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THE IMMEDIATE EFFECTS OF STRESS ON HORMONES AND PLASMA LYSOZYME IN RAINBOW TROUT

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☐Abstract—**The fight-or-flight response prepares an animal for coping with alarming situations and their potential consequences, which include injury. The possible involvement of innate components of immunity in the response has received little attention. We determined plasma concentrations of stress hormones and lysozyme activity before and after a 10 min handling stressor. Rainbow trout (*Oncorhynchus mykiss*) were anesthetized in their home tanks, bled, revived, and then stressed by being held in the air in a net for 30 s and placed in a shallow bucket of water for 10 min. Fish were then captured, concussed (in one of two experiments) and bled again. Control fish were also bled twice, but were kept anesthetized in their holding tanks between bleedings. Following the stressor, plasma cortisol, adrenaline and lysozyme activity were significantly increased. The experiment was repeated 4 months later with a similar outcome. While chronic stress is eventually immunosuppressive, acute stress/trauma may help enhance both cellular and humoral components of innate defenses at times of likely need.** © 1997 Elsevier Science Ltd.

☐Keywords—**Acute stress; Innate immunity; Plasma stress hormones; Adrenaline; Cortisol; Plasma lysozyme; Fight-or-flight.**

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Introduction

Enhancement of innate defenses such as opsonization, phagocytosis, lysis, etc. can be reasonably expected to increase an individual's capacity to neutralize potentially invasive microbes, and increase chances for survival following non-sterile injury. As early as the 1920s, Cannon (1) described a plethora of physiological respones to alarm, such as increased heart rate, increased circulation to the brain and muscle, decreased blood clotting time and a release of red blood cells from the spleen. Most of these changes are initiated by catecholamines, the archetypical indicators of the flight-or-flight response. Cannon postulated that the changes were the adaptive response of the body to an insult. Chronic stress, epitomized by prolonged elevations of plasma cortisol, has been found to be generally detrimental to immune status. Few reports, however, deal with the immediate effects of acute stressors on immune systems, although some instances of enhanced immunity (2–4) and altered hematology (5,6) immediately following stress have been documented.

As the fight-or-flight response appears to have been selected to help an organism respond to potentially dangerous situations, we considered (7,8) that it might include enhancements that would help the organism to deal with and to survive invasions of pathogens (and damage to

tissues) that may be the consequence of acute stressors. Alterations in leukocyte distribution and functionality having already been documented (5,6,9), we asked if the basis of such putative enhancement includes increases in the concentrations of plasma proteins that help to identify, remove and destroy foreign entities and damaged tissues. Lysozyme, a plasma protein with the ability to digest the surface of Gram-negative bacteria, contributes to innate defenses in many species including fish, is easily assayed, and was therefore selected for detailed study.

As an evolutionarily old lineage of vertebrates, the rainbow trout (*Oncorhynchus mykiss*) seems to rely more heavily on innate defenses than do more recently evolved taxa (10). Knowledge of its physiology is quite extensive, and the species has proven to have merit as a model for biomedical research (11). For these reasons, and because it is both economically important and readily available, it was chosen as the subject for our studies.

We reported earlier (7,8) that four of 12 rainbow trout plasma proteins, measured by crossed immunoelectrophoresis, increased in concentration minutes after confinement of fish in a shallow bucket of water following a brief period in a net out of water. One of the proteins that increased was identified as complement component C3, a plasma protein central to innate defenses. We now report that the activity of lysozyme (another defense related plasma protein) also increased within minutes of a brief handling stressor, following kinetics faster than those of the acute phase response. These results suggest that the well-known immunosuppressive effects of stress may be preceded by short-term enhancement, at least following acute stressors.

Materials and Methods

Fish

Shasta strain rainbow trout (*Oncorhynchus mykiss*), spawned in June of 1994, were raised at the Food Science and Technology laboratory in Corvallis, Oregon. To prevent sexual maturation and avoid other seasonal effects, the fish were reared on a 12 h light/dark cycle and maintained in flow through (approximately 12 L/min) well water (12±2°C) in 250 L tanks. They were fed daily on Biobrood (Warrenton, OR). Fish were not fed or otherwise disturbed on the days they were sampled. At the time of the experiments, fish weighed 100–450 g and were approximately 16 or 20 months old. Individuals were not marked or otherwise manipulated prior to the experiments. After the initial bleed, fish were placed in individual containers to allow for their subsequent identification. To determine the robustness of the results, the experiment was run in October 1995 and again in February 1996.

Stress Regime and Sampling

Experiment 1. Ten fish were stocked in each of five 400 L tanks. This experimental design was used for several reasons. First, we wished to be able to identify any tank effects (11); secondly, the low stocking density ensured the avoidance of crowding as a stressor yet was sufficient to encourage schooling behavior (thought to minimize the potential influence of dominance heirarchies); and thirdly, it allowed for the complete running of an experiment within 1 week with daily access to a tank that had not been sampled previously. Sampling commenced after 2 weeks' acclimatization. Using one tank per day, fish were sampled between 0800 and 1000 h to reduce the potential influence of diurnal variation in hormone levels. Without raising the tank

lid or otherwise disturbing the fish, anesthetic (100 mL of 2-phenoxy-ethanol, shaken vigorously with 100 mL water) was infused into the tank (a final concentration of approximately 0.25 mL 2-PE per liter) via a tube in the water inflow. After 2 min, all 10 anesthetized fish were removed individually from the tank and bled (about 1.0 mL) from the caudal vessel into a heparinized syringe. Except for stressed fish 1–5 (bled on the first day of the experiment), the five experimental fish were then revived in fresh water, then stressed by being held in a net in the air for 30 s and placed in a shallow bucket of water. After 10 min, these fish were killed by cerebral concussion, and bled again. The five control fish were bled while anesthetized, returned to the tank containing anesthetic and bled again 10 min later. All fish were ventilating regularly while under anesthesia. Blood samples were kept on ice less than 30 min until centrifuged for 10 min at 4°C and 400×*g*, to separate the plasma from the cells.

Lysozyme activity was assayed within 1 h of bleeding using fresh aliquots of plasma. For determination of adrenaline and cortisol, aliquots were frozen at – 80°C. Experiment 1 was performed during October 1995.

Experiment 2. This was similar in design to experiment 1, with three tanks of 10 fish each. Thus, 30 fish (10 per day) were sampled over 3 days in February 1996. Owing to resource limitations, instead of adrenaline analysis, a subset of samples (those from day 1) was analyzed for cortisol. Control fish were not concussed before the second bleed.

Lysozyme Activity

A turbidimetric assay was used to determine lysozyme activity (12). Dilutions of hen egg white lysozyme (HEWL, Sigma, St Louis, MO) were prepared fresh daily from a frozen aliquot of a standard solution (1 mg/mL) using a 0.1 M phosphate/citrate buffer pH 5.8. Dilutions of the standard and of the test plasma (25 µL) were placed into wells of a 96-well plate in triplicate. One hundred and seventy-five microliters of a 0.075% (wt:v) *Micrococcus lysodeikticus* (Sigma, St Louis, MO) suspension prepared in the same buffer was then added to each well. After rapid mixing, the change in turbidity was measured every 30 s for 5 min at 450 nm. Softmax computer application provided equivalent units of activity of test sera as compared to the HEWL.

Cortisol

Cortisol levels in fish 51–60 of experiment 2 were analyzed by radioimmunoassay (13).

Adrenaline

Adrenaline levels were determined, in plasma samples from experiment 1, using high pressure liquid chromatography (HPLC) with electrochemical detection (14). One milliliter of 0.1 M aqueous perchloric acid (PCA, Sigma, St Louis, MO) was added to each thawed plasma sample (100 µL). Dihydroxybenzylamine (DHBA) was added as an internal standard (50 µL of a 4.5 nmol/mL solution was added to each sample). After a brief vortex, the samples were centrifuged at 8000×*g* at 4°C. The supernatant was transferred to a clean microfuge tube containing 10 mg acid washed alumina (Sigma), 25 µL 5 mM sodium metabisulfite and 25 µL 10% (wt:v) EDTA (Sigma, St Louis, MO). Six hundred microliters of Tris buffer (2.0 M) pH 8.0 was added and the samples were vigorously vortexed. The tubes were incubated at room temperature on a rocking platform for 30 min, to allow catecholamines to adsorb to the alumina. The samples were

then washed three times with 1 mL chilled NANOpure water with 2 min centrifugation at 2000×*g* between each wash. After the final wash, the catecholamines were eluted from the alumina with 200 µL 0.1 M PCA. Ten microliters of this solution were injected into the HPLC apparatus. The levels of adrenaline were calculated by the relative areas of their peaks compared to the peak area for the internal standard (DHBA).

Statistics

Differences in the levels of hormones and lysozyme activity in stressed trout plasma compared to the changes in values for control fish were evaluated by ANOVA. Differences were considered significant when $p < 0.05$. Tank-to-tank and fish-to-fish variations were analyzed separately, and the non-parametric sign test was used on the lysozyme data as an independent test of significance (15).

Results

Experiment 1

When the data were pooled for all control fish and for all stressed fish, the change in mean plasma lysozyme activity was significantly greater in fish after an acute handling stress than in control fish ($p = 0.016$). Lysozyme activities increased in 19 of 25 stressed fish, but in only nine of 25 control fish (Tables 1 and 2). Of these nine, the only three with increases > 0.18 µg/mL were also the three with the highest adrenaline levels at the time of the second bleed, perhaps indicative of a minor, unintended alarm signal of which we were not aware. Units of lysozyme activity varied among individual trout from a low of 2.67 µg/mL to a high of 7.83 µg/mL (Fig. 1). There was an increase of 0.274±0.148 µg/mL (mean±SE) in experimental fish, and a decrease of 0.031±0.051 µg/mL in control fish. This decrease was not statistically significant ($p = 0.55$). Two stressed fish had increases of nearly 2 µg/mL, and two other stressed fish had decreases of about 1.5 µg/mL. All other fish (control or experimental) had changes of < 1 µg/mL. Anesthetization and bleeding in the absence of an intentional stressor did not increase plasma lysozyme activity in control fish.

Among initial samples, adrenaline levels varied widely, from nearly undetectable (< in Tables 1 and 2) to 64.39 pmol/mL. Adrenaline rose in every fish that was revived before being stressed. In stressed fish, levels ranged from 24.28 to 2862.8 pmol/mL. Fish 1–5, which were not revived between bleeds, had adrenaline levels < 87.0 pmol/mL at the time of the second, post-stress, bleed. In the remaining experimental (stressed) fish, which were revived before being stressed, the plasma adrenaline levels, while varying widely, were significantly higher (average 782.31 pmol/mL, $p < 0.001$). For these statistical tests, fish-to-fish variation was used (15). Levels remained low in most control fish, with a mean of 66.53 pmol/mL, although there were increases of over 100 pmol/mL in two fish. Although catecholamine levels were not obtained for several samples, the available data, analyzed on a log scale, indicate a dramatic rise in adrenaline in association with stress ($p < 0.0001$). Fish-to-fish variation was used for this comparison. Using the statistically more conservative tank-to-tank variation as the basis for the analysis, the p value for a stress effect on adrenaline levels was 0.026.

Experiment 2

Again, most fish that were stressed (12 of 15) had increased plasma lysozyme activity: levels were increased in only six of 15 control fish (Table 3). Lysozyme activity ranged from 2.70 to 6.73 µg/mL,

Table 1. Lysozyme and adrenaline levels in individual rainbow trout bled before and after stress in Experiment 1.

	Lysozyme activity(μg/mL)			Adrenaline(pmol/mL)		
No.	Initial*	Second†	Change‡	Initial*	Second†	Change‡
Control trout						
Tank 1						
6	5.50	5.53	0.03	23.35	9.60	− 13.75
7	5.05	4.78	− 0.27	10.03	9.58	− 0.45
8	4.74	4.54	− 0.20	12.56	<	
9	5.30	5.16	− 0.14	10.49	<	
10	4.76	nd		nd	nd	
Tank 2						
26	4.78	4.72	− 0.06	nd	nd	
27	3.22	2.67	− 0.55	nd	nd	
28	3.13	3.24	0.11	nd	nd	
29	5.97	5.56	− 0.41	nd	nd	
30	3.59	3.53	− 0.06	nd	nd	
Tank 3						
16	5.33	5.31	− 0.02	10.84	37.40	26.56
17	4.64	4.55	− 0.09	nd	31.50	
18	5.65	5.46	− 0.19	16.58	28.34	11.76
19	4.42	5.20	0.78	nd	168.75	
20	6.55	6.34	− 0.21	22.93	nd	
Tank 4						
36	4.01	3.90	− 0.11	<	<	
37	4.97	4.88	− 0.09	<	49.96	
38	4.99	5.10	0.11	<	<	
39	4.14	4.28	0.14	<	22.26	
40	4.24	4.15	− 0.09	12.79	21.08	8.29
Tank 5						
46	5.78	6.00	0.22	14.93	248.80	233.87
47	4.64	4.60	− 0.04	36.91	nd	
48	5.67	5.76	0.09	25.46	66.96	41.50
49	4.86	5.04	0.18	12.26	139.95	127.69
50	6.25	6.38	0.13	13.94	30.64	16.70
Average:			− 0.03			50.24
±Std dev.:			±0.25			±80.14

*The initial sample was from fish which were remotely anesthetized with 2 − PE before being bled.
†The second sample was from fish which were revived, then stressed by 30 s in the air and 10 min in a shallow bucket of water. Control fish were held under anesthesia between bleeds.
‡The change is the difference between the second and initial levels.
No. refers to fish code.
nd, no data (insufficient plasma was obtained).
< indicates HPLC difficulty.

except in one fish, number 73, which had an unusually high lysozyme activity of 15.96 μg/mL in the initial sample that rose to 17.38 μg/mL after stress. The change in plasma lysozyme activity of stressed fish (Fig. 1) was +0.184±0.110 μg/mL. In the control group, the change in lysozyme activity was − 0.058±0.105 μg/mL. The difference between control and stressed lysozyme levels, analyzed as tank-to-tank variation, was again statistically significant ($p = 0.0081$).

Plasma cortisol levels, measured in fish 51–60, were low (mean 5.4 ng/mL) at the initial sampling (Table 4), and increased significantly in experimental animals ($p < 0.0001$). The mean plasma cortisol rose to 79.5 ng/mL in stressed fish. In

Table 2. Lysozyme and adrenaline levels in individual rainbow trout bled before and after stress in Experiment 1.

	Lysozyme activity (μg/mL)			Adrenaline (pmol/mL)		
No.	Initial*	Second†	Change‡	Initial*	Second†	Change‡
Stressed trout						
Tank 1						
1	4.58	5.08	0.50	<	31.24	
2	4.15	4.64	0.49	64.39	65.14	0.75
3	5.12	5.40	0.28	28.22	86.37	58.15
4	3.70	3.59	− 0.11	9.04	24.25	15.21
5	nd	4.25		nd	nd	
Tank 2						
21	5.60	6.29	0.69	<	392.47	
22	3.12	3.40	0.28	12.90	165.44	152.54
23	3.35	5.11	1.76	<	1169.10	
24	4.53	3.20	− 1.33	12.93	405.21	392.28
25	3.08	3.43	0.35	<	1509.50	
Tank 3						
11	4.91	5.66	0.75	18.57	1679.80	1661.23
12	4.15	4.48	0.33	21.01	1260.40	1239.39
13	3.78	4.10	0.32	7.99	1298.60	1290.61
14	5.77	6.18	0.41	<	2862.80	
15	6.64	6.09	− 0.55	<	nd	
Tank 4						
31	5.72	4.42	− 1.30	nd	1542.90	
32	4.14	4.34	0.20	6.53	461.54	455.01
33	4.21	6.28	2.07	<	849.30	
34	6.00	6.29	0.29	<	888.20	
35	5.31	5.19	− 0.12	<	243.84	
Tank 5						
41	5.44	5.75	0.31	<	1503.10	
42	6.22	6.76	0.54	17.13	660.70	643.57
43	7.69	7.83	0.14	13.58	1738.40	1724.82
44	4.33	4.52	0.19	nd	nd	
45	5.04	5.14	0.10	49.46	2256.30	2206.84
Average:			0.27			820.03
±Std dev.:			±0.73			±771.02

*The initial sample was from fish which were remotely anesthetized with 2-PE before being bled.
†The second sample was from fish which were revived, then stressed by 30 s in the air and 10 min in a shallow bucket of water. Control fish were held under anesthesia between bleeds.
‡The change is the difference between the second and initial levels.
No. refers to fish code.
nd, no data.
< indicates HPLC difficulty.

control animals, the mean plasma cortisol was elevated to 27.0 ng/mL after 10 min.

Discussion

Marked individual variability in physiological parameters is a common feature in teleosts. Values for plasma lysozyme are consistent with this generalization, and were the reason that we decided to take repeat bleeds of individual fish rather than sample discrete groups of "resting" and stressed fish. By doing so we have found that elevation of plasma lysozyme is the typical, though not universal, immediate (10 min) response of trout to acute stress. Others working with Atlantic salmon report similar findings after 30 or more minutes of stress (21). Some

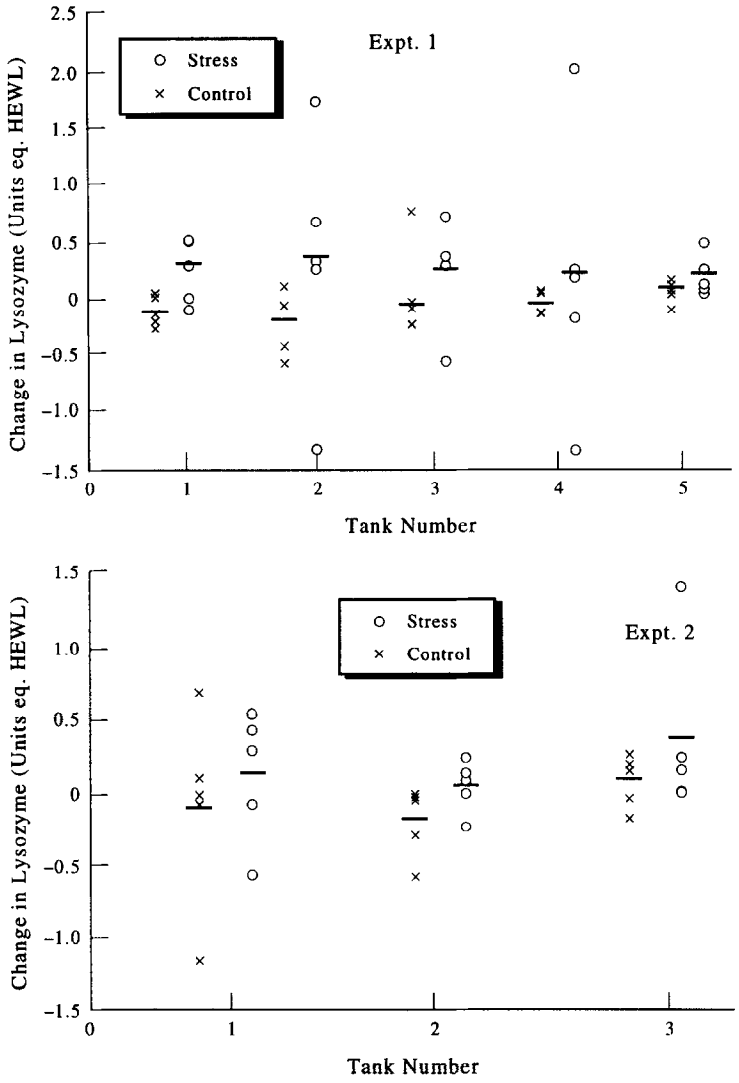

Figure 1. Lysozyme activity in trout plasma, determined in two experiments. Each individual trout was anesthetized and bled. Controls were then held under anesthesia for 10 min in their holding tanks before being bled again. Experimental fish ("stress") were revived in fresh water after the first bleed, then stressed by being held in the air for 30 s and in a shallow bucket of water at ambient temperature until 10 min had elapsed, when they were re-bled. Data are plotted for every sample, and stressed and control samples are identified within each tank. Despite high variance, in each tank the mean value was higher for stressed fish. Using the very conservative sign test, the p values [0.0315 for experiment 1 (five tanks) and 0.125 for experiment 2 (three tanks)] reflect the consistency of the stress-induced increase.

experimental animals did not respond with increased levels of plasma lysozyme activity. Reasons for this might include the presence of non-responders in the population, but may also possibly be due to logistical difficulties obtaining some blood samples.

Data showing an increase in plasma lysozyme activity in this model are similar to others on C3 (7,8). Acute stress has also been found to lead to a redistribution of leukocytes and their altered functionality in both fish and mammals (4–6). It appears, then, that acute stress may well enhance innate immunity in vertebrates. This contrasts with the more frequently

Table 3. Lysozyme activity levels in individual trout plasma samples before and after acute stress; data from Experiment 2.

	Lysozyme activity (μg/mL)		
No.	Initial*	Second†	Change‡
Control trout			
Tank 1			
56	4.399	5.076	0.677
57	5.525	4.374	− 1.151
58	6.051	6.149	0.098
59	6.374	6.346	− 0.028
60	5.878	5.790	− 0.088
Tank 2			
66	3.724	3.161	− 0.563
67	4.511	4.503	− 0.008
68	4.035	3.752	− 0.283
69	3.840	3.812	− 0.028
70	3.567	3.580	0.013
Tank 3			
76	2.933	2.768	− 0.165
77	4.004	4.220	0.216
78	3.825	4.003	0.178
79	2.406	2.694	0.288
80	3.994	3.968	− 0.026
Average:			− 0.058
±Std dev.:			±0.409
Stressed trout			
Tank 1			
51	6.729	6.645	− 0.084
52	6.708	6.155	− 0.553
53	6.155	6.684	0.529
54	6.483	6.756	0.273
55	5.820	6.247	0.427
Tank 2			
61	3.749	3.842	0.093
62	3.794	3.568	− 0.226
63	4.610	4.847	0.237
64	3.911	3.914	0.003
65	2.832	2.975	0.143
Tank 3			
71	2.817	2.856	0.039
72	4.369	4.546	0.177
73	15.960	17.380	1.420
74	3.529	3.557	0.028
75	2.701	2.958	0.257
Average:			0.184
±Std dev.:			±0.430

*The initial sample was from fish which were remotely anesthetized with 2-PE before being bled.
†The second sample was from fish which were revived, then stressed by 30 s in the air and 10 min in a shallow bucket of water. Control fish were held under anesthesia between bleeds.
‡The change is the difference between the second and initial levels.
No. refers to fish code.

Table 4. Cortisol levels in individual trout plasma samples before and after acute stress; data from Experiment 2.

	Cortisol (ng/mL)		
No.	Initial*	Second†	Change‡
Control fish			
56	1.25	23.35	22.10
57	1.30	22.20	20.90
58	15.30	34.35	19.05
59	3.95	25.10	21.15
60	17.60	30.00	12.40
Average:			19.12
±Std. dev.:			± 3.92
Stressed fish			
51	3.20	65.80	62.60
52	0.60	49.30	48.70
53	0.00	55.40	55.40
54	6.20	111.80	105.60
55	3.70	115.30	111.60
Average:			76.78
±Std dev.:			±29.54

*The initial samples were from fish which were remotely anesthetized with 2-PE before being bled.
†The second samples were from fish which were revived, then stressed by 30 s in the air and 10 min in a shallow bucket of water. Control fish were held under anesthesia between bleeds.
‡The change is the difference between the second and initial levels.
No. refers to fish code.

reported reduction in defenses—including lysozyme—under more chronic stress e.g. (16).

The changes in lysozyme were qualitatively and quantitatively similar in the two experiments, though control fish in experiment 1 were not concussed prior to the second bleed, while those in experiment 2 were. It is therefore unlikely that concussion altered plasma lysozyme detectably. Differences in basal lysozyme activity may be genetically determined, or may be due to environmental causes e.g. diet (17), or recent infections. One fish in these experiments had a level over three times higher than any other fish. Even in such an individual, plasma lysozyme activity increased after a brief aerial exposure and 10 min in a shallow bucket of water.

A full characterization of the kinetics of change of lysozyme activity as a component of the fight-or-flight response will require further research. What is already clear, however, is that the changes we demonstrate here precede the classical acute phase response. The latter response involves genomic activation, with plasma protein gene transcription, de novo protein synthesis, and secretion. Even immediate early genes in mammals require 5 min or more before new mRNA is detected (18). At 12°C (the temperature at which these experiments were run), it is conceivable that pre-existing (but inactive) mRNA might initiate translation, or that pro-proteins may be converted to the active form and released. But, we suggest, the kinetics of the change we have reported warrant the term pre-acute phase response. A search for presynthesized pools of plasma proteins or their mRNAs should prove rewarding.

Surreptitious introduction of the anesthetic into tanks before handling yielded lower adrenaline levels relative to those obtained after netting and concussing without anesthetic (19). It also prevented plasma hormones from rising as high as in fish stressed without anesthesia. In fish that were not revived before being stressed (experiment 1, 1–5), adrenaline levels increased minimally as a result of the handling stressor. In revived fish, however, levels increased much more. It appears that anesthesia reduced the effect of the stressor, probably by blocking either the sensory input to the hypothalamus or the sympathetic response. A more complete revival before stress is predicted to yield increased differences in plasma lysozyme.

Cortisol data on a subset of the fish in experiment 2 also indicated that stressed fish may not have been fully revived. The average cortisol concentration in the plasma of the stressed fish measured from experiment 2 was 79.5 ng/mL. In other experiments using the same stock of fish (19), the average plasma cortisol level from fish which had been similarly stressed, but without anesthesia, was 122.0 ng/mL. Although some fish ($n = 6$) in those experiments had plasma cortisol levels less than 100 ng/mL, most ($n = 15$) had levels greater than 100 ng/mL, and in six of these plasma cortisol levels were greater than 150 ng/mL. In a previous study (7) plasma cortisol levels averaged 119.1 ng/mL in trout stressed in the same manner. Thus, anesthetic may have prevented some of the increase in plasma cortisol, even after the fish had been revived in fresh water. Furthermore, control animals had elevated plasma cortisol after 10 min in the anesthetic bath. This differs from the results of others (20), who found plasma cortisol decreased following anesthetization.

Fevolden et al. (21) discussed a negative correlation between elevated lysozyme and resistance of Atlantic salmon to two bacterial pathogens, suggesting that "enhanced lysozyme activity in a fish following exposure to a stressor is not indicative of a more resistant fish...; it may rather reflect a more disease susceptible organism" (p. 515). We suggest the possibility that the accompanying rise in cortisol might account for the higher susceptibility to pathogens, and that the rise in lysozyme is a compensatory adaptation that, if dissociated from the cortisol-mediated immune suppression, would tend to bolster innate resistance. We emphasize that lysozyme may be a rather small component of innate resistance, whereas cortisol may have rather widespread negative effects on resistance mechanisms.

The broad implication of this work is that immunosuppression is not a universal consequence of stress. As acute responses to alarm and trauma are generally adaptive (22), it is to be expected that immediate changes in leukocytes (5,6,23) and in humoral components of innate defenses (this study) in response to stress will also enhance survival. Only later, as a consequence of

chronic inescapable stress, do reductions occur in the efficacy of the immune system.

In summary, serial bleeding of individual fish before and after an acute handling stressor revealed that plasma lysozyme activity, adrenaline and cortisol levels were significantly elevated in stressed fish. While definitive demonstration of altered resistance to pathogens remains to be demonstrated, these new results support the postulate that innate immunity may be transiently enhanced as a component of the fight-or-flight response.

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