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Swimming Speeds of Yellow Perch (*Perca flavescens*) Following an Abrupt Change in Environmental Temperature

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OTTO, R. G., AND J. O'HARA RICE. 1974. Swimming speeds of yellow perch (*Perca flavescens*) following an abrupt change in environmental temperature. J. Fish. Res. Board Can. 31: 1731–1734.

Groups of yellow perch (*Perca flavescens*) were acclimated to constant temperatures of 10 and 20 C. Acclimation temperatures were then abruptly reversed. Critical swimming speeds were determined prior to and following the temperature change at 24-h intervals. Adjustment (acclimation) of fish subjected to an increase in temperature was immediate. Fish subjected to a decrease in temperature required less than 24 h to regain maximum swimming capability.

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Des groupes de perchaudes (*Perca flavescens*) ont été acclimatés à des températures constantes de 10 et 20 C. Les températures d'acclimatation ont été ensuite brusquement interverties. Les vitesses maximales de nage soutenue ont été déterminées avant et après les changements de température à intervalles de 24 h. L'ajustement (acclimatation) des poissons soumis à une augmentation de température a été immédiate. Les poissons soumis à un abaissement de température prirent moins de 24 h à regagner leur aptitude à une vitesse de nage maximale.

Received June 10, 1974
Accepted July 31, 1974

Reçu le 10 juin 1974
Accepté le 31 juillet 1974

ADAPTATION to changing temperatures can be subdivided temporally into several aspects. Most rapid is that process termed accommodation, occurring in seconds or minutes as the threshold of an excitable tissue rises in conformance with an increased level of stimulus (Fisher 1958). Shifts in whole animal response to environmental temperature changes (acclimation) are somewhat slower, typically requiring days or weeks (Roberts 1967). Slowest of all are gradual changes in population or species characteristics in response to long-term shifts in environmental temperatures (Somero et al. 1968). Such changes comprise the evolutionary process and are frequently measured in geologic time units.

Previous investigators have considered the effects of changing temperatures on a wide variety of criteria (Brett 1971; Fry 1971; Hochachka and Somero 1971). The majority of such studies have been concerned with steady state or homoiostatic conditions existing after the time course of individual adaptation was completed. Consideration of transient changes in whole animal response occurring during the time interval separating steady state conditions has been restricted primarily to the determination of tolerance limits (Brett 1944; Allen and Strawn 1971) and various measures of metabolic rate or oxygen consumption (Auerbach 1957; Klicka 1965). The nature of such transient changes in response is of particular interest for fishes occupying habitats in which rapid, short-term temperature fluctuations occur routinely. This report describes the time course of individual adaptation to a rapid change in temperature for a eurythermal fish in terms of its ability to swim or perform work.

Materials and Methods

APPARATUS

Performance capabilities were determined using a stamina tunnel similar in design to that employed by Griffiths and Alderdice (1973). The apparatus was an open loop of some 1110-liter capacity. Water was pumped into a fiberglass pipe from a stainless steel header box by a propeller hooked to a 3/4 hp variable speed DC motor. The water was forced through screen into a 12.7 cm diameter clear plexiglass swimming

Printed in Canada (J3458)
Imprimé au Canada (J3458)

chamber approximately 50 cm in length. At the rear of the chamber, three graphite rings were connected to a low voltage AC source to provide a shock stimulus to the fish.

Behind the rings, where the tunnel emptied into the header box, either a screen or chute could be fitted over the end of the tunnel. The header box contained a chilling coil and three 4000-W heaters. When operated in unison, these heaters were capable of raising the water temperature 1 C each 2 1/2 min. Rapid chilling could be achieved by adding ice to the header box. One of the heaters could be operated independently with a thermostat to provide precise temperature control. Speeds up to 100 cm/s could be achieved. Water velocities in cm/s were read directly from an electronic tachometer attached to the propeller drive. Calibration was performed with a pitot-tube manometer.

Procedure

Groups of 10 yellow perch ranging in standard length from 9 to 10 cm were maintained in 150-liter fiberglass tanks at 10 and 20 C for 30 days. Test groups of five fish were then randomly selected from an acclimation category, placed in the tunnel at the acclimation temperature, and maintained for 30 min at a water velocity of 5 cm/s. Water velocity was then increased in increments of 5 cm/s at 15-min intervals. Individual fish were removed from the tunnel as they fatigued.

This test sequence was continued for both acclimation groups at 24-h intervals for 4 days to allow the fish to adjust to the procedure. On the fifth day, acclimation temperatures were reversed, 10 C fish being moved to 20 C and vice versa. The temperature change was imposed while the fish were in the stamina tunnel during the 30-min pre-test period. Fish were tested immediately following the reversal of acclimation temperatures and at 24-h intervals thereafter for 6 days.

Critical swimming speed for each fish was calculated according to the formula:

Critical Speed = Last Recorded Speed + Time at New Speed Increment × Increment of Speed

as described by Brett (1967). Median values for each test group were estimated graphically by plotting the logarithms of individual critical speeds against the cumulative percentage of fish fatigued in probit units. The systematic small sample error inherent in this procedure was corrected as described by Bliss (1937).

Results and Discussion

Perch acclimated to 10 and 20 C had median critical swimming speeds of 15.5 cm/s and 25.2 cm/s, respectively, on the first day of testing (Fig. 1). These speeds increased to 21.0 cm/s for 10 C-acclimated fish and 33.0 cm/s for 20 C fish on the second day. Performance levels for both acclimation groups then remained stable for the remainder of the 4-day training period. The improvement in swimming performance resulting from experience for 20 C fish was approximately twice that for 10 C fish.

Since a random process was employed to select the five test fish from the 10-fish acclimation group, test groups after day one might have contained both naive and experienced fish. However, variability of response as indicated by slopes of the probit distributions remained approximately the same throughout the 10-day test period, suggesting a group effect wherein the presence of experienced individuals improved performance of naive fish (Fig. 2).

An immediate increase in performance was observed following an increase in water temperature

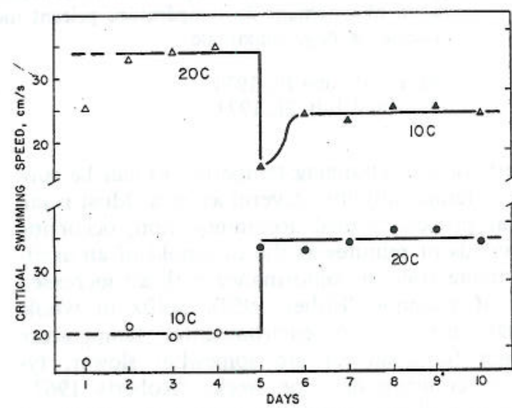

FIG. 1. The effects of an abrupt change in temperature on the maximum sustained swimming speed of the yellow perch (*Perca flavescens*). The time of temperature change is indicated by arrows.

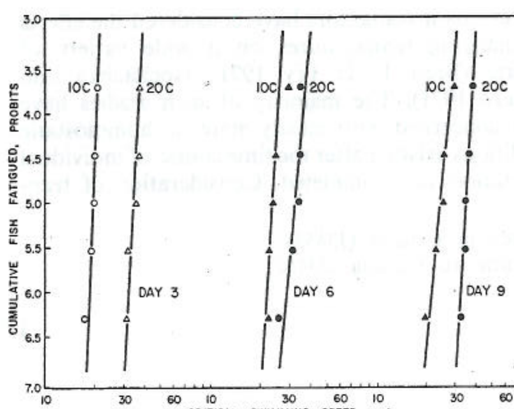

FIG. 2. Sample probit plot showing results for individual tests. Symbols are as in Fig. 1.

from 10 to 20 C. Mean critical swimming speed was raised to 33.5 cm/s, a gain of 12.5 cm/s. This value is comparable to the swimming speed of fish acclimated to 20 C for 30 days. Performance levels for this group remained stable for the remainder of the 10-day period. Upper and lower 95% confidence limits for the stabilized mean critical swimming speed were 36.9 cm/s and 32.0 cm/s, respectively.

Fish transferred directly from 20 to 10 C exhibited a loss of performance capability. Mean swimming speed decreased to 15.5 cm/s, a loss of 17.5 cm/s. Swimming speed for this group then increased to 24.5 cm/s at the end of 24 h, remaining at this level for the remainder of the test period. Upper and lower 95% confidence limits for the stabilized mean critical swimming speed were 26.3 cm/s and 22.9 cm/s, respectively.

The stable performance level for fish transferred from 20 to 10 C (24.5 cm/s) was significantly higher than anticipated from swimming speeds observed for fish acclimated to 10 C only (20.0 cm/s). The difference corresponds with the greater increase in performance associated with experience in the tunnel for 20 C-acclimated fish when compared with 10 C-acclimated fish. However, the physiological (or behavioral) basis for this difference in response remains obscure.

In evaluating our results, it is important to recognize the complexity of temperature adaptation where different rates of application and levels of temperature may be involved in conjunction with seasonal, size, age, and species differences. In general, our results contrast with studies on rates of change in tolerance following abrupt changes in temperature. For example, the opaleye (*Girella nigricans*) required 1 day to complete 90% acclimation of heat resistance following a temperature increase from 14 to 26 C (Doudoroff 1942). Fifteen days were required for a 90% loss of cold resistance. When the temperature change was reversed, more than 25 days were required for a 90% loss of heat resistance with a similar time needed for 90% gain in cold resistance. Similar examples are given by Brett (1971) for a number of species.

Our results are in somewhat better agreement with observations on rates of change in metabolic rate (oxygen consumption) following temperature changes. For example, Klicka (1965) found that for the goldfish (*Carassius auratus*) stable rates of oxygen consumption were regained in 2–5 days following an increase or decrease in temperature of 15 C.

Ecological implications of our results are apparent. Yellow perch are commonly found in shallow lake waters where rapid temperature fluctuations occur, particularly during late spring and summer months. For example, in Lake Michigan (the source of fish for this study), stratification occurs during spring and summer and temperatures as high as 21–22 C are typical in inshore waters. Upwelling conditions associated with offshore winds frequently result in temperature fluctuations of the order employed in this study occurring over short (<6 h) periods of time.

The abilities of fishes resident in a thermally unstable environment of this nature to avoid predation, capture prey, and maintain "normal" activities are obviously dependent on the time course of adaptation. In the case of the yellow perch, at least, it appears that compensation for any adverse reduction in performance capabilities resulting from a sudden fluctuation in temperature is completed in an appropriately short time period.

Acknowledgments

Facilities and funding for this study were provided by Commonwealth Edison Company, Chicago, Ill. We thank Mr P. Howe, Environmental Affairs Division, Commonwealth Edison Company, and Mr M. Kitchel, Industrial BIO-TEST Laboratories, Inc., for their advice and assistance. Ms M. Leider assisted with the preparation of the manuscript.

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