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Research Article

Impacts of Different Exercise Routines on Rainbow Trout Rearing Performance

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Abstract: Exercising fish during hatchery rearing may provide considerable benefits. This study evaluated a combination of different exercise regimens and feeding levels during juvenile rainbow trout (*Oncorhynchus mykiss*) rearing for 109 days. Four treatments were used: 1. continual exercise at a water velocity of 12.2 cm s^{-1} and feeding to near-satiation (low exercise, low feed), 2. continual exercise at a water velocity of 30.5 cm s^{-1} and feeding an increased ration (high exercise, high feed), 3. exercise routine using a water velocity that alternated weekly between 12.2 cm s^{-1} and 30.5 cm s^{-1} and feeding to satiation (exercise routine, low feed), and 4. exercise routine and feeding an increased ration (exercise routine, high feed). Final tank weight, gain, percent gain,and feed conversion ratio were all significantly lower in the high exercise, high feed treatment compared to the other three treatments. Feed conversion ratio was significantly greater in the exercise routine, high feed treatment compared to both of the lower feed treatments. Specific growth rate and individual fish length and weight were all also significantly lower in the trout reared under constant high velocity compared to the other three treatments, but there was no significant difference in condition factor among treatments.

Because the troutfed to satiation in this novel exercise routine grew similar to, and as efficiently as,the trout receiving low exercise and fed to satiation, this exercise regime can be used to obtain the benefits of exercise without sacrificing rearing performance.

Keywords: Salmonids; Velocity; *Oncorhynchus mykiss;* Feed Ration

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Introduction

Subjecting fish to exercise has been shown to produce several benefits. Growth during hatchery rearing is increased with exercise (Davison and Goldspink, 1977; Leon, 1986; Houlihan and Laurent, 1987; Barrett and McKeown, 1988; Christiansen and Jobling, 1989; Christiansen et al., 1989; Farrell et al., 1990; Jørgensen and Jobling, 1993; Gregory and Wood, 1998; Ibarz et al., 2011; Good et al., 2016; Liu et al., 2018; Waldrop et al., 2018). Exercise in hatchery fish also increases post-stocking survival (Evenson and Ewing, 1993). In addition, exercised fish exhibit decreased agonistic behavior (Christiansen and Jobling, 1989; Jørgensen and Jobling, 1993), decreased stress levels (Hoffnagle et al., 2006), and recover quicker from stressful events (Woodward and Smith 1985; Barrett and McKeown, 1988;Gallaugher et al., 2001). Exercise increasesfish swimming performance (Leon, 1986; Anttila et al., 2006, 2011; He et al., 2013),and improves disease resistance (Castro et al., 2011; Liu et al., 2018).These positive results could be due to behavioral or physiological changes (Leon, 1986; Christiansen and Jobling, 1989; Christiansen et al., 1989; Parker and Barnes, 2014).

Experiments involving fish and exercise have used a variety of water velocities to influence fish swimming speeds. Swimming speeds have ranged from zero to four body lengths per second (BL s^{-1}) (Liu et al., 2018). However optimum speeds typically range from one to two body lengths per second (Jørgensen and Jobling, 1993; Anttila et al., 2006; Deschamps et al., 2009; Parker and Barnes, 2015; Waldrop et al., 2018).

The duration of continuous exercise experiments has been from two weeks to almost a year (Anttila et al., 2006, 2011; Hoffngale et al., 2006; Waldrop et al., 2018; Zhang et al., 2018). However, most studies are four to eight weeks long (Davison and Goldspink, 1977; Cresswell and Williams, 1983; Woodward and Smith, 1985; Houlihan and Laurent, 1987; Christiansen and Jobling, 1989; Farrell et al., 1990; Evenson and Ewing, 1993; Jørgensen and Jobling, 1993; Deschamps et al., 2009; Castro et al., 2011; Ibarz et al., 2011; He et al., 2013; Parker and Barnes, 2014; Liu et al., 2018). Voorhees et al. (2018b, 2019) reported increased growth in rainbow trout (*Oncorhynchus mykiss*) over the first two months of continuous exercise, with reduced growth by the third month, suggesting potential exercise fatigue.

Very few studies have examined non-continuous exercise. Intermittent exercise routines that include rest periods for the fish were first examined by Woodward and Smith (1985), who exercised rainbow troutfor eight hours per day for only five days a week and found total stress response was lower in exercised fish than unexercised fish. Farrell et al. (1990) used a twice daily regime of 10 hours of exercise, two hours of rest with rainbow trout for one to two months and found exercised fish grew larger, could swim faster, and produced isometric growth. Anttila et al. (2006, 2011) exercised Atlantic salmon (*Salmo salar*) for six hours a day for five days per week and found exercise increased density of muscle fibers and unexercised fish fatigued quicker, while Liu et al. (2018) exercised ya-fish (*Schizothoraxprenati*) for eight hours per dayfor two days of the week, and found exercise increased food consumption, feed efficiency (for fish swimming at 1 – 2BL s^{-1}), and the fish at these speeds also had higher specific growth rate and growth.

Continually exercised fish require increased feed rations to maintain growth similar to unexercised fish (Parker and Barnes 2015). There is no information available however concerning the feeding rates required for fish subjected to non-continuous exercise regimes. Thus, the objectives of this experiment were to first evaluate the impacts onrainbow trout growth of a novel exercise routine in conjunction with two different feeding rations.

Methods

This experiment occurred at McNenny State Fish Hatchery, rural Spearfish, South Dakota, USA, using degassed and aerated 11°C well-water (total hardness as $CaCO_3$, 360 mg L^{-1}; alkalinity as $CaCO_3$, 210 mg L^{-1}; pH, 7.6; total dissolved solids, 390 mg L^{-1}). Shasta strain juvenilerainbow trout (mean ± SE individual initial fish weight = 3.6 ± 0.2 g, length 69 ± 1 mm, n = 30) were placed into 16circular tanks (1.8 m diameter x 0.6 m deep; 0.4 m water depth) Each tank contained approximately 2,400 fish (8.4 kg). Flows were kept constant throughout the experiment, which began on June 1, 2018 and continued for 109 days.

Four treatments were used: 1. continual exercise at a water velocity of 12.2 cm s^{-1} and fed to satiation (low exercise, low feed), 2. continual exercise at a water velocity of 30.5 cm $s^{-1}$and fed increased ration (high exercise, high feed), 3. exercise routine using a water velocity that alternated weekly between 12.2 cm $s^{-1}$and 30.5 cm s^{-1} and fed to satiation (exercise routine, low feed), and 4. exercise routine and fed increased ration (exercise routine, high feed).Velocity was changed by adjusting the angle of the incoming water spray bar and were measured using a flow probe (FP111 Global Water Flow Probe, Global Water, College Station, Texas, USA). Readings were taken directly behind the spray bar about 0.2 m deep (halfway in water column). Feeding rates were projected using the hatchery constant method (Buterbaugh and Willoughby, 1967), with an expected feed conversion ratio of 1.1. The projected growth rates used were 0.08 cm d^{-1}(satiation) and 0.09 cm d^{-1}(increased ration). All fish were fed 1.5 mm extruded floating trout diet (Protec, Skretting USA, Tooele, Utah, USA) every 15 minutes during daylight hours with automatic feeders.

At the end of the experiment, total tank weight was measured to the nearest 0.5 kg. A sample of ten fish from each tank were weighed to the nearest 0.1 g, and total lengths measured to the nearest 1.0 mm. Gain, percent gain, feed conversion ratio (FCR), specific growth rate (SGR), and condition factor (K) were calculated using the following formulas:

Gain = end weight - start weight

$$\text{Percent gain}\left(\%\right) = 100^* \frac{\text{gain}}{\text{start weight}}$$

$$\text{Feed conversion ratio}(\text{FCR}) = \frac{\text{food fed}}{\text{gain}}$$

$$\text{SGR} = 100^* \frac{\ln\left(\text{end weight}\right) - \ln(\text{start weight})}{\text{number of days}}$$

$$\text{K} = 10^5 * \frac{\text{fish weight}}{\text{fish length}^3}$$

Data were analyzed using theSPSS (24.0) statistical program (IBM, Armonk, New York, USA). Significance was predetermined at $p < 0.05$. One-way analysis of variance was performed and if significant differences among the means was observed, Tukey's post hoc multiple comparison test was conducted.

Results

Mean ending tank weight, gain, and percent gain were all significantly lower in the high exercise, high feed treatment compared to the other three treatments **(Table 1)**. At 2.00, mean feed conversion ratio was also significantly elevated in the high exercise, high feed treatmentcompared to the other treatments. The 1.56 feed conversion ratio was significantly greaterin the exercise routine, high feed treatmentcompared to the ratios of 1.16 or lower in both of the lowfeed treatments. Mortality was less than 1% and was not significantly different among treatments.

Specific growth rate and individual fish length and weight were all significantly lower in the trout reared under constant high velocity compared to the other three treatments, although there was some overlap **(Table 2)**. There was no significant difference in condition factor among the treatments.

Discussion and Conclusion

The results of this study, where the fish in the exercise routine fed to satiation grew similarly and as efficiently as fish receiving low exercise and fed to satiation, indicate that it is possible to obtain the benefits of exercise during hatchery rearing without sacrificing rearing performance. The benefits of exercise to fish have been well-documented. It has been shown to decrease stress (Woodward and Smith, 1985; Barrett and McKeown, 1988; Palstra and Planas, 2011), decrease agonistic behavior (Christiansen and Jobling, 1989; Jørgensen and Jobling, 1993), increase swimming performance (Leon, 1986; Anttila et al., 2006, 2011; He et al., 2013), increases disease resistance (Castro et al., 2011; Liu et al., 2018) and increase post-stocking survival (Evenson and Ewing, 1993).

Table 1: Mean (±SE) final tankweight, gain, percent gain, feed conversion ratio (FCR[a]), and percent mortality for juvenile rainbow trout reared in with one of four different treatments: Low/Low= continual low-intensityexercise/lower feed, High/High=continual high-intensity exercise/higher feed, Routine/Low=exercise routine with rest periods/lower feed, Routine/High=exercise routine/higher feed. Means with different letters in same row are significantly different (n=4; p<0.05).

Velocity/Ration	**Low/Low**	**High/High**	**Routine/Low**	**Routine/High**
Tank weight (kg)	104.4 ± 6.0z	86.4 ± 3.5y	95.3 ± 3.4zy	108.9 ± 6.0z
Gain (kg)	96 ± 6.0z	78 ± 3.5y	86.9 ± 3.4zy	100.5 ± 6.0z
Gain (%)	1143 ± 72z	929 ± 42y	1034 ± 40zy	1196 ± 71z
FCR	1.05 ± 0.06z	2.00 ± 0.009x	1.16 ± 0.04z	1.56 ± 0.10y
Mortality (%)	0.3 ± 0.1	0.2 ± 0.0	0.5 ± 0.4	0.2 ± 0.0
[a] FCR = food fed / gain				

Table 2: Mean (±SE) individual fish total length, weight, specific growth rate (SGR[a]), and condition factor (K[b]) for juvenile rainbow trout reared in with one of four different treatments: Low/Low= continual low-intensity exercise/lower feed, High/High=continual high-intensity exercise/higher feed, Routine/Low=exercise routine with rest periods/lower feed, Routine/High=exercise routine/higher feed. Means with different letters in same row are significantly different (n=4; p<0.05).

Velocity/Ration	**Low/Low**	**High/High**	**Routine/Low**	**Routine/High**
Length (mm)	156 ± 2z	141 ± 2y	151 ± 3zy	156 ± 3z
Weight (g)	45.2 ± 2.9z	34.3 ± 1.7y	43.9 ± 2.6 zy	47.9 ± 3.9z
SGR	2.33 ± 0.05zy	2.16 ± 0.04y	2.25 ± 0.03zy	2.37 ± 0.05z
K	1.23 ± 0.01	1.22 ± 0.01	1.19 ± 0.03	1.25 ± 0.04
[a] SGR = 100 * (ln(end weight) – ln (start weight)) / (number of days)				
[b] K = 10^5 * (fish weight) / (fish length)^3				

Long-term constant exercise has been shown to be problematic, as was observed in the high exercise treatment in this study. The high feed conversion ratio and poor growth associated with the constant high velocity are likely a result of exercise fatigue, similar to that reported in other long-term exercise studies (Voorhees et al., 2018b, 2019). The results from the exercise routines which included rest intervals were clearly beneficial during hatchery rearing of rainbow trout.

In another study examining feed rations and exercise in rainbow trout, Parker and Barnes (2015) reported that constantlyexercised fish fed to satiationgrew similarly to unexercised fish receiving a restricted ration. Their results are not directly comparable to this study however, which did not include a reduced feeding rate. In addition, Parker and Barnes (2015) used velocities of 0.5, 1.5, and 3.0 BL s^{-1}, compared to the 4.4 BL s^{-1} used in this study. The faster water velocities (increased exercise intensity) in this study likely explains why growth was slower and feed conversion ratio higher than that reported by Parker and Barnes (2015). The initial swimming velocity used in this study was also much higher than the 1.0-2.0 BL s^{-1}recommended by other authors to maximize fish growth and feeding efficiency (Leon, 1986; Christiansen and Jobling, 1989; Davison, 1989, 1997; Jobling et al., 1993; Hammer ,1995; Liu et al., 2018).

The feed conversion ratio for both of the lower feed treatment groups are within the range reported previously for juvenile rainbow trout, but the ratio observed in the constant high velocity treatment is extremely poor (Jobling et al., 1993; Parker and Barnes, 2015; Kientz and Barnes,2016; Walker et al., 2016; Krebs et al., 2017, 2018; Kientz et al., 2018; Voorhees et al., 2018a, 2019, 2020; Crank et al., 2019; Huysman et al., 2019a, 2019b; White et al., 2019). Swimming speeds above 2.0 BL s^{-1}may increase feed consumption at the cost of feed efficiency (Davison and Goldspink, 1977; Leon, 1986; Jørgensen and Jobling, 1993; Christiansen and Jobling, 1989). The feed conversion ratio in the exercise routine, high feed, treatment isat the upper end of that reported for rainbow trout(Kientz and Barnes, 2016; Walker et al., 2016; Krebs et al., 2017; Kientz et al., 2018), including studies who exercised fish (Parker and Barnes, 2015).

Although the specific growth rate was statistically significantly lower in the high exercise, high feed fish, the difference is likely biologically insignificant. Voorhees et al. (2020) and Huysman et al. (2019a) observed similar specific growth rates in juvenile rainbow trout. However, others have reported much lower rates (Gregory and Wood, 1998; Ibarz et al., 2011; Jørgensen and Jobling ,1993; Liu et al., 2018; Voorhees et al., 2018a, 2018b, 2019).The disparities in the reported specific growth rates are likely due to difference in feed formulations, dietary ingredients, and genetic differences among rainbow trout strains.

In conclusion, this study shows that an exercise routine of alternating vigorous exercise with rest periods can be safely incorporated into the hatchery rearing of juvenile rainbow trout. This regime can provide the benefits of exercise without impeding hatchery growth or feeding efficiencies. However, it is unknown if these results are size or species specific. The effectsof using this exercise routine for a longer duration are also unknown. Lastly, this weekly repetition of exercise and rest is just one of many possible exercise routines, and other routines may, or may not, be more beneficial during fish rearing. Research is obviously needed to answer these questions.

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