Temperature Discrimination by Captive Free-Swimming Tuna, *Euthynnus affinis*[1]

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ABSTRACT

Captive kawakawa, *Euthynnus affinis*, were instrumentally conditioned to respond to an increase in temperature to determine discrimination abilities. Two fish yielded a discrimination threshold of 0.10 to 0.15 C. Thermal sensitivity of this high-seas pelagic fish is thus no more acute than that of inshore fishes and appears inadequate for direct sensing of weak horizontal temperature gradients at sea.

Tunas (family Scombridae) are distributed within definite ranges of sea temperature (Thompson 1917; Clemens 1961; Broadhead and Barrett 1964) so consistently that fishery biologists use temperature to predict catches (Hester 1961; Johnson 1962). No one has clearly determined, however, whether temperature differences directly influence scombrid behavior. Precise sensing of temperature differences could be important or even essential for direct thermal mediation of tuna distribution. In order to estimate temperature discrimination thresholds, we developed and applied a method for use with these pelagic, continuously swimming fishes.

METHODS

Captive kawakawa, *Euthynnus affinis* (Cantor), 36 to 66 cm in fork length were held in circular pools 7.3 m in diameter and 1.2 m deep at the Kewalo Research Facility of the National Marine Fisheries Service, Honolulu, Hawaii; Nakamura (1972) described techniques for maintaining and handling live scombrids. Individual fish were then trained and tested in a similar pool over several months. Previous studies with unrestrained scombrids have estimated visual acuity (Nakamura 1968), auditory thresholds (Iversen 1967, 1969), and olfactory abilities (Van Weel 1952; Tester et al. 1953; Tester et al. 1955).

An instrumental conditioning technique was employed. Fish were trained to swim through an open trough in the tank (a "pass") during 5-min trial periods. Water flowed into the trough from above at about 6.5 liters/min (initiation of the water flow signaled the start of a trial). The temperature of this water flow (thermal stimulus) was ambient or heated. As the fish swam through the trough, it came in contact with this water flow. We used an ambient temperature stimulus (24 C) for half the trials and heated stimulus (40 C) for the other half. The 5-min trials, heated and ambient, were alternated in a quasi-random order (Gellermann 1933) and were separated by 5-min intertrial periods. If the stimulus was ambient, the fish would continue to make passes through the trough to receive

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TABLE 1.—*Last 12 days of data for fish K8 tested for temperature discrimination threshold (see Fig. 1 for graph of data). The number of passes made during each part of the trial-pair is given in chronological order. Each trial-pair consists of two subtrials (one heated and the other ambient). The number of passes made during ambient (reinforced) trials is given in boldface type. Lightface numbers represent incorrect passes made during heated trials. (It would be impossible to reduce this number to zero since the fish was required to make at least one pass each trial to contact the stimulus water flowing into the trough.) The last columns represent parameters used in the statistical test (n = number of pairs minus any pairs whose difference is zero. T = the smaller of the sums of the like signed ranks), and the temperature change encountered during heated trials for that particular day (C).*

Day	Trial-pair												n	T	C
	1	2	3	4	5	6	7	8	9	10	11	12			
1	**32**/20	**19**/19	**23**/15	**16**/39	**23**/17	**27**/20	**32**/12	**37**/13	**23**/34	**28**/17	**16**/33		10	0	1.00
2	**27**/18	**26**/20	**25**/15	**25**/33	**26**/21	**13**/36	**41**/10	**29**/25	**24**/10	**26**/10			10	0	0.50
3	**35**/18	**23**/13	**22**/6	**15**/7	**18**/13	**15**/15	**7**/11	**14**/5	**26**/15				8	1	0.30
4	**36**/12	**36**/7	**15**/29	**10**/12	**8**/33	**29**/4	**37**/9	**24**/12	**29**/15	**15**/18			10	1	0.20
5	**38**/27	**28**/12	**33**/19	**19**/28	**22**/38	**29**/30	**24**/16	**25**/11	**13**/12	**19**/4	**14**/32	**22**/18	12	6	0.20
6	**23**/10	**20**/7	**7**/11	**31**/5	**12**/24	**19**/11	**25**/13	**10**/31					8	1	0.15
7	**27**/24	**18**/19	**14**/8	**22**/22	**10**/20	**15**/15	**14**/23	**13**/7					6	1	0.10
8	**29**/15	**16**/11	**8**/14	**20**/13	**28**/23	**29**/22	**14**/15	**19**/13	**16**/7				9	1	0.15
9	**25**/30	**16**/17	**8**/14	**19**/7	**12**/8	**13**/12	**15**/17	**11**/14	**12**/13	**12**/17			10	30	0.10
10	**14**/8	**12**/5	**9**/7	**15**/13	**8**/10	**9**/3	**4**/5	**18**/15					8	0	0.15
11	**21**/16	**18**/13	**15**/17	**20**/10	**17**/14	**17**/12	**16**/19	**13**/16					8	7	0.10
12	**14**/11	**8**/8	**7**/6	**17**/8	**7**/9	**8**/8	**5**/9	**11**/6	**14**/12				7	0	0.15

food reinforcement; the food was pieces of thawed smelt (family Osmeridae). If the stimulus was heated, the fish would not receive any food reinforcement for passes. Most fish learned in 1 day to make more passes under ambient temperature conditions. The number of passes made during trials and intertrials was recorded for analysis; fish never made passes during intertrial periods. Each day, successive trials were paired for examination with a Wilcoxon matched-pairs, signed-ranks test (Siegel 1956)[3] (Table 1).

Work on threshold determination progressed over several months for each fish. A 90-sec variable interval schedule (Ferster and Skinner 1957) of reinforcement was introduced gradually to minimize reinforcement cueing. The temperature of the water stimulus during heated trials was also gradually decreased toward ambient. The temperature at the water flow directly encountered by the fish is of greatest importance and was measured with a 0.01 C graduated mercury thermometer. It is these measured and encountered temperature differences, rather than direct heat input to the system, that are used in the present analysis. If fish discriminated a given temperature difference, a smaller difference was presented at the next day's testing session. If fish did not distinguish between ambient and heated water, the temperature difference (heated minus ambient) was considered below threshold. Temperature threshold was defined as the midpoint between the smallest temperature difference fish discriminated and the greatest difference they did not discriminate.[4]

Initial experiments were conducted and recorded manually. The last fish was tested automatically: logic circuitry,[5] an underwater photosensor assembly in the trough, and a four-channel event recorder controlled the stimulus presentation, recorded and reinforced the fish's performance.

RESULTS

Two fish yielded temperature discrimination thresholds; six others jumped out of the tank during training and died. Results of the last 12 days of testing on the two fish provided threshold estimates of 0.10 C for the manually tested fish and 0.125 C for the automatically tested fish, the latter being our more reliable estimate (Fig. 1). To control for possible discrimination of extraneous stimuli [e.g.,

[3] Our tests were run with $P = 0.01$ (for a one-tailed test).

[4] This is essentially the "staircase" technique used extensively in sensory threshold determination. The method is discussed in Dixon and Mood (1948) and Tavolga and Wodinsky (1963).

[5] Lehigh Valley Electronics Inc., Box 125, Fogelsville, Pennsylvania 18051. Reference to trade name does not imply endorsement by the National Marine Fisheries Service, NOAA, or the University of Wisconsin, Madison.

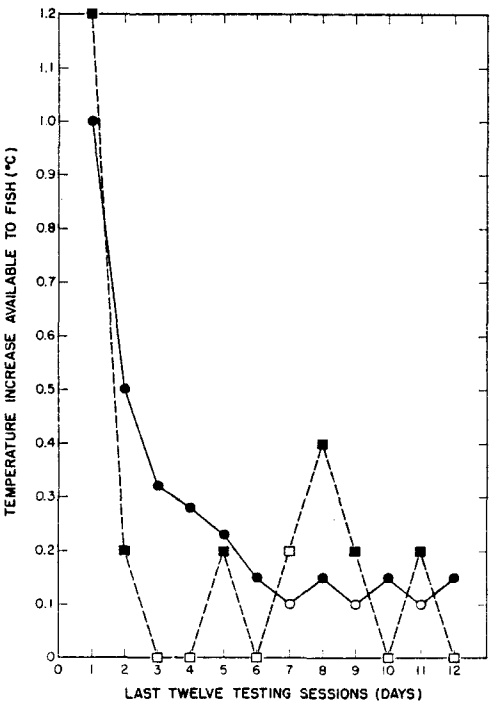

FIGURE 1.—*Discrimination ability of fish during last 12 days of testing for temperature thresholds. Squares represent fish K3 (1.45 kg, 45.6 cm fork length) tested manually. Threshold was determined as midway between 0.0 and 0.20 C (0.10 C). Circles represent fish K8 (2.39 kg, 50.0 cm fork length) tested automatically. Threshold was determined as midway between 0.10 and 0.15 C (0.125 C). For both fish, closed symbols represent days of significant thermal discrimination at* $P \leqslant 0.01$; *open symbols represent days of no apparent thermal discrimination at* $P \leqslant 0.01$ *(not even significant at* $P \leqslant 0.05$*).*

relay sounds, electric fields, reinforcement scheduling, etc. (Steffel 1973)], control systems were utilized periodically during the testing sessions. In one case, water was treated as in normal trials but heat added during heated trials was dissipated prior to delivery of the stimulus water to the tank. To do this, stimulus water was piped through a stainless steel coil over which cold water passed, reducing heated-stimulus-trial water to ambient temperature. Discrimination was not evident between ambient water and this water heated 1.0 C above ambient and cooled back to ambient. Therefore, fish in our experiments could only have been discriminating temperature differences and not nonthermal stimuli incidental to heated trials.

DISCUSSION

Many species of fish have been conditioned to respond to temperature differences of 0.03 to 0.25 C (Wells 1914; Bull 1936; Dijkgraaf 1940; Bardach and Bjorklund 1957). Most studies involved unrestrained fishes and positive reinforcement (food); however, all these previous experiments used small, benthic or inshore fishes and the techniques of classical conditioning. Our study is the first temperature-threshold determination utilizing larger, free-swimming pelagic fishes and instrumental conditioning methods. Previous work on restrained skipjack tuna, *Katsuwonus pelamis*,[6] using classical conditioning has indicated that scombrids could respond to temperature differences of 1 to 2 C (Dizon et al. 1974). While our current threshold values (0.10–0.15 C) fall within the range of published thresholds for other marine and freshwater fishes, they would apparently still preclude a scombrid from orienting to the gradual horizontal gradients of the ocean (0.0001–0.001 C/m). If temperature is indeed a primary factor controlling tuna distribution, a mechanism other than direct sensing of horizontal temperature differences is responsible, or our results are conservative estimates. Other work analyzing scombrid behavior in thermal gradients is in progress.

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[6] Sometimes still referred to as *Euthynnus pelamis* (Linnaeus). In any case, skipjack tuna are very closely related to the kawakawa and they are sometimes placed in the same genus.

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