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Evidence to Challenge the "2% Rule" for Biotelemetry

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Abstract.—Swimming performance was compared among groups of juvenile rainbow trout *Oncorhynchus mykiss* (5–10 g) with and without intraperitoneally implanted radio transmitters. The generally accepted rule of 2% body weight : transmitter weight was extended to a 6–12% ratio, and swimming performance was not altered by the presence of the transmitter or effects of the operation. Also, no relationship was found between the weight of the fish and its swimming performance among the groups examined. Although we found swimming performance was not affected by implantation of transmitters weighing up to 12% of the body weight, changes in behavior were not evaluated. We suggest further research be done so that the ''2% rule'' can be replaced by an index with a more scientific basis. Instead of using a scale based on percentage of transmitter to body weight in air, preferred indices could be weight in water, volume of the tag, or both.

Radiotelemetry has many advantages over other techniques for quantifying fish movements (Gowan et al. 1994) and habitat use and preferences (Tyus et al. 1984). However, transmitter size has precluded the study of smaller fish because it is commonly believed that transmitters should weigh no more than 2% of the body weight of a fish in air or 1.25% of the weight in water (Winter 1983). Despite many researchers accepting this ''2% rule,'' little experimentation has been conducted.

The 2% rule has been based partly on the assumption that tags heavier than this would affect the swimming performance of fish. Some research has been done on surgical implantation of small salmonids with transmitters exceeding 2% of the fish's weight. Adams et al. (1998b) found that transmitters weighing 2.2–10% (in air) of the fish's weight decreased the swimming capacity of small (95–160 mm fork length, FL) chinook salmon *Oncorhynchus tshawytscha* and that these fish were preyed upon almost three times more often than control fish. However, these researchers used transmitters that had antennas two to three times the length of the fish, which may have caused decreased swimming performance and increased vulnerability to predation. Although shortening the length of transmitter antennas does decrease the range of detection, it may enhance their utility for smaller fish.

We hypothesized that intraperitoneal implantation of a transmitter that weighed over 2% of the fish's body weight in air would not adversely affect swimming performance. We also expected that reducing the antenna length to less than the body length of the test fish would not result in reduced swimming capacity as Adams et al. (1998b) found when they broke the 2% rule. To test this hypothesis, we compared critical swimming speeds of juvenile rainbow trout *O. mykiss* implanted with radio transmitters composing 6–12% of the fish's weight (in air) with trout lacking transmitters. This experiment was undertaken using some of the smallest commercially available transmitters so that results could be applied to field studies in the future.

Methods

Effects of transmitter implantation were quantified by comparing critical swimming speed (a measure of prolonged swimming ability) among three groups of small (5–10 g) hatchery-reared rainbow trout. Fish were randomly placed into one of the three treatment groups. The first group was implanted with radio transmitters. After the antenna was trimmed to 2.5 cm, radio transmitters (7 mm ×12 mm) weighed 0.6 g in air (6–12% of the fish's weight) and 0.4 g in water and had a water displacement of 0.22 mL. Surgery was also completed on a second sham group in which no transmitter was implanted. The last group served as a control, and did not undergo anesthesia or surgery. Means (±SE) for the three groups were as follows: transmitter implanted group ($N = 12$) weight 7.41 g ± 0.43 and FL 88.9 mm ± 3.5, sham group ($N = 11$) weight 7.37 g ± 0.47 and FL 88.7 mm ± 1.9, controls ($N = 15$) weight 7.27 g ± 0.28 and FL 87.7 mm ± 1.3.

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Fish were individually anesthetized with clove oil at 40 mg/L (Anderson et al. 1997; Keene et al. 1998). An 8-mm incision was made slightly to one side of the ventral midline, midway between the pectoral girdle and the pelvic girdle. Transmitters (model FHRT-1K, Lotek Engineering, Newmarket, Ontario) were cleaned in ethanol and rinsed with water and subsequently positioned within the peritoneal cavity to lie directly below the incision. The incision was then closed with two braided silk sutures (Ethicon 2/0), the antenna protruding from the posterior aspect of the incision. After surgery, all fish were transferred to a recovery tank and monitored until recovered.

To reduce interference with the swimming movement of the test fish, the transmitter antenna was trimmed to 2.5 cm, which reduced the detection range. In some instances this may impair the use of these transmitters in the field. However, in many situations, the signal strength output associated with the trimmed antennas could still be used effectively to locate fish.

Tests of swimming speed were performed in a 6-L Blazka type swim chamber (described by Smith and Newcomb 1970), 24–28 h after surgery. The swim chamber was supplied with aerated well water at 11°C via an external pump. Fish were acclimated to the chamber by having them swim at 0.09 m/s for 15 min. Fish were then forced to swim until fatigued at speeds increasing by increments of 0.071 m/s and lasting 5 min. Fatigue was determined as described by Beamish (1978), occurring when the test fish, after repeated efforts, could no longer swim off the back screen of the swim chamber. Critical swimming speed was calculated using the formula of Brett (1964).

The first step in the statistical analysis was to determine if a relationship existed between fish weight and swimming performance and how consistent the relation was among groups. This was examined using analysis of covariance (ANCOVA). Because we found no effect of weight on swimming speed, a one-way analysis of variance (ANOVA) was used to determine if critical swimming speeds differed among groups. Normality was confirmed with a Lilliefors test (SYSTAT 1992) and differences in variance were compared with an F-test. Statistical significance of all tests was determined at $\alpha = 0.05$. A power analysis was also performed at a 25% level. This level was used because differences at levels lower than this may not be biologically significant.

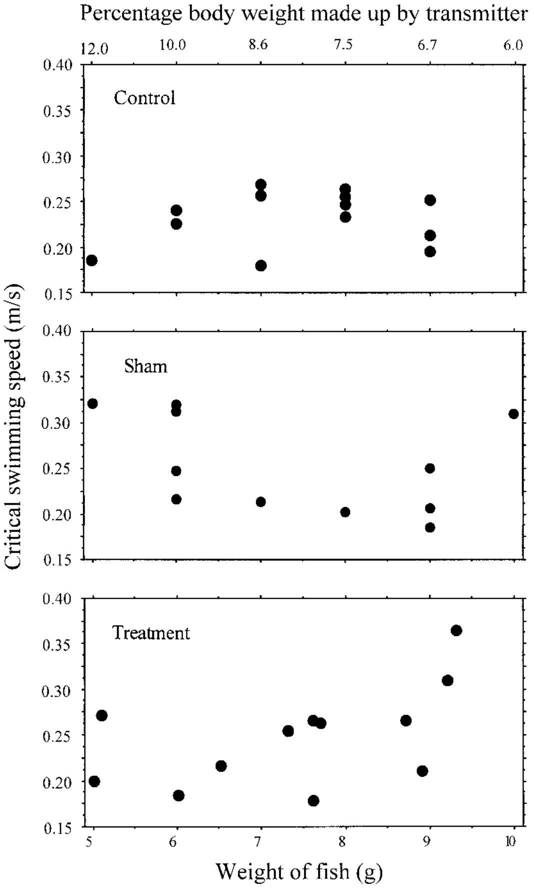

FIGURE 1.—A plot of body weight and percentage of body weight made up by implanted radio transmitters versus critical swimming speed of juvenile rainbow trout that had radio transmitters surgically implanted (treatment), underwent surgery but were not implanted with transmitters (sham), and did not undergo surgery (control).

Results and Discussion

No relationship ($P > 0.05$) was found to exist between fish weight and swimming performance among the three groups (Figure 1). Also, swimming performance was not significantly ($P > 0.05$) altered by either transmitter implantation or by the surgery alone (80% power of detecting a 25% difference; actual difference was 8%; Figure 2).

Our study demonstrated that intraperitoneal implantation did not affect swimming performance of the test fish. Indeed previous studies on larger fish have also reported no evidence of altered swimming performance in fish radio-tagged intraperitoneally (Mellas and Haynes 1985; Moore et al. 1990). Mellas and Haynes (1985) increased the

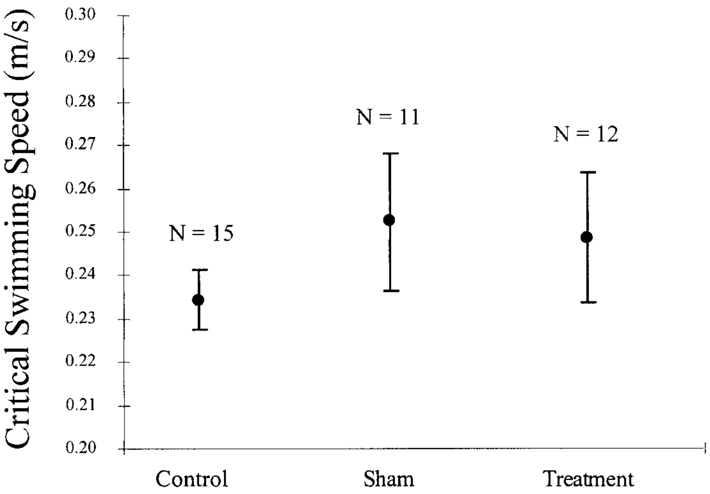

FIGURE 2.—Mean (±SD) critical swimming speed of three groups of small (5–10 g) rainbow trout. The control group did not undergo surgery, the sham group underwent surgery but not transmitter implantation, and the treatment group was surgically implanted with transmitters weighing (in air) 6–12% of the fish's body weight.

2% ratio of transmitter to body weight to 2.8% and found no effect of intraperitoneal implantation on swimming performance. Whether Moore et al. (1990) extended the 2% rule is unknown because they only provided the weight of the test fish for the growth component of their study. However, previous studies have shown that breaking the 2% rule can have negative effects on swimming performance, growth, and predator avoidance (Adams et al. 1998a, 1998b). They used transmitters weighing 2.2–10.4% of juvenile chinook salmon body weight in air, but in both studies the transmitters had antennas that were 2–3 times the length of the fish, which could have had additional impact on the fish's ability to swim and avoid predation. A long antenna may also increase the likelihood of predation by acting as an attractor.

Others have also found that intraperitoneal implantation did not affect growth, survival, gonad development, social interactions, feeding, or swimming behavior (Lucas 1989; Moore at al. 1990; Swanberg and Geist 1997). Of these studies, however, only the growth portion of the study by Moore et al. (1990) broke the 2% rule, and then only slightly (i.e., transmitter to body weight ratios were up to 2.2% and 3.3%).

Most studies that examined the effects of gastric implants and external attachment have been limited to larger fish; they did not exceed the 2% rule or did so only slightly (by <1%), whereas others did not report weights of fish (McCleave and Stred 1975; Lewis and Muntz 1984; Mellas and Hayes 1985; Greenstreet and Morgan 1989; Armstrong and Rawlings 1993). However, Adams et al. (1998a, 1998b) found that fish with gastric implants that exceeded the 2% rule grew more slowly and had impaired swimming performance.

Although our findings provide only a small component of what will be needed to form a true guideline, we suggest that the 2% rule be replaced by an index with a more scientific basis. We also suggest that, instead of using a scale based on percentage of transmitter to body weight in air, preferred indices would be weight in water or the volume of the tag. Weight in air is a poor scale because two tags may weigh the same in air but have very different bouyancies in water. Gallepp and Magnuson (1972) found that bluegills *Lepomis macrochirus* compensated for the additional weight of a transmitter implanted in their stomach by secreting gas into the air bladder. The amount of water displaced by this increasing of the gas bladder size reflected the mass of the transmitter in water, not in air. Thus, a more buoyant tag of similar dimensions has less effect on fish. Because some species and sizes of fish may be able to compensate for additional weight better than others (Gallepp and Magnuson 1972), it is unlikely that a single weight ratio would be suitable in all species, or even within species. The volume of the tag is also an important factor and should be included in any index. While a transmitter may be neutrally buoyant, it may fill much of the body cavity putting pressure on the internal organs. This pressure could cause decreases in stomach capacity and reduce growth, increase transmitter expulsion, or provoke other complications (Lucas 1989). A relatively large transmitter may also put pressure on the the sutures, causing them to rupture and the wound to open. Considering these factors, more research is needed before any standard is available. Future research should include examining the effect of antenna length on swimming performance, and effects of transmitters on other aspects of behavior at a transmitter weight: body weight ratio that does not affect swimming performance.

Even if transmitter sizes do not appear to affect swimming performance in fish, the further miniaturization of transmitters may still be required for use in species with small body cavities and with smaller life stages. Despite successfully extending the 2% rule, we submit that for any application, the smallest transmitters possible should be used in an effort to minimize behavioral and physiological response to implantation.

Although the swimming ability of fish may not be reduced by intraperitoneal implantation, fish may still be affected by the loss of motivation due to surgical stress or the burden of the transmitter. However, this research has provided means for rethinking the 2% rule, which has been a relatively unchallenged standard for over a decade. We hope this work will stimulate further experimentation to determine accurate guidelines for use of radiotelemetry.

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