS	NS	4,945 (P=0,001)	NS	5,964 (P=0,001)	NS
	60/75 (df = 14)	NS	NS	1,905 (P=0,1)	NS	3,083 (P=0,01)	3,688 (P=0,01)
	60/90 (df = 14)	3,168 (P=0,01)	3,268 (P=0,01)	NS	3,848 (P=0,01)	NS	7,126 (P=0,001)
	75/90 (df = 14)	2,376 (P=0,05)	2,005 (P=0,1)	3,959 (P=0,01)	2,089 (P=0,1)	3,809 (P=0,01)	3,127 (P=0,01)

df = degree of freedom; P = two-tailed probability; NS = not significant

during which it is clear to an observer that the animal is disoriented *(Phase 3)*.

As has already been pointed out, the recovery time can be difficult to determine accurately, as fish were sometimes observed to swim a distance in the correct position only to revert to the earlier disorientation. It must also be pointed out that, as gill activity is also initially erratic before settling into a steady beat, the opercular activity time is not a particularly suitable measure of narcosis.

For these reasons it is proposed that narcosis time, i.e., the initial response to a stimulus, can be used to evaluate narcotic potency of an electrical current. This, however, does not preclude the use of the other parameters to support the narcosis time values. It must be remembered, however, that fish length plays an important role in determining the duration of narcosis time (Barham *et al.*, 1987a).

It is also necessary to take into account the mucus layer which exists to a greater or lesser degree on the surface of all fish. This is probably a good conductor, as it is essentially protein and is in direct contact with the epidermal layer. It is clear, therefore, that, although one

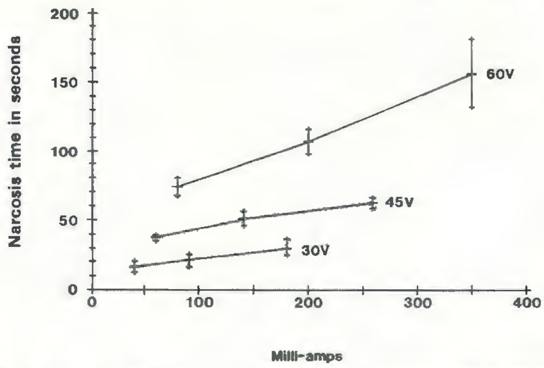

FIG. 1 The effect of increasing currents, at 3 voltages, on mean narcosis time (± SE) in *O. mossambicus*

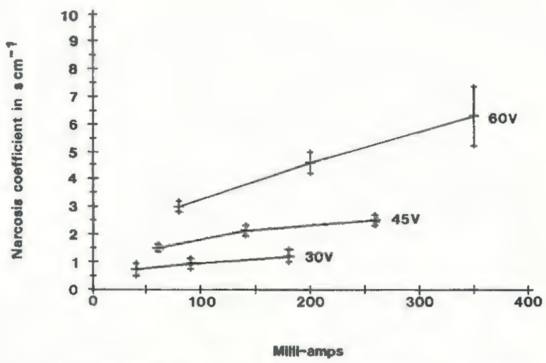

FIG. 2 The effect of increasing currents, at 3 voltages, on mean narcosis coefficients (± SE) in *O. mossambicus*

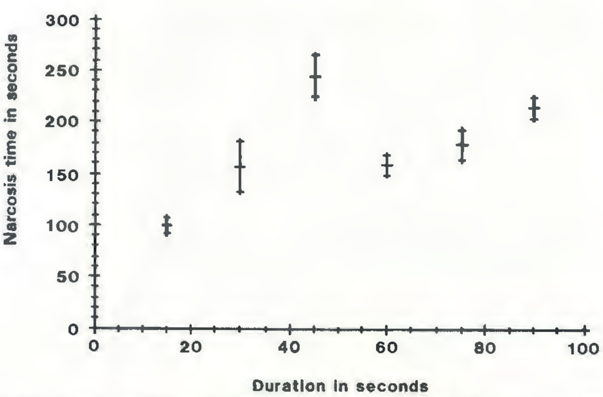

FIG. 3 The effect of duration of current flow on mean narcosis times (± SE) in *O. mossambicus* subjected to a.c. electronarcosis at 60 Vrms

can use the narcosis coefficient to evaluate narcotic potency, it is necessary that one be aware that this value is modified by both biological and physical factors.

From the results obtained in this study it is clear that square wave electronarcosis is slightly superior to sine wave electronarcosis. A 50 Hz sine wave, however, can be obtained without elaborate equipment and, being only marginally inferior to a square wave, is recommended for routine use.

The role of water conductivity in electrical effects of fish in freshwater has been described by Barham, Schoonbee & Visser, (1987b). In essence, as the conductivity of the tank water increases so does the electrical potential between the head and the tail of the fish. Thus, for a given applied potential across the electrodes of a tank the head-tail potential of the fish will increase with increasing water conductivity. This phenomenon explains the increased nacrosis times observed with increasing conductivity.

Fish are poikilothermic animals, and therefore, at lower temperatures there is a reduction in metabolic rate. Consequently, this would suggest an inverse relationship between environmental temperature and narcosis times. This, however, does not seem to apply at temperatures below 20 °C, a phenomenon which requires further investigation.

Two patterns emerged in the study of the effects of duration of current flow on narcosis times, namely between 15 and 45 s and between 60 and 90 s (Fig. 3). The decline in narcosis times at 60 s and the subsequent increase are peculiar features, a phenomenon which cannot be explained.

It is tempting to theorize regarding the role of the cell membranes, particularly the membranes of nerve cells, in the induction and duration of electronarcosis. A major role would indeed appear appropriate for such membranes, since the presence of an external electrical field has many obvious disruptive components in terms of membrane polarity.

It is thought that the mode of action of chemical anaesthetics is via disruption of the signal transmitting function of nerve membranes (Bangham, Hill & Mason, 1980; Robertson, 1983). The mode of action suggested involves a loosening up of the component molecules of the membrane, which is then incapable of operating.

We suggest that electronarcosis acts in a similar way, either by changing the packing arrangements or by disturbing the membrane potentials. The nature and degree of disruption may be dependent on whether the current is alternating or direct. Wave shape may also be important. In this respect, it is interesting to note that the electric eel, *Electrophorus electricus*, produces an electrical wave impulse characterized by a fast rise time and a relatively gradual decay (Meyer-Waarden, 1957). A study of the narcotizing effects of similar waves may prove fruitful.

The present study has indicated that 60 V, 50 Hz alternating current electronarcosis appears to be a useful and viable alternative to chemical anaesthesia for the effective immobilization of freshwater fish. Physiological effects of electronarcosis on *O. mossambicus* will be reported on in a later paper.

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