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THE EFFECT OF PHOTOCYCLE ON SELF-CONTROL IN *BETTA SPLENDENS*

by

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Professional Paper

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The Effect of Photocycle on Self-Control in *Betta splendens*

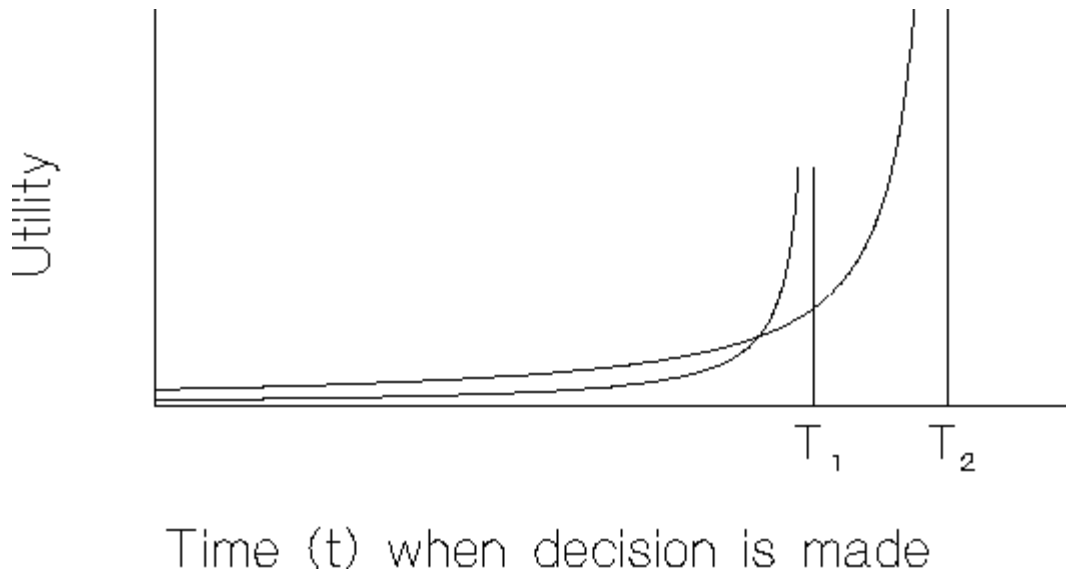
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The present study examined the effect of varying light cycles on self-control in Siamese fighting fish (*Betta splendens*). The subjects included 16 male *Betta splendens*, and instrumental choice trials were run. A subject began each trial in the start box and, when a guillotine divider door was lifted, entered one side of a divided terminus. The checkerboard side of the choice door represented either the smaller, more immediate choice (SS) or the larger, more delayed choice (LL). When the subject had entered one side of the goal box, the guillotine divider door was lowered and the subject was given food pellets, 1 pellet immediately or 3 pellets after 18 seconds, depending on which side of the choice door the subject entered. Prior to and during these trials, subjects experienced various levels of daily light exposure (12:12 h light-dark or 6:18 h light-dark). Fish exposed to 6 hours of light and 18 hours of darkness were expected to have more impulsive choices, while fish exposed to 12 hours of light and 12 hours of darkness were expected to exhibit more self-control choices. Contrary to the hypothesis, fish exposed to 6 hours of light and 18 hours of darkness exhibited more self-control choices than fish exposed to 12 hours of light and 12 hours of darkness.

The Effect of Photocycle on Self-Control Choice in *Betta Splendens*

Self-control and impulsiveness affect both humans and non-human animals in their daily lives; thus, it is important to understand the biological and neurological factors involved. Ainslie (1974, 1975) defined self-control as the preference for a larger but delayed reinforcer over a smaller, immediate reinforcer, and impulsiveness as the opposite, when the organism's preference switches to a smaller, more immediate reinforcer over a larger but delayed reinforcer. For example, if a person was given the choice between receiving \$10 immediately or receiving \$100 after a year, her choice would either show impulsiveness or self-control. If she chose to receive the smaller reward, \$10, immediately, she would be exhibiting impulsiveness, and if she chose to wait a year to receive the larger reward, \$100, she would be exhibiting self-control.

Ainslie (1975) proposed a model to explain why humans act impulsively when it should be apparent that a more beneficial but delayed reinforcer is the better option in a situation. He reviewed past literature on self-control and how self-control plays a role in many areas of human activity including economics, behavioral psychology and psychiatry. As the delay before a reward is delivered increases from the time the individual makes a choice, it appears that impulsiveness increases as well. Ainslie examined this phenomenon in order to explain the apparent counter-intuitiveness of impulsive choices. Ainslie said that delay reduces the value of an option, and much of the research he reviewed on this devaluation points to the possibility of a hyperbolic discounting function. Below is a visual depiction of hyperbolic discounting:



(Image from <http://www.psych.upenn.edu/~baron/900/p444.gif>)

In other words, at time 1, option B is preferred because it has a higher apparent value. At time 2, however, the preference reverses because option A now was the higher apparent value.

Further explanation as to why individuals make impulsive choices can be found in Herrnstein's collection of papers, *The Matching Law: Papers in Psychology and Economics*, edited by Rachlin and Laibson (1961). Prelec and Herrnstein (1997) examined the question of why individuals make impulsive choices even if those choices are suboptimal. Prelec and Herrnstein argued that individuals engage in cost-benefit analyses when making decisions. However, problems are encountered when making such an analysis and prevent an individual from choosing the better of two alternatives. One such problem is the temporal mismatch, when a time interval separates the cost and the benefit. In other words, when the cost of a choice does not immediately occur, even if the cost is high, an individual will be more likely to choose that alternative if the benefit is immediately present. This relates to self-control in that an individual will act impulsively, most likely choosing the less valuable reward, if the benefit of acting

impulsively is immediately available and the cost is not, or if the benefit of exhibiting self-control is not immediately present. For example, a smoker can either choose to act impulsively or exhibit self-control when he or she has the craving to smoke a cigarette. Choosing to smoke will satisfy the nicotine craving immediately, and even though the cost of smoking (e.g. lung problems, etc.) is high, the smoker may ignore this cost because it does not occur at or before the time that the immediate benefit occurs. Choosing to exhibit self-control and not smoke the cigarette is the better choice for the smoker's long-term health, but the long-term health benefits do not occur immediately and the cost of an increased desire to smoke and the side effects of withdrawal are high and immediately felt by the smoker.

Rachlin (2000) examined the reasons humans exhibit impulsivity when self-control is clearly the more valuable option in many situations. Alcoholics, overeaters, and smokers are examples of individuals who choose to be impulsive to receive immediate gratification or rewards when choosing to exhibit self-control would be the more valuable option. Individuals evaluate choices based on their value, and when an option, even if it is clearly the less valuable alternative, is immediately available, the individual will desire this alternative and choose it over a more valuable, albeit delayed, reward.

Past research in the area of self-control using human subjects has shown that choice behavior can be manipulated. Tobin and Logue (1994) examined studies which used 3-year old, 5-year old and adult humans in an experiment with a choice paradigm that provided subjects with a choice between a smaller but immediate reinforcer and a larger but delayed reinforcer. With children, the reward was food and with adults, the reward was either food or points that could be exchanged for money. Tobin and Logue found that 5-year old children showed more self-control than 3-year old children, and adults showed more self-control when the reward was

points for money rather than food. These findings revealed that age differences must be accounted for when examining self-control in human subjects.

In her 1998 study, Logue explored the potential applications of self-control research for administrators, particularly those administrators who worked in higher education. She looked at how impulsive decisions by administrators hurt their institutions in the long-term future. One example she used was that of hiring decisions by administrators at universities. She examined the possible reasons for impulsive and poor decisions made in this area by administrators, and had several explanations for such behavior. One possibility is the idea that the unselected option is less valuable because the reward is delayed (larger-later reinforcement), as the result of a failure in the future-time perspective, or an individual's ability to aggregate the value of a series of events that extends far into the future. The failure of the future-time perspective can account for impulsive behavior because the affected individual cannot accurately conceptualize how a delayed reward will be more beneficial in a future time period than an immediate reward would be in the present time period. As a result, Logue suggested strategies for academic administrators to extend their time perspective. For example, when considering nontenured, tenure-track faculty, Logue suggests that administrators should educate these faculty members on the long-term benefits of balancing time devoted to their research with time spent teaching because teaching has short-term benefits while devoting time to research has the long-term benefit of helping the faculty member receive tenure. A more broad suggestion given by Logue is that administrators should take into account the long-term consequences of their actions with the aim that this suggestion (along with attending to the evidence from research that supports it) will decrease impulsive behavior by administrators.

The study of self-control in non-human subjects appears to have a very different framework due to the differences in behavioral observation when researching non-human animals as opposed to human subjects. Ainslie (1974) examined self-control in pigeons. He gave subjects a choice between a smaller-sooner (i.e. smaller but immediate) reward and a larger-later (i.e. larger but delayed) reward, with the pecking of a key providing the smaller-sooner reward and not pecking the key providing the larger-later reward. When pecking a different-colored key prevented the smaller-sooner reward and only provided the larger-later reward, some subjects consistently chose this option, showing that pigeons have the ability to learn to exhibit self-control over time. In 1994, Chelonis, et. al examined this phenomenon in pigeons as well. In their study, Chelonis, et. al manipulated the delay of reward for those subjects which chose the self-control option of a larger later reward. He found that gradually increasing delays of the larger reward increased self-control in the pigeons. Finally, Logue, et. al, (1988) found that pigeons were impulsive when conditions of food-deprivation, consecutive nature of the trials, and frequency of reinforcement were manipulated.

Tobin, et. al (1996) examined self-control in long-tailed macaques monkeys (*Macaca fascicularis*). In one experiment, the delay for reinforcement with larger-later rewards was held constant, and, in this experiment, subjects showed significant self-control in choice behavior. In a second experiment, this time delay was manipulated in order to desensitize the subjects to the difference between immediate and delayed reinforcement, and researchers found that the subjects were more sensitive to variation in reinforcer amount as a result. In both experiments, researchers found that long-tailed macaques monkeys exhibited self-control.

Jackson and Hackenberg (1996) examined the effect of token reinforcement and choice on self-control in pigeons. Subjects were exposed to light-emitting diodes (LEDs) as a form of

token reinforcement, and subjects could choose between 1 and 3 LEDs which could be exchanged for 2 seconds of access to food in post-trial periods. In the first experiment, subjects preferred immediate exposure to 1 LED; however, there was a difference in the delay period between the choice and the exchange period between the two alternatives. In the second experiment, this difference was eliminated and subjects preferred the delayed 3 LEDs. In the third experiment, subjects preferred the option that resulted in a greater amount of food if the choices produced more LEDs as well. In the fourth experiment, subjects preferred the delayed 3 LEDs when the delay periods to the exchange were equal between 1 and 3 LEDs, but preference changed to 1 LED when the delay period between the choice and the exchange period was shorter for 1 LED. These results had several implications. One implication is that the delay between choice and reinforcement has a greater effect on choice behavior than does the delay before token reinforcement is presented. A second implication is that token reinforcements can function as conditioned reinforcers, and a third implication is that differences across species in self-control studies (namely, pigeons and humans) could have been the result of using token reinforcers with human subjects and food reinforcers with pigeons.

Abeyesinghe, et. al (2004) examined the possibility of self-control in the domestic hens (*Gallus gallus domesticus*). Subjects were given a two-key operant task to choose between a smaller-sooner reinforcer and a larger-later reinforcer, and then were given a two-choice return maze (TCRM) task. One group of subjects was given the operant task first and then the TCRM task, and another group of subjects performed the task in the reverse order. Subjects appeared to be unable to discriminate between a 2-second delay for 3 seconds of food exposure and a 6-second delay for 7 seconds of food exposure in the TCRM even though they showed impulsiveness in the operant task. One possibility considered by Abeyesinghe, et. al was that

subjects were reacting to the *expected* delay between feed access time and actual food intake. When discussing these results, the authors indicated that the self-control paradigm has not been used to study cognition and thus this explanation did not have support in past literature. A second experiment was designed to test the possibility of a cognitive explanation. In a second experiment, new subjects were given a choice between a 2-s delay to 3 s of food and either a 6-s delay to 7 s of food or a 22-s delay to 22 s of food (a standard self-control option). Subjects showed significant self-control with the 22-s delay option present, and the researchers explained this behavior through temporal discounting, which occurs when the uncertainty of delay results in a perceived devaluation of the larger-later reward. The results from the second experiment showed that a cognitive explanation was not likely, but rather that hyperbolic discounting and temporal discounting were more likely to explain such behavior.

Studying self-control in non-human subjects has revealed interesting findings that support the argument that several species other than humans can differentiate and choose between a smaller-sooner reinforcer and a larger-later reinforcer. Studies in self-control behavior using pigeons (Ainslie, 1974; Chelonis, 1994; Logue, et. al, 1988; Jackson & Hackenberg, 1996) and domestic hens (Abeyesinghe, et. al, 2004) have shown that this ability exists in these species, and Tobin, et. al (1996) found that long-tailed macaques monkeys exhibit the ability to show self-control in choice behavior as well.

Neurochemistry of Self-Control

While there is a rich literature regarding environmental variables that modulate self-control and impulsivity, less is known about the underlying neurochemistry involved. However, research on impulsiveness in both humans and non-human animals is suggestive of a link

between self-control (and its counterpart impulsivity) and serotonin (Fitzgerald, 2011, Wolf & Leander, 2002; Bari, et al, 2010 & Cools, et. al, 2007).

Fitzgerald (2011) proposed that two neurotransmitters, serotonin and norepinephrine, have opposing effects on the prefrontal cortex in: serotonin activating this region, and norepinephrine deactivating this region. He argued that the prefrontal cortex has several “executive” functions, one being the management of impulsive behavior. In his discussion on the relationship between serotonin (5-HT) and impulsivity, Fitzgerald argued that decreased serotonin results in increased impulsivity (Roggenbach et al, 2002; Spreux-Varoquaux et al, 2001; Virkkunen et al, 1995; Linnoila et al, 1983 & Fishbein et al, 1989). He also argued that there is a relationship between selective serotonin reuptake inhibitors and decreased impulsivity (Wolff & Leander, 2002; Evenden, 1998; Homberg et al, 2007; Rutz et al, 2006; Brunner & Hen, 1997; Scarce-Levie et al, 1999; Pattij et al, 2003; Winstanley et al, 2004 & Fletcher et al, 2007).

Additional research has examined the relationship between SSRIs and impulsive behavior in pigeons. Wolff and Leander (2002) used an adjustable delay schedule in which pigeons were trained to choose between an immediate, brief access to a reward and a delayed, longer access to a reward. Results showed that pigeons given chronic (as opposed to acute) injections of several SSRIs chose to increase the delay interval (in the adjustable delay schedule), demonstrating a greater sensitivity to reward amount or a decrease in impulsivity.

In addition to research that has examined the role that serotonin plays in impulsive behavior in pigeons (Wolff & Leander, 2002), research has been done examining the effect of serotonin on sensitivity to reward and negative feedback in rats. Bari et al (2010) conducted three experiments where they manipulated 5-HT levels and examined the effect of these manipulations on cognitive flexibility, reward sensitivity, and reaction to negative feedback in an operant two-

choice probabilistic reversal learning task. The researchers noted that this type of task allows the subject to switch a response after receiving negative feedback (or lack of reward) or to maintain a response after receiving continuous positive feedback (reward). Because of this ability of the subject to make this choice and the ability of the researcher to measure the conditional probability of the subject making such a switch, it is an ideal task for measuring and monitoring changes in reward and negative feedback sensitivity. In the first experiment, the subjects were given three acute injections of the SSRI citalopram, and were tested using the probabilistic reversal learning (PRL) task. Because the levels of citalopram used in Experiment 1 did not significantly affect performance on the PRL task, researchers tested the effects of “repeated and sub-chronic administration” of the same SSRI on task performance in Experiment 2. In Experiment 3, researchers surgically depleted 5-HT levels in the subjects’ forebrains. Performance on the PRL task was tested after this manipulation. The results of Experiments 2 and 3 demonstrated that acute manipulations of the 5-HT system produced more sensitivity to negative feedback, while longer-lasting treatments (manipulations) to the 5-HT system produced more sensitivity to reward.

Cools, et al (2007) reviewed research examining the role of 5-HT in disorders like depression and anxiety, and behavioral processes such as impulse control disorders. One topic they discussed at length was the role that 5-HT plays in several impulse control disorders in humans. Research supports the argument that 5-HT plays a role in impulse control disorders (such as mania, aggression as a result of alcoholism, and suicide) in that 5-HT levels are reduced in patients with these disorders (Evenden, 1999; Coccaro, 1989; Linnoila & Virkkunen, 1992 & Thakore et al, 1996). The authors noted that these findings are in line with additional research that demonstrates that 5-HT mediates behavioral inhibition (or self-control) in rats (Lister et al,

1996; Harrison et al, 1997 & Winstanley et al, 2003). These findings support the hypotheses that serotonin plays a role in impulsivity and self-control in behavior.

Photocycle and Serotonin

In addition to the extensive research on the relationship between serotonin and self-control, research has been conducted examining the effect of environmental stimuli on the release of serotonin in the brain. One possible environmental variable associated with serotonin level is exposure to light.

Knoch, et. al (2004) examined the effect of constant light exposure on serotonin and circadian rhythms. Syrian hamsters were exposed to constant light for 1 to 3 days. This constant light exposure suppresses locomotor activity and reduces the daily rhythm of the suprachiasmatic nucleus (SCN) and associated 5-HT release. A 5-HT agonist, 8-OH-DAPT, was given to subjects who were exposed to constant light. Knoch, et. al found that constant exposure to light supersensitized the 5-HT receptor in the brain, and the 5-HT agonist was more active as a result. These findings suggest that serotonin levels were significantly affected by the constant light exposure.

Ferraro and Steger (1990) also examined the effect of light exposure on serotonin levels in Syrian hamsters; however, they focused on whether 5-HT levels were driven by circadian rhythms or by external factors, namely light. Subjects were exposed to one of four light conditions over a period of 10 weeks. Locomotor activity was measured to determine circadian times for each animal and 5-HT levels were measured from the medial basal hypothalamus, the anterior hypothalamus, and the olfactory bulbs. Researchers found that there was no significant time of day effect in hamsters exposed to total light or total darkness conditions; rather, 5-HT levels appeared to change in response to environmental time cues (in this case, light).

Winder, et al (2008) examined the effect of fluoxetine (FLX, a common SSRI) on serotonin-related activity in sheepshead minnows. Researchers noted that all initial and subsequent doses of FLX, as well as the removal of fish, were carried out as close as possible to the dark-light transition in the 16:8 light-dark cycle used throughout the experiment. This was done because researchers noted that the highest levels of serotonergic activity occurred close to this transition period, demonstrating the effect of the light cycle on serotonin levels in the subjects.

In addition to research on light exposure and serotonin in non-human animals (Knoch, et al, 2004; Ferraro & Steger, 1990; Winder, et al, 2008), there has also been research demonstrating this relationship in humans. Epperson, et al (2004) treated 10 pregnant women diagnosed with major depressive disorder using bright light therapy, with half of the subjects being randomly assigned to the bright light condition (7000 lux) and half of the subjects being randomly assigned to the placebo (dim light, 500 lux) condition. Researchers found that subjects exposed to the bright light condition over a 10 week period showed the most improvement in their symptoms, demonstrating that light therapy may be an effective treatment for such disorders as depression.

While some past research has examined the possible relationship between light exposure and depression (Epperson, et al, 2004), other research has examined more directly the effect of light exposure on serotonin levels. Lambert, et al (2002) examined the relationship between sunlight exposure and serotonin levels in male humans. Researchers sampled blood from the brains of healthy male participants, and examined the relationship between serotonin and metabolite levels and the weather conditions and seasons during which the samples were taken. Not only did researchers find that turnover of serotonin was lowest in winter months (when

presumably, sunlight exposure for individuals is at its lowest), but they also found that serotonin production was directly related to the duration of sunlight.

Self-control has been studied and demonstrated in both humans (Ainslie, 1975; Rachlin, 2000; Tobin & Logue, 1994; Logue, 1998) and non-human animals (Ainslie, 1974; Chelonis, et al, 1994; Logue, et. al, 1988; Jackson & Hackenberg, 1996; Abeyesinghe, et. al, 2004; Tobin, et al, 1996). The underlying neurochemistry of self-control has also been examined by several researchers, and this research has supported the idea that serotonin plays a significant role in self-control (Fitzgerald, 2011, Wolf & Leander, 2002; Bari, et al, 2010 & Cools, et. al, 2007). While there has been substantial research done in the area of self-control, and still more research done examining the neurochemistry of self-control, there is less research that has been conducted examining the effect of light exposure on serotonin; however, the research that has been conducted supports a relationship between light and serotonin (Knoch, et al, 2004; Ferraro, et al 1990; Winder, et al, 2008; Epperson, et al, 2004; Lambert, et al, 2002).

Thus, the present study examined the effect of light exposure on self-control in Siamese fighting fish. It was hypothesized that the 12:12 light-dark group would exhibit more self-control choices than the 6:18 light-dark group.

Method

Subjects

The subjects included 16 male Siamese fighting fish (*Betta splendens*) purchased from a local pet store. They were housed in tanks containing de-chlorinated water kept at a constant temperature of 25 degrees Celsius. Depending on the group assignment, the light cycle was either a 12:12 h light-dark cycle or a 6:18 h light-dark cycle. Subjects in the 12:12 h light-dark

group were exposed to light from 6:00 AM to 6:00 PM each day. Subjects in the 6:18 h light-dark group were exposed to light from 7:30 AM to 1:30 PM each day. Subjects were fed a daily diet consisting of nine Betta baby pellets (Hikari, Himeji, Japan). During choice trial days, subjects were given food for completing the choice task which supplemented their necessary daily food requirement. All subjects were treated in accordance with the ethical principles regarding animal treatment set forth by the American Psychological Association (APA, 2002).

Materials

Each fish was housed in a 12-gallon tank that contained a modified T-maze (see Figure 1 for diagram of the apparatus). The T-maze was submerged in a 65 x 45 x 15 cm tank and contained approximately 8 gallons of de-chlorinated water. Each tank was equipped with a gravel base, a tank heater and a temperature gauge. The discriminative stimulus consisted of contact paper printed with a blue and white checkerboard pattern. The contact paper was attached to the inside of one choice arm and the corresponding choice door. The other choice arm and corresponding choice door were a solid black color.

Procedure

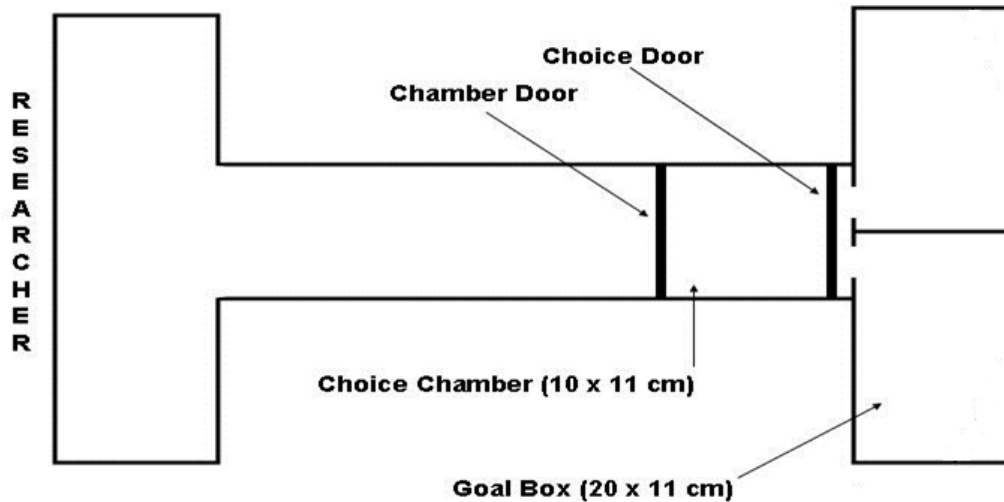
Subjects were housed in the T-mazes and completed two trials at 8:00 AM, 9:00 AM, and 10:00 AM for a total of 6 trials each day. The 8:00 AM trials consisted of two forced choice trials. During the forced choice trials only one choice option was made available. The alternate choice option was available on the next consecutive trial. The daily order of forced choice options was assigned randomly without replacement. The 9:00 AM and 10:00 AM consisted of four free choice trials, two during each hour. During the free choice trials, both choice options were made available. Subjects were randomly assigned to the groups, with 8 subjects in each group. The discriminative stimulus was counterbalanced across subjects such that the

checkerboard pattern was associated with the larger reward, longer delay (LL) option for half of the subjects in each group and the smaller reward, shorter delay (SS) option for the other half of the subjects in each group. Additionally, the discriminative stimulus was pseudo-randomly assigned each day to one side of the terminus such that the discriminative stimulus was not assigned to the same side of the terminus for more than two consecutive days.

At the beginning of each trial, the subject swam into the choice box and the choice box guillotine door was lowered into place. Once the choice doors and corresponding choice arms were in place in the goal box, the guillotine choice door was raised, beginning the trial and the choice box latency (response latency) measure. Once the subject swam through a choice door into one of the goal boxes, the choice latency ended and the guillotine door to the goal box was lowered. The subject was then given either 1 pellet immediately after making a choice or 3 pellets after 18 s, depending on the side of the terminus the subject entered. The subject remained in the goal box until all pellets of food were eaten. The subject was then returned to the choice box and remained there until the next trial began. Choice and choice latency were recorded for each trial. When a subject completed both trials, all doors were removed and the subject was allowed to swim throughout the T-maze until the next set of trials.

Figure 1

Choice apparatus



Results

The total number of times the subject chose the LL option was summed across the last five days and divided by five to produce a proportion of LL choices. A one-sample *t*-test was conducted on the number of LL choices for each group (see table 1). The Control group (12L:12D) failed to show a preference for the LL option ($t(7)=0.6432$, $p=0.54$, $d=0.23$), and the Experimental group (6L:18D) group also failed to show a preference for the LL option ($t(7)=1.55$, $p=0.16$, $d=0.55$). A two-sample *t*-test was conducted on the number of LL choices comparing the Control and Experimental groups. The Experimental group (6L:18D) did not demonstrate a significantly higher proportion of LL choices compared to the Control group ($t(14)=-1.48$, $p=0.16$, $d=0.74$).

TABLE 1

DESCRIPTIVE STATISTICS FOR PROPORTION OF LL CHOICES FOR EACH GROUP

	<u>Control Group (12L:12D)</u>	<u>Dark Group (6L:18D)</u>
<i>M</i>	0.44	0.63
<i>SD</i>	0.27	0.23
<i>n</i>	8	8
*Effect size, <i>d</i>	0.23	0.55

Discussion

In the present study, subjects were expected to have differing levels of self-control depending on how much they were exposed to light each day. One group was exposed to a 12:12 light-dark cycle each day, while the second group was exposed to a 6:18 light-dark cycle each day, in order to examine whether levels of self-control were dependent on the duration of exposure to light. Subjects experiencing a longer period of light exposure were expected to make more self-control choices than subjects experiencing a shorter period of light exposure.

The results from this study are inconsistent with past results from research on light exposure and self-control. Subjects experiencing a longer period of light exposure did not show a preference for self-control, while subjects experiencing a shorter period of light exposure did not show a significant preference for self-control, but did demonstrate a shift towards more self-control than the control group. Research examining the effect of light exposure on serotonin in other species (Knoch, 2004; Ferraro & Steger, 1990; Winder, et al, 2008) has found that while photocycle does have an impact on serotonin levels, it can also impact the daily rhythms for animals when the light cycle is significantly altered. Thus, it could be inferred from the findings of the current experiment that subjects experiencing a lower amount of daily light (6:18 light-dark cycle) had daily cycles that were disrupted as a result.

While the results do not indicate that a decrease in light exposure resulted in a decrease in self-control (but rather, an increase in self-control, albeit a smaller one), it nevertheless indicates that a relationship could exist between light exposure and self-control. There are several plausible explanations that can be considered when attempting to explain the unpredicted direction of these findings. First, there has been no previous research examining the possible correlates between light, serotonin, and self-control in Siamese fighting fish. Therefore, it is possible that the effect of light on serotonin in this species is different than the effect that has been seen in other species. Previous research done with a similar species, the sheephead minnow, supports this argument (Winder, et. al, 2008). Winder's study demonstrated a relationship between light and serotonin, but the direction of this relationship was not as clear, supporting the idea that light may affect aquatic species differently than non-aquatic species.

Secondly, is it possible that light impacts neurological systems in addition to serotonin in Siamese fighting fish, and this is the reason for the change in self-control. Because the present study did not involve direct measurement of serotonin, but rather observation of a possible behavioral manifestation of changes in serotonin, it is possible that light exposure impacted a different physiological process which still resulted in a change in behavior. Past research has suggested that norepinephrine is impacted by light exposure. Fitzgerald (2011) reviewed previous research done with humans, rats, and monkeys (Oquendo & Mann, 2000; Russell, 2002; Fairbanks, et. al, 1999) and found that an increase in norepinephrine deactivated the prefrontal cortex, which is responsible for managing impulsive behavior; thus, an increase in norepinephrine could increase impulsive behavior, and a decrease in norepinephrine could decrease impulsive behavior (or increase self-control). Based on these findings, it could be

argued that light exposure decreases norepinephrine activity in Siamese fighting fish, resulting in an increase in self-control.

There are a number of limitations to the present study that may address why the results are not consistent with existing literature. While some past research has examined serotonin levels in subjects through specific physiological measurements of the brain such as serotonin metabolites, the present study observed changes in serotonin levels through behavior manifestations believed to be associated with these changes; namely, a change in self-control (Fitzgerald, 2011, Wolf & Leander, 2002; Bari, et al, 2010 & Cools, et. al, 2007). Due to the nature of the experimental preparation and other constraints, the present study could not directly observe changes in chemical levels in the brains of the subjects and could only infer these changes through behavioral observations. Additionally, the small sample size of the present study makes it difficult to determine whether or not the findings are unique to this sample. It is possible that an effect was not seen due to the limited number of subjects.

There are several possible implications of these findings. One implication is that environment has a greater effect on an organism's choice behavior than one might have previously thought. Past research suggests that self-control can be influenced by the type of reward (Tobin & Logue, 1994), perceived value of the reward (Rachlin, 2000; Logue, 1998), and delay to reward (Ainslie, 1975; Prelec & Herrnstein, 1997; Chelonis, et. al, 1994; Tobin, et. al, 1996). The findings of the present study suggest that self-control could also be influenced by environment factors (e.g. light exposure) unrelated to reward type or delay to reward. By changing the environmental conditions and observing a slight shift in self-control in choice behavior, the present study supports this idea. Another implication of these findings is an increased understanding of the constructs of self-control and impulsivity. Self-control and

impulsivity have been examined in humans (Ainslie, 1975; Prelec & Herrnstein, 1997; Rachlin, 2000; Tobin & Logue, 1994; Logue, 1998) as well as several non-human animal species (Ainslie, 1974; Chelonis, 1994; Logue, et. al, 1988; Jackson & Hackenberg, 1996; Abeyesinghe, et. al, 2004; Tobin, et. al, 2006), and the present study provides a better understanding of this behavioral construct in Siamese fighting fish (*Betta splendens*). Understanding self-control and impulsivity as constructs of behavior in species other than humans will contribute to the overall understanding of behavior across species.

Future research in this area of study could take one of several paths. Future research should examine this choice paradigm under an 18:6 light-dark cycle in order to compare these results to the findings from the 6:18 light-dark cycle group. Future studies could also have the researcher making more subtle changes in light exposure in order to examine whether self-control is consistently seen more often in shorter periods of light exposure (e.g. any daily light exposure less than 12 hours) or not. For example, the difference between a 12:12 light-dark cycle and a 10:14 light-dark cycle (or 14:10 light-dark cycle) could show slight differences in choice behavior in *Betta splendens*. While the present study aimed to find significant differences in choice behavior as a result of substantially different times of light exposure, future research could examine more subtle manipulations to see if more subtle changes in behavior would result. Future research could also aim to directly measure serotonin levels in the brains of *Betta splendens*. While this process is more complex and has more constraints than observing behavioral manifestations of certain neurotransmitters at work, future studies could attempt to examine this relationship between serotonin and self-control more closely through indirect or direct measurement of serotonin levels in the subjects' brains.

The phenomenon of self-control in both humans and non-human animals is one that has been examined substantially and the literature provides strong evidence for the argument that this phenomenon not only exists but that choice behavior can be manipulated. When given the choice between a smaller, more immediate reward and a larger but delayed reward, an individual should choose the more valuable reward even when a delay is present. However, organisms frequently display impulsive behavior when given this choice, and Ainslie (1975) presented the hyperbolic discounting theory to explain this counter-intuitive response. His theory provides the explanation that delay of a reward devalues the option and organisms act impulsively as a result. Another explanation for impulsive choice behavior is a biological one; namely, that the neurotransmitter serotonin is responsible for impulsive behavior in humans and some non-human animals species. The next step in this exploration would be to examine environmental factors that affect serotonin levels, and past research has in fact examined the effect of light exposure on serotonin levels in hamsters. Because the evidence in the literature for the relationship between light and serotonin is not as strong, further research should continue to be done in this area. Because light has a possible effect on serotonin, and serotonin appears to have a strong effect on impulsivity (and conversely, self-control), the present study aimed to find evidence supporting a relationship between light exposure and self-control. While the results did not indicate that light exposure had a strong impact on self-control, the present study was attempting to expand on previous research findings in a different species, Siamese fighting fish; therefore, further research should be done exploring the possibility of an effect existing in this species.

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