Mouse Sleep Deprivation Device

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Abstract

Dr. Rama Maganti is currently researching the effects of sleep deprivation in epileptic mice and how this impacts abilities to learn and retain memory. To do so, he is currently using an industry standard sleep deprivation cage which features a flexible plastic propeller on a circular motor which rotates and delivers stimulus to keep the mouse awake. However, the device itself is rather fragile and expensive, and the accompanying software is very limited in terms of how the cage can be programmed to operate. Thus, our design team has been tasked with developing a new and more complex program and to possibly redesign the cage if need be. Between three design alternatives, our design team has decided to improve upon the propeller concept in addition to developing software which will allow for far greater degrees of control of the device during experimental trials.

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Problem Statement

Dr. Rama Maganti intends to study the effects of sleep deprivation in pubertal and epileptic mice and how sleep deprivation affects learning and memory. To accomplish this research, a device is needed that can awaken mice as they are beginning to fall asleep. The device should be easily programmable by a user and should monitor the mice, deliver a non-painful stimulus to awaken the mice, and allow arbitrary control of this stimulus.

More specifically, this device should be operable for 6 hours to 2 weeks at a time. This device must ensure that the mice do not fall asleep even for 30 seconds during the time periods of interest specified by the client, and should be able to be taken apart to be cleaned. It should also allow mouse access to food, and should not injure the mouse in any way. The device should be able to be programmed by the user for experiment customization and any programs created should be able to be run on multiple mouse cages at the same time.

Project Motivation

Medical Motivation

Epilepsy is a broad-scope diagnosis that indicates the presence of seizures. A person is considered to have epilepsy after they have had two or more unprovoked seizures. This disease affects 50 million people worldwide and 2.2 million Americans. (1) Despite the high prevalence of the disease, there is still much left to be determined in terms of the causes, triggers, and exact effects of epileptic activity. For example, in 70% of diagnosed cases of epilepsy, the cause of epileptic activity is unknown. Furthermore, the Epilepsy Foundation states that "epilepsy is among the least understood of major chronic medical conditions." (2)

It is also important to note that epilepsy primarily affects children and the elderly, and in some cases, the epileptic seizures cannot be controlled with any treatment methods currently available. Within the United States, of the more than 300,000 children under the age of 15 affected by epilepsy, 90,000 of them are affected by seizures that cannot be controlled with medication. (1) Additionally, more than 570,000 cases of epilepsy have been reported in adults' aged 65 and over. (1)

It is due to these staggering numbers that research on epilepsy has continued to grow in recent years. Through scientific research, scientists and medical professionals can gain a better understanding of this disease as well as its causes and effects, and using this knowledge, researchers can better develop tools to properly manage epilepsy symptoms.

Product Motivation

There are many commercial sleep deprivation cages currently available for use with mice. These are explained in greater detail in the current products section below. However, these devices (especially the device currently in use by the client) are lacking in several areas. First, these devices are often built with less than ideal materials. The plastics and motors used in the creation of these devices are often flimsy, and, in the case of the current client device, the adhesives used to hold the pieces of the device together are not very strong. An example of the current client product and experimental setup can be seen in figure 1 below. Second, the software on which these devices operate is often limited in the scope of customization. Though this was not able to be researched in other currently available products, the current client product can only be programmed for one session at a time. This means that each time the clients want to incorporate a rest period in their device and then later start the device again, someone must come into the lab to manually begin the new session. This is cumbersome, especially if a new session needs to be started, for example, in the middle of the night. The current software also does not allow control of speed or directionality of the propeller. Furthermore, this software acts as a completely closed black box. The software cannot be changed and is only allowed to operate on one computer. Additionally, the coding mechanisms of the software are often not known.

Another way in which current devices are undesirable in is their compatibility with other devices and the ability to be expanded for other uses. The current client device is only compatible with other products from the same brand. This can give rise to problem such as another brand may offer a more optimal product (for example, a more efficient food dispenser) that is incompatible with other current devices. Finally, as the market for rodent sleep deprivation devices is a niche market, current products can range anywhere from 3,000 to 7,000 dollars (USD) (3, 4, 5).

Because of these reasons it is important to build a product that eliminates some of the flaws in current designs. This means that the prototype should be created of strong materials, manufactured in a sturdy manner, be able to be manipulated in any way that the client desires, and be compatible with other devices and more devices of the same type. This prototype should also be low cost.

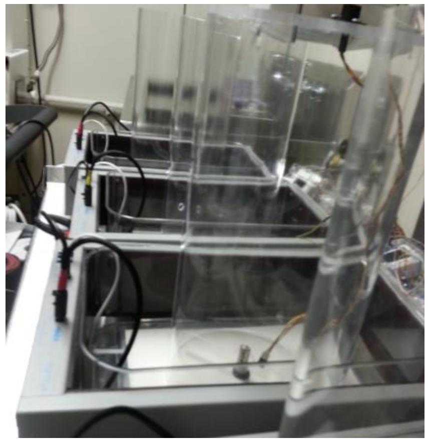

Figure 1: Current client experimental setup – Current client devices are unsatisfactory in several ways. This project aims to eliminate some of the fundamental flaws in currently available mice sleep deprivation devices.

Background

Dr. Rama Maganti is a professor in the University of Wisconsin-Madison department of Neurology studying the relationship between sleep loss, epilepsy, and memory. To reiterate, epilepsy stems from a series of neurophysiological disorders and is characterized by spontaneous seizures. The diagnosis of epilepsy encompasses a very wide range of seizure types and causes, but all diagnoses united by the common attribute of synchronous neuronal activity that is abnormal or excessive (6).

It has been seen in past research that there is a physiological relationship between sleep loss and a decrease in ability to code and store long-term memory (7,8,9). When individuals learn, long-term storage of this memory occurs when the brain "rehearses" the information to be learned by stimulating and re-stimulating neural pathways associated with that memory in the hippocampus. Typically, the brain accomplishes these actions during sleep (7). It has been suggested in scientific literature that the inverse correlation between sleep and memory may be caused by a number of different factors, including deficiencies in microtubule proteins, adenosine buildup in the hippocampus, or in increase in oxidative stress in the brain. However, all three of these factors have been shown to have a detrimental effect on memory in mice or rats (7,8,9). Therefore, the exact mechanism for the relationships between memory and seizures is not well understood.

Similarly, the relationship between sleep loss and seizures has been studied but is not currently well understood. An increase in epileptic activity has been shown to occur with sleep deprivation in both mice and humans, but scientists questions the mechanism for this relation (10). In fact, researchers are even unsure whether or not the increase in seizures is the cause or result of sleep deprivation (10). However, it has been seen that sleep loss potentiates damage in brain cells that are already hurt by epilepsy (11). Therefore, it is important to better understand how sleep loss, memory, and epileptic activity are interrelated in order to better treat individuals who experience problems associated with memory and epilepsy.

Dr. Rama Maganti and his research assistant Eli Wallace are investigating the relationship between sleep loss, memory, and epilepsy in order to develop a better understanding of the biological origins associated with increased epileptic activity associated with sleep loss. They would also like to develop a quantifiable model showing how and to what degree sleep loss affects memory in epileptic mice as well as how sleep loss affects epileptic activity. The long-term objectives of their research are to apply any correlations between sleep loss and epilepsy found in mice and apply these relations to treating epilepsy in human individuals.

To meet these goals, mice that are predisposed to epileptic seizures are bred for experimentation. They are then subjected to a certain degree of sleep deprivation, and the mice's change in behavior with regard to memory driven tasks is observed. The data is then compared with that of sleep deprived non-epileptic mice along with their non-sleep deprived peers. The mice, which have sleep cycles as short as 30 – 90 seconds, are deprived of sleep for 6 hours to up to 3 weeks at a time using a physical stimulus to awaken them. This research is being used to simulate sleep apnea and chronic sleep restriction due to working 2nd or 3rd shift in industry. The apparatus discussed in this report provides a means to simulate these conditions effectively and repeatedly in animal models.

Dr. Maganti and Eli Wallace currently use a "smart" rodent cage for their experiments from a product manufacturer named AfaSci (12). This product allows tracking of position, movement, active time, and speed of the mice. Additionally, they have bought several add-ons for his products that can induce sleep deprivation in the experimental mice by means of a small, flexible plastic propeller that turns with the frequency desired by the consumer. The propeller is flexible enough so that it will not hurt the mouse but will provide a stimulus to wake it up.

Product Specifications

The final product must contain stable housing for one mouse. This housing must be able to provide access to food and water and must be able to fit in a 20 by 35 cm area. The product should have an intuitive user interface for programing speed, frequency, and duration of mouse stimulus and must be able to operate continuously for up to two weeks.

The device will be used on a weekly or semi-weekly basis, and will house a mouse weighing 25-50 g. Because of the intended use of the device, all materials and processes used must be able to be approved by the IACUC and the cage must be transparent in order to be able to see the mouse inside it. Additionally, materials should be chosen to fit the following specifications: first, the device will be operating continuously for up to 2 weeks at a time, and therefore considerations must be made so that the device does not overheat. Second, the stimulus delivered by the device, due to the length of the experiment, may be delivered several hundred to several thousand times during a single use (720-40,000, or, once every thirty seconds for 6 hours up to 2 weeks), and this must be considered when choosing materials for a motor and circuitry. Third, materials may come into contact with mice bodily fluids, and this must be considered when choosing materials. Finally, the device should be able to conduct experiments on a weekly or semi-weekly basis for at least two years.

Mice should not be able to sleep at all over the course of the experiment. While scientific literature has shown that 100% sleep prevention is nearly impossible (13), the device should be able to prevent sleep in mice at least 90% of the time in order for experiments to be considered effective. As mice sleep cycles can be as short as 60 seconds in length, and the delivered stimulus must not injure the mouse, as any stimulus delivered will be delivered very repeatedly. This must be taken into consideration when designing the software as well as selecting materials for the stimulus and determining stimulus strength. For the software component, this means it must be programmed to be able to deliver a stimulus at least once every 60 seconds during the mouse sleep deprivation periods and should not allow speeds any faster than 1 revolution per second as this would injure the mouse. For the circuitry component, this means that any propeller or motor used should not deliver any more than 9.5 kg/mm^2 of force and, if possible, should be well under this limit. This number represents the amount of force needed to break a mouse tibia, indicating that this amount of force would cause severe bodily harm to the experimental mice (14).

Finally the client has requested that the device be able to be autoclaved between uses. This means that any non-removable components of the device must be able to withstand 82 degrees C for 5 minutes at a time.

Existing Products

Forced exercise/walking wheel

The forced exercise and walking wheel device consists of a bed with wheel tracks, which spin all of the wheels simultaneously (15). An example of this device is shown in figure 2 below. The bed itself costs $3,600 dollars and each walking wheel costs $505. Waste from the mice is collected in steel pans underneath the wheels. There are swing hatches on each cage to allow handling and this device also has an LCD interface where the user can set the walking speed, exercise time, rest time, and the number of cycles. This particular device interfaces with a computer through the company's exclusive software called AWM Activity Software. The available speed range is 1-28 m/min with a speed resolution of 0.5 m/min. And the test time range is 0-24 hours or 0-99 cycles. Water support options for this particular device cost an additional $99 each (15). The benefits of this device are: the LCD interface, the degree of available variables in designing an experiment, and the waste collection. The drawbacks of this device are that the device costs more than $8,000 total, trials are limited to a maximum of one day, and forcing the mice to do exercise can adverse effects on the research the clients are conducting.

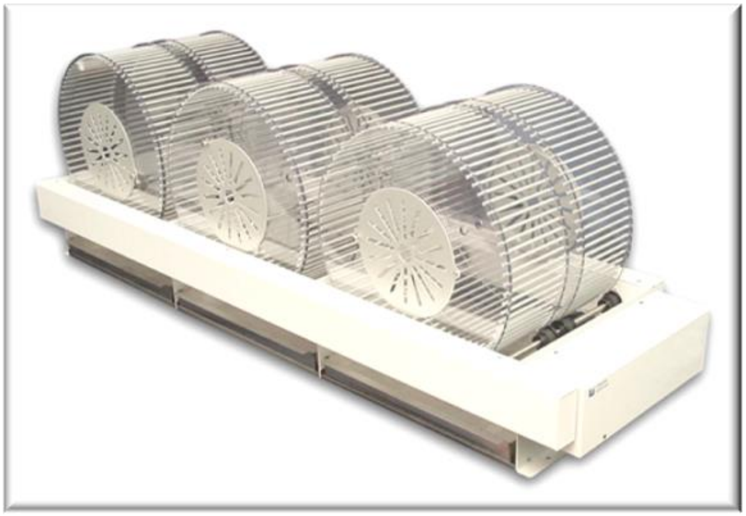

Figure 2 - Forced exercise/walking wheel existing product: A set of exercise wheels with waste collection trays below them for the purpose of sleep deprivation experimentation. (15)

Sliding Bar Chamber

The sleep deprivation chamber model employs a sliding bar on a track which keeps the mice awake by forcing them to step over the bar. A device of this type can be seen in figure 3 below. There are several devices which expound on this concept of a sweeping horizontal bar. The product from the Lafayette Instrument company provides water and food support and an inter-cycle time of 15 seconds to 20 minutes and requires a 28V DC power supply (16). One other variation features speed, torque, and movement intervals variables in the program and the ability to detect the end of the cage and relay engages it in the other direction (17). The cost for the Lafayette product is approximately $1,650, though according to their product manager the motor has become obsolete due to excessive noise and not providing enough torque to meet their desired product quality. This product and other derivations have good support for physiological needs, provide a unique tactile stimulus, and have several programmable variables; however the cost, noise, and difficulty with cleaning and maintaining the motor and track are less than favorable aspects to this product.

Figure 3 - Sleep deprivation chamber existing product: A device which features a sliding bar which is swept across the bottom of the cage forcing the mice to walk over it. (16)

Rotating drum

The rotating drum model features a fixed interior wall and a rotating floor which the rodents stand on. While this product has been used with rats and shown to be extremely effective, this model has yet to be tested for effectiveness with mice (18). This device can be seen in figure 4 below. Speed and directional variability gradually increases to compensate for increasing sleep pressures as the experiment progresses. Sleep state is detected by infrared sensors, EEG, and EMG. Aside from sleep deprivation, part of the original desired function for this model was to research social interaction and how it connects to sleep deprivation. To do so, there are thirteen holes in the interior wall for communication between two rodents. The drum wall is made of Plexiglas, and the rotating plate is aluminum. Food and water are provided via tubes in the central wall (18). While this device has proven very effective with rats, the complexity of its fabrication and untested use with mice makes it a less than desirable design option for our purposes.

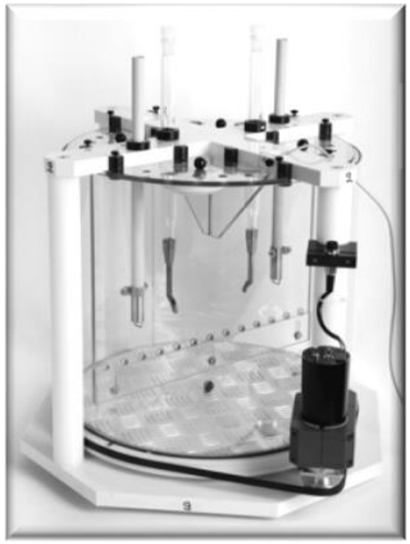

Figure 4 - Rotating drum existing product: A barrel shaped cage with a rotating bottom to entice movement and ensure deprivation of sleep. This model was also developed for used with two rodents for experiments separated to observe effects of social interaction. (18)

Propeller (existing)

The last existing product is a propeller-based design being produced by Pinnacle Technology Inc. which is priced $4,000-$7,000 varying on the specific model (19). This device can be seen in figure 5 below. The tactile stimulus for keeping the mice awake is the propeller that spins around, mimicking gentle handling. Each unit can operate on its own through the use of an LCD screen, but it is also possible to wire multiple cages together to form a system, which can connect directly to a computer. In addition, it also features an EEG/EMG recording system. The cage itself is 10 inches in diameter, and the propeller has a variable spin rate, from 5-15 rpm, and can change direction. This model also accommodates all the basic physiological needs such as bedding, food, and water. The price for this model prevents it from being a viable option for our client, despite its performance.

Figure 5 - Propeller existing product: A propeller raised from the bottom of the cage spins gently in a rotational fashion and delivers stimulus to waken the mouse. While effective, the product is very expensive. (19)

Cage Design Alternatives

Slide Bar

The slide bar design alternative features a bar along a track with a motor that slides it back and forth along the bottom of the cage. The motor and track are housed together in a separate section on top of the cage. The slide bar wakens the mouse by forcing it to step over the bar. The slide bar would detect when it is close to the side of the cage and reverse directions. The dimensions of this design are identical to those of the cages the client is currently using: 8 inches wide, 14 inches long, and 10 inches tall. A solidworks model of this design can be seen in figure 6 below.

There are three holes in the top of the cage. The smallest one, close to the edge, is for electronic cables running between the mice and computer. And the purpose of the two larger holes is for the dispensing of food and water to the mouse. In addition, the motor/slide bar complex can be removed for cleaning and the rest of the parts can be autoclaved. This device has the advantage in that it is sanitary and has been proven effective in preventing REM sleep (16). The track would need to be cleaned and maintained in an oiled state, to prevent it from rusting or otherwise malfunctioning. This could be a potential complication for use. This design differs from existing products in the mechanism in which food and water are delivered. The current device has food and water dispensers within the cage while this device will dispense food and water from the top of the cage to improve on sanitation. It also differs in the ability to function with mice that have wires running from their head to the computer. This means that the current device cannot operate with mice that must be wired to a computer, but this design features a large hole from which cords can run from the mice back to the computer. Additionally, in this design, the bar would be made out of a more flexible plastic so as to not injure the mouse.

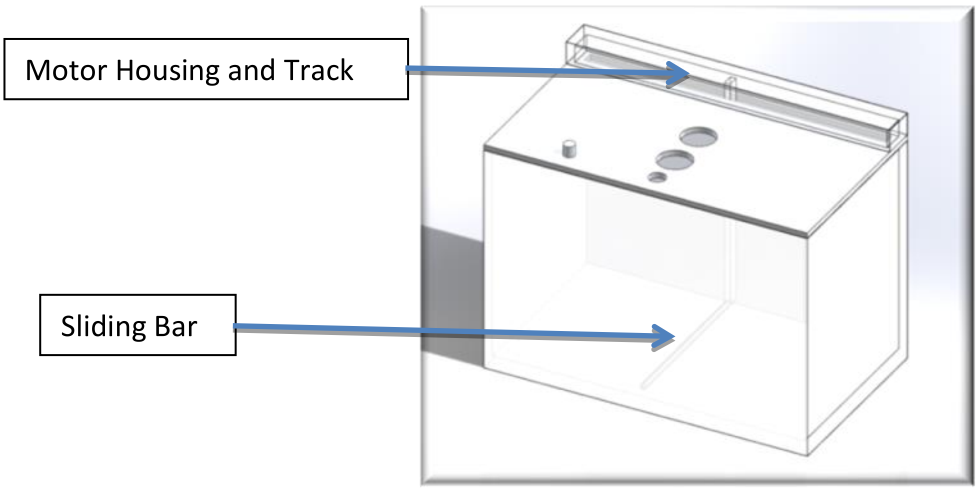

Figure 6-Slide Bar Alternative: The slide bar design features a bar which sweeps from one end of the cage to the other along a track, forcing the mouse to react and walk over it.

Propeller

The propeller design features a round cage with a diameter of 6 inches. This allows the mouse the maximum living area while still fitting snugly in the housing container. The cage is 8 inches tall, which prevents the mouse from escaping. Halfway up the cage there is a cut in the side of the cage to dispense food and water into the cage for the mouse. A key feature of this design is a propeller protruding from the bottom of the cage which is mounted onto a spinning bar. This bar is centered on top of a rotating motor that controls the speed and direction of the propeller. The propeller radius of 2.9 inches was selected to ensure that the mouse would be disturbed by the propeller, but the propeller would not have problems with rubbing against the side of the cage. The propeller itself is made of soft, flexible plastic, so the mouse would not be harmed upon tactile stimulation. This product is simpler than the existing products, which make it more mass producible (as our clients need 8) and would cost much less than $4,000-$7,000. This design has variable spin speed, frequency, direction, and other user options. Also, compared to the existing products, this design is smaller: it is 6 inches in diameter instead of 10 inches. A solidworks model of this design can be seen in figure 7 below.

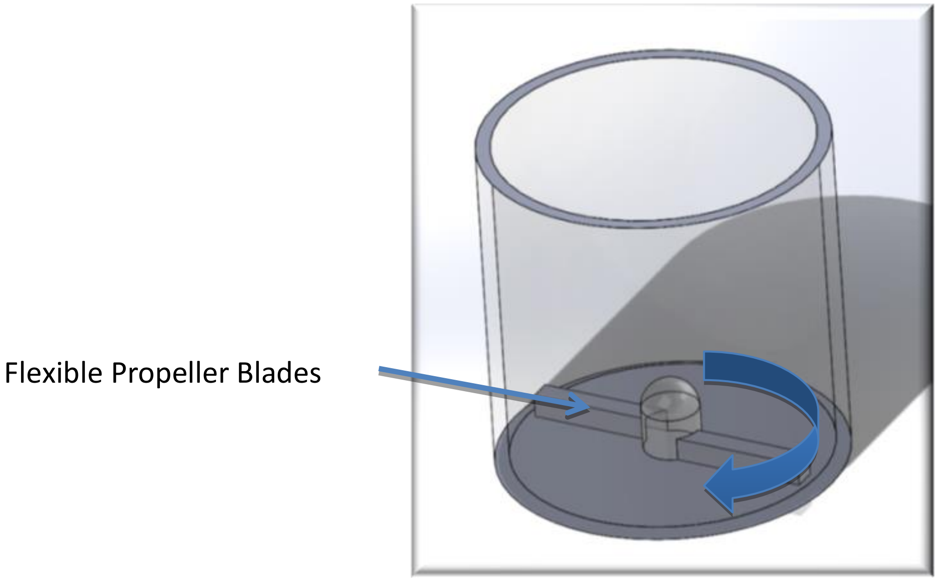

Figure 7-Propeller Alternative: The propeller design consists of two flexible propeller blades attached to a rotating motor which are capable of rotating clockwise or counter-clockwise. Contact with the propeller blades is the stimulus delivered to wake the mouse.

Platform

Our platform design alternative consists of a circular cage 6 inches in diameter, a circular platform suspended above the bottom of the cage by its connection to the motor, and a shallow pool of water. This design wakes the mouse through the partial rotation of its platform. This rotation causes two things: 1) it creates a change in the incline of the platform that forces the mouse to readjust its center of gravity and 2) it forces the mouse to avoid the parts of the platform that are becoming submerged. Studies employing EEG, EMG and theta brain wave activity as methods of sleep detection have reported effective reductions in NREM sleep (96%) and that disk rotation occupied around 16% of the total trial duration in such cases (20). Food and water are provided from above along the axis of the rotation of the platform to allow for ease of access during any time throughout the duration of the trial. The unique feature of this design is its combined method for waking up mice. This is different from current devices as most water based current devices do not employ a moving disk, but rather depend on small platforms that do not allow the mouse to fall asleep as they would simply fall off of the platforms. A solidworks model of this design can be seen in figure 8 below.

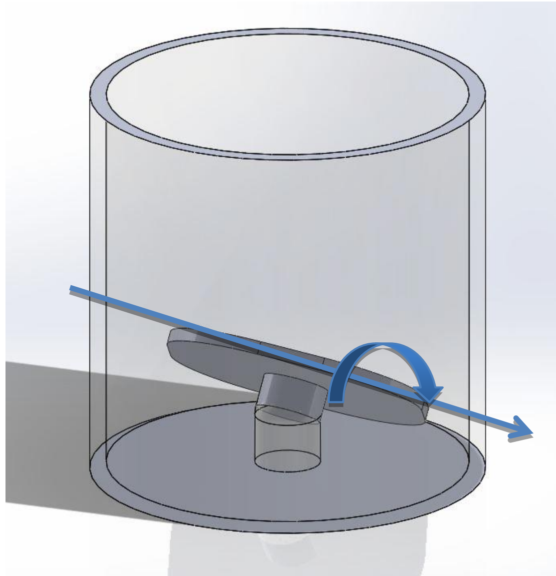

Figure 8-Platform Alternative: The platform design features a platform, which partially rotates in either direction along an axis above a shallow pool of water which partially submerges one side into the water. The incline of the platform and the evasion of the submerged portion are the stimuli to prevent the mouse from sleeping.

Design Matrix Analysis

Design Criteria	Weight	Design Alternative		
		Slide Bar	Propeller	Platform
Ability to Wake Mouse	20	15	12	15
Ability to Implement Software	15	10	10	10
Ability to Implement Circuit	15	7	15	5
Ease of Operation	15	10	15	5
Ease of IACUC Approval	10	10	10	7
Feasibility	10	6	8	4
Ease of Sterilization	5	3	5	3
Ease of Producing >1	5	3	5	4
Cost	5	3	5	3
	Total			
	100	67	85	56

Table 1 - Design matrix evaluating design alternatives: The propeller design alternative received the highest rankings in nearly all categories due to the relative simplicity of its design whereas the slide bar and platform design alternatives had problems associated with complexity and waterproofing respectively

The designs were evaluated according to a wide variety of categories. This variety was chosen because there are many components that contribute to the success of the prototype as a whole. These components include: the ability of each design to wake the mouse, the compatibility of the design with the intended software, the compatibility of the design with the intended hardware, ease of everyday operations of the design, the ease with which the design will receive IACUC approval, the feasibility of the design, the ease of sterilization using autoclave of the design, the ease of production of the design, and the cost of the design.

The "ability to wake mouse" component of the design is the most important parameter for evaluation because this is the primary function of the design, and without it, the device would not be useful. All three waking mechanisms in these designs have been studied scientifically and have been shown to be effective to an acceptable degree. The efficacy of all of these designs for the purpose of scientific investigation is as follows: the flowerpot technique (from which the tilting platform is derived) has been seen to prevent REM sleep at least 90.4% of the time, and the addition of the tilting platform onto the current technique will likely improve this (21). The sliding bar design has been seen to prevent REM sleep at least 95.5% of the time in sleep fragmentation studies, and this will also likely improve in total sleep deprivation (22). The propeller design also displayed a high degree of effectiveness, though its prevention of REM sleep has been seen to vary from 87% effectiveness to 98.4% in varying studies (23, 24) Due to the varying flexibility of the propeller over its length, we can infer that the propeller will be less effective than either of these two designs. However, the propeller design is still an industry standard, and the torque applied can be varied with the plastic chosen as well as other factors and therefore receives a relatively high ranking.

The compatibility of the design with the software and the circuitry was considered the next most important parameter, because compatibility in these two areas was vital for the successful operation of the design. All three designs received a high score for compatibility with the program, as the program would be universal to all three. The differences lie in the implementation of circuitry for each design. For this, the propeller design was given the highest ranking because it simply requires a circular motor, which is simplistic in terms of mechanical components. As further discussed below, this design would feature a stepper motor that would simply fit directly into the plastic cage. By contrast, the platform design needs motors that can go in multiple directions in order to tip the platform in varying directions and needs take into account the aquatic environment surrounding the platform. Similarly, the sliding beam design requires complex hardware and tracks for the design to be successful, as the beam needs to travel the length of the cage.

Ease of everyday operation was also weighted heavily as it is a necessity for the day-to-day operations of the device such as restocking food and water, cleaning the cage, and resupplying of the bedding, and all these should be able to done frequently without the device breaking down or encountering problems. The propeller device was given the highest ranking due to the simplicity of its mechanics such as the discrete propeller size which cut down on the number of aspects of the device that could be more likely to degrade and break down over time. This relatively conservative approach allows for cleaning and the restocking of broken components relatively easy the user. However, the platform design would prove to add more difficulty to cleaning procedures with the user having to deal with the disposal of wastewater with each cleaning. The concern of any watertight sealing leaks leading to contamination of the circuitry which could lead to damage is also another problem that could easily arise from improper fabrication or wear of the device. Finally, the slide bar design has many components that could break down in day-to-day operation, and the large size of the circuitry makes cleaning while still running the experiment difficult.

The ability of the design to meet IACUC standards and the feasibility of construction of the design were given the next highest rankings. All designs will meet basic standards of care for mice and will therefore meet IACUC sanctions. However, the water aspect of the platform cage will inherently introduce further sanitary concerns and will therefore make it more difficult for this design to receive this approval, while the other designs have no foreseeable complications for IACUC approval. Feasibility of construction is important considering the time constraints placed on the project, but should not be a dominating factor in choosing a design. Similar rationale was applied to this category as to some of the other categories in ranking the designs: as the platform design needs extensive waterproofing, it was given a low feasibility ranking. Extensive waterproofing and ensuring that these watertight seals do not leak poses problems that make the design less feasible given the level of fabrication experience of our design team. The slide bar was also given a relatively lower feasibility ranking due to the complexity of its extensive circuitry.

Finally, ease of sterilization, ease of larger scale production, and cost were given the lowest weighting. Sterilization and larger scale production were given this lower ranking because they were aspects that were desired by the client but were not crucial in comparison to the product's performance and feasibility. Additionally, the client desires eight prototypes for use. However, it was decided that these could, if necessary, be fabricated at a future date. Cost was given a low weighting because the budget is much larger than the foreseeable expenses of this project. The platform and sliding beam design received lower ratings in all three of these categories due to their respective design complexities associated with waterproofing and more extensive mechanics respectively.

The propeller design received the highest total ranking and received the highest ranking in every category except for the ability to wake the mouse. The slide bar alternative received the next highest total ranking with deficiencies resulting from its complex circuitry. Finally, the platform design received the lowest ranking due to complications arising from the inclusion of water into the design. Therefore, the team will proceed forward using the propeller design as a final design.

System Process

The start of the process for a sleep deprivation device begins with user input. A user can define the variables for a desired for inputs including frequency of stimuli, duration of the experiment, speed of the propeller, and number of rotations of the propeller. The computer that defines the program connects with a microcontroller, which is the connection between the computer and the circuit itself. Then circuit takes the signal from the microcontroller and implements it into the motor through the use of a driver chip. Lastly, the motor then operates the cage specific components that deliver a stimulus to awake the mouse according to the program that was defined by the user. A flow diagram of the whole system process used in the final design is outlined in the figure below.

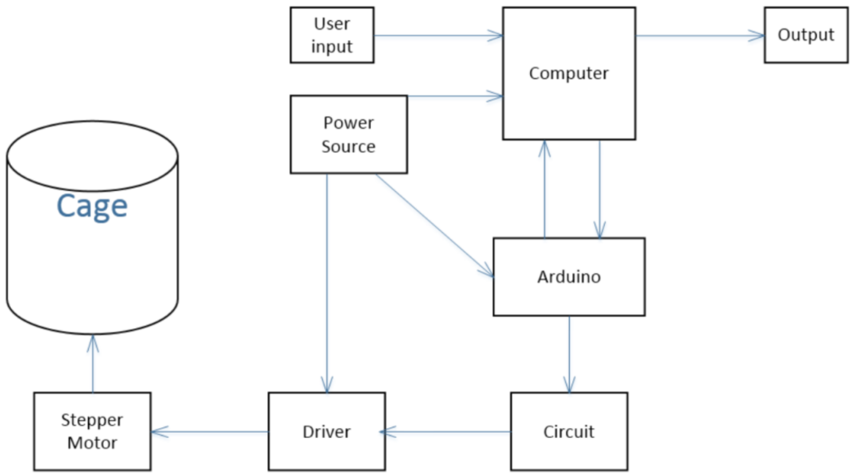

Figure 9: Flow Diagram for final Design: The computer program sends a signal to an Arduino, which sends this signal through a driver and to the motor, which turns the propeller in the cage. The computer receives user input to coordinate this process and also generates feedback for the user to see

Final Design

Software

The software constructed for the final design consists of a LabVIEW program (see figure x). This program contains a graphical user interface that allows the user to specify a start time and an end time for each sleep deprivation session, the frequency with which the propeller will turn on, how many times the propeller will turn each time it is turned on, and the speed of the propeller. These are stored in LabVIEW as arrays, and therefore the user can expand and contract the size of these arrays to program as many or as few sessions as they desire. This user interface also provides an LED indicator which conveys to the user that the software is sending the signal to the motor to turn the propeller. The LED indicator provides a quick and easy feedback as to whether or not the software is functioning accordingly. The user interface also contains a start button which will begin running the currently specified program as well as a stop button to terminate the program. Finally, the program will prompt the user to create or specify a text file where the inputted information (start times, end times, etc.) will be stored for future use.

The mechanism by which the code works is outlined in the Figure10 and is explained in the following paragraphs. First, the program establishes contact with the Arduino and the stepper motor through the resource (USB connection in most cases) and pins in the Arduino specified in the program. Next, the program determines how many sessions were specified by the user by indexing the start times array on the front panel.

The program then operates within a "for" loop that completes as many iterations as sessions specified by the user.

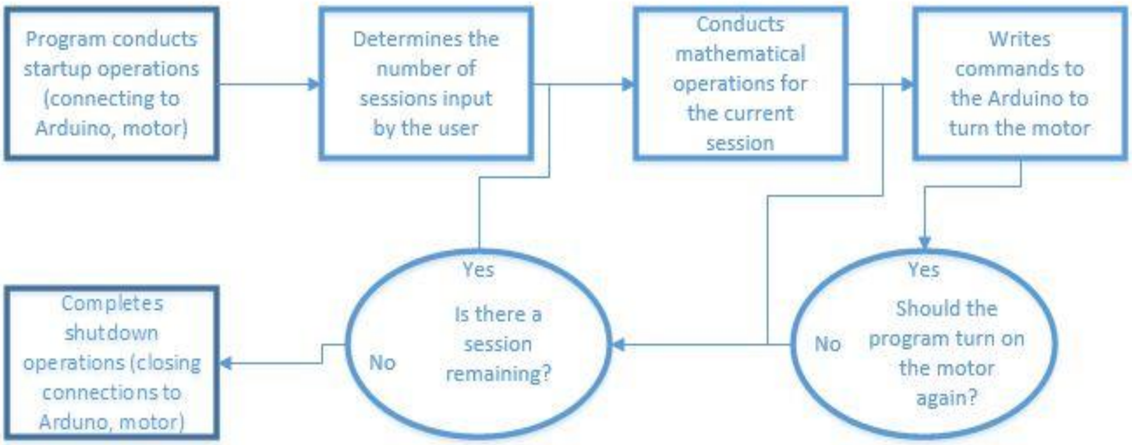

Figure 10: Flow chart for final program – The LabVIEW program created conducts startup operations, then determines the number of sessions indicated by the user. After this it conducts various mathematical operations for that specific session and then writes command to the Arduino. These commands then tell the motor how to move. Next it checks if the motor should be turned on again and if there are sessions remaining. If both of these are not true, it conducts shutdown operations.

Within this "for" loop mathematical manipulation of the inputs specified by the user take place and signals are sent to the motor to cause it to turn. First, the mathematical manipulation will be discussed. Then, in the following paragraphs, the manner in which these inputs are used to turn the motor on and off will be discussed.

The program performs five mathematical operations for each sleep deprivation session. First, the program calculates the number of steps the motor should take. This is calculated according to the following equation:

$$Steps\ to\ move = Rotations\ per\ iteration * 200$$

Equation 1: Calculation of steps for the stepper motor to move

Equation 1 holds true because in the stepper motor used in the project, there are 200 steps in 1 rotation. Next, the motor calculates the speed of the motor in steps according to the following equation:

$$Speed\ (in\ steps) = \left(Speed\frac{(in\ rotations\ per\ second)}{5}\right) * 200$$

Equation 2: Calculation of speed of the stepper motor in steps

Equation 2 holds true because of a feature used in LabVIEW known as an enumeration. We have specified that the user can only select from 5 options for the speed, ranging from 1 rotation every 5 seconds to 1 rotation every 1 second. Each of these speeds is assigned a numeric value within LabVIEW, that, when divided by 5, shows the true speed in rotations per second. When this is multiplied by the number of steps in 1 rotation of the motor, it gives the speed in steps per second. After this, the program calculates the time of the session according to the following equation:

$$Time\ of\ session = End\ time\ for\ session - Start\ time\ for\ session$$

Equation 3: Calculation of time of session

The program next calculates the number of times the motor turns on during each session according to the following equation:

$$Iterations\ for\ turning\ motor\ on = Time\ of session/Frequency\ of\ propeller$$

Equation 4: Calculation of the number of iterations the motor will be turned on

Equation 4 is true because the motor will need to turn on an integer number of times determined by how many frequencies the motor turns on that fit within the time of the session. Finally, the program calculates the time delay for turning the motor on according to the following equation:

$$Time\ Delay = Frequency\ of\ propeller - (Rotations\ per\ iteration * Speed\ in\ rotations\ per\ second/5)$$

Equation 5: Calculation for the time delay for the propeller

Equation 5 occurs because the time delay after each time the motor turns off will be equal to the amount of time specified in the frequency minus the time that the motor is running which is specified by the rotations per iteration multiplied by the speed in rotations per second. It is useful to note that the speed used here is also divided by 5 in this equation for the reasons specified above. Each of these equations takes place within a subVI in LabVIEW which frees up CPU space.

After these mathematical operations, the program is then ready to send signals to the Arduino and the stepper motor. First, the program checks whether the current time is later than the start time for the current session. If this is true, the program writes the number of steps to take and the speed of steps to the Arduino, which then sends alternating voltages to the stepper motor, as discussed in the circuitry section. After writing this to the Arduino, the program tells the stepper to step and waits for it to do so. Next, the program waits the specified amount of time specified by the time delay calculated above (eq. 5). This process then repeats for the number of iterations calculated for turning the motor on calculated above (eq. 4). When the specified number of iterations is complete, the program checks if there are remaining session and repeats the process if so from the calculation of new variables. If there are no remaining sessions, the program proceeds to the shut down steps explained below.

In the shut down steps, the program safely closes connections established with the stepper motor and then safely closes connections established with the Arduino. The program finishes by saving all of the information input by the user and checking for any outstanding errors that occurred within the program and notifying the user of their occurrence. However, it is important to note that any errors that occur when the program is writing information to the Arduino will cause the program to automatically shut down.

The basic structure of the establishing contact, writing to, and closing contact with the Arduino and stepper motor was taken from a stock existing LabVIEW virtual instrument and edited for our specific use. A screenshot of both the user interface can be seen in Figure 11.

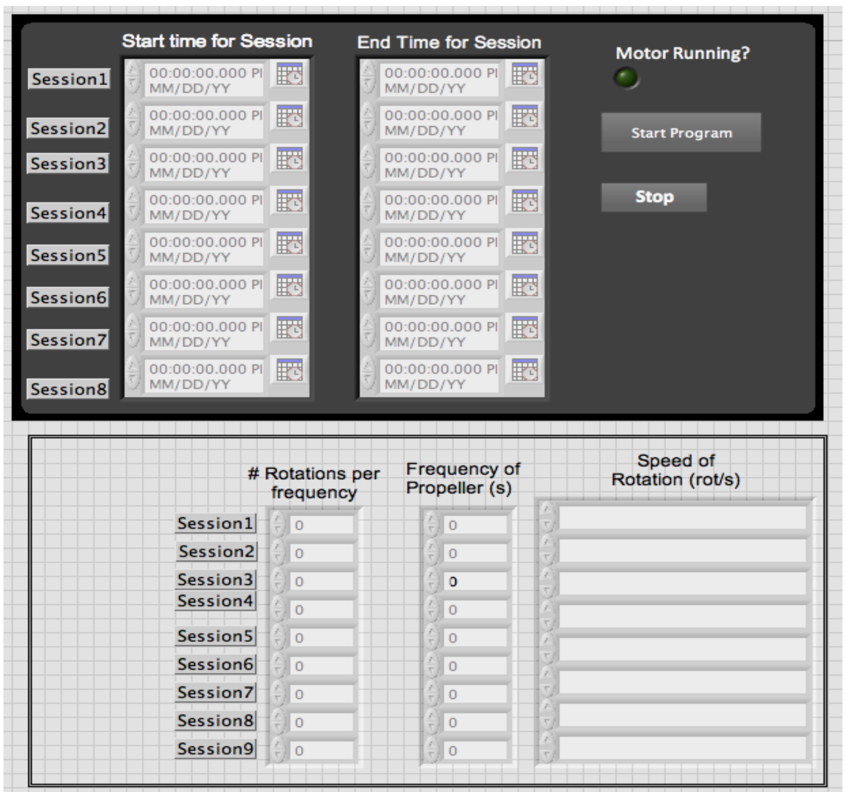

Figure 11: Front Panel of LabVIEW Software – The upper image shows the front panel or user interface of the program where users can input selected variables for control of the motor.

This program allows users a great deal of flexibility. Users can select as many sessions as needed for the program to run, which represents an improvement over the software of our client's current device. Additionally LabVIEW derived software is relatively easy and intuitive to learn due to its graphical programming nature, and any potential users could tailor the program to suit their needs for future customization. Finally, also due to the graphical nature of LabVIEW programming, any future add-ons to the current prototype (such as a sensing mechanism) can both use the information in this program and could be very easily incorporated into the current program.

The program for use in conjunction with our prototype was made into an executable. This allows the program to be run on any computer without requiring a license to LabVIEW or for the program to be installed. This is very helpful for cost saving measures; however, when the program is made into an executable, it can no longer be edited. This does not mean that the user can no longer input start times, end times, etc., but rather means that the program could not be further tailored or edited in its executable form. Put simply, this means that the GUI is still interactive but the code alone cannot be edited.

Cage Design

Our final cage design is constructed out of .375” thick polycarbonate and stainless steel screws. Polycarbonate was chosen due to its adherence of the requirements for being a clear and transparent material for the construction of the cage, so the mouse can be observed from outside. Another determining factor was polycarbonate’s heat deflection temperature satisfying the requirements for autoclaving. (25) The cage components have successfully survived their first experimental autoclaving at 82°C, and there are no concerns regarding their continual autoclaving in the future.

The cage design consists of 4 separate, distinct features: the base, the propeller, the supports, and the stepper motor housing (Figure 12). The base of the cage is approximately 10”x6.2” and is supported by two, two inch blocks (referred to as supports) on either end to ensure the cage can sit evenly on a level surface.

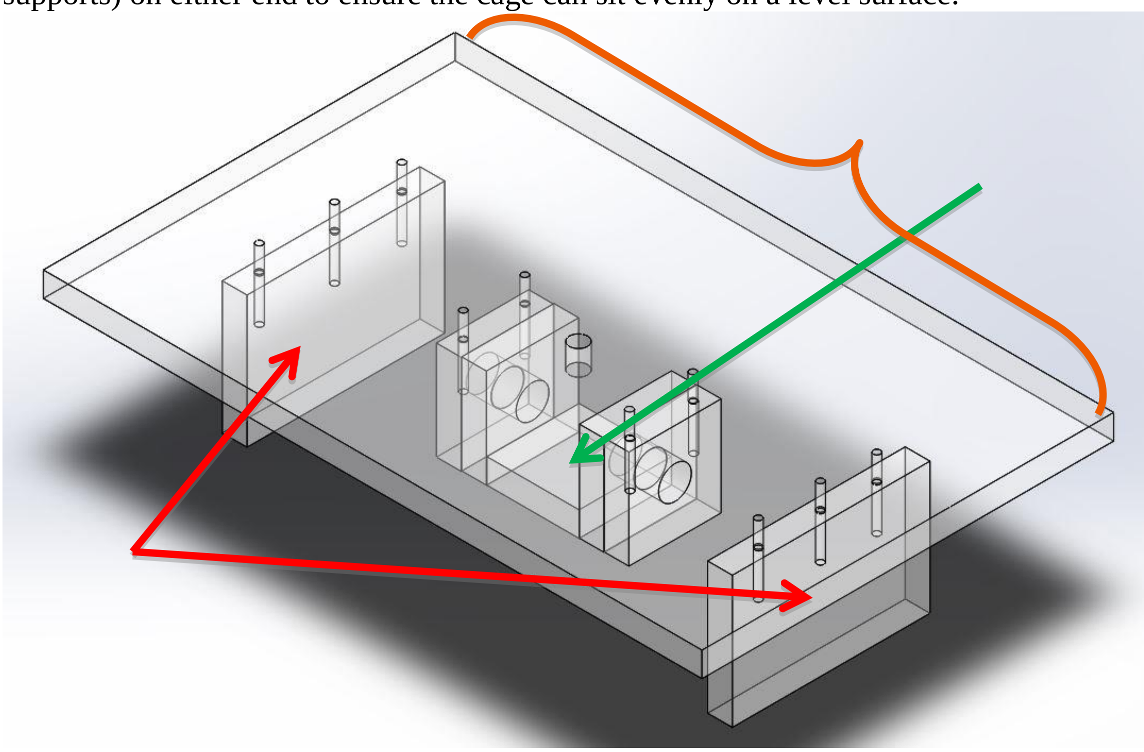

Figure 12: The final cage design for the prototype consists of 4 separate components: the **base**, the **supports**, the **cage housing**, and the propeller (not shown).

The propeller is machined from .5” diameter polycarbonate rod to a semi-circular shape approximately 5.75” in length and .5” in width and .25” tall. The propeller is centered relative to the base and is held in place by the shaft of the motor which runs through the complement .25” hole in the center propeller. A screw perpendicular to the hole for the shaft in the propeller can be tightened to contact the flat face of the semicircular stepper motor shaft to lock the two components together. Two rubber washers with a 1/16” thickness and an inside diameters of .25” are placed along the shaft to act as the contact between the bottom of the propeller and the top face of the base. These washers act to elevate the propeller off the surface of the base and prevent any contaminant from reaching the stepper motor. (Figure 13.)

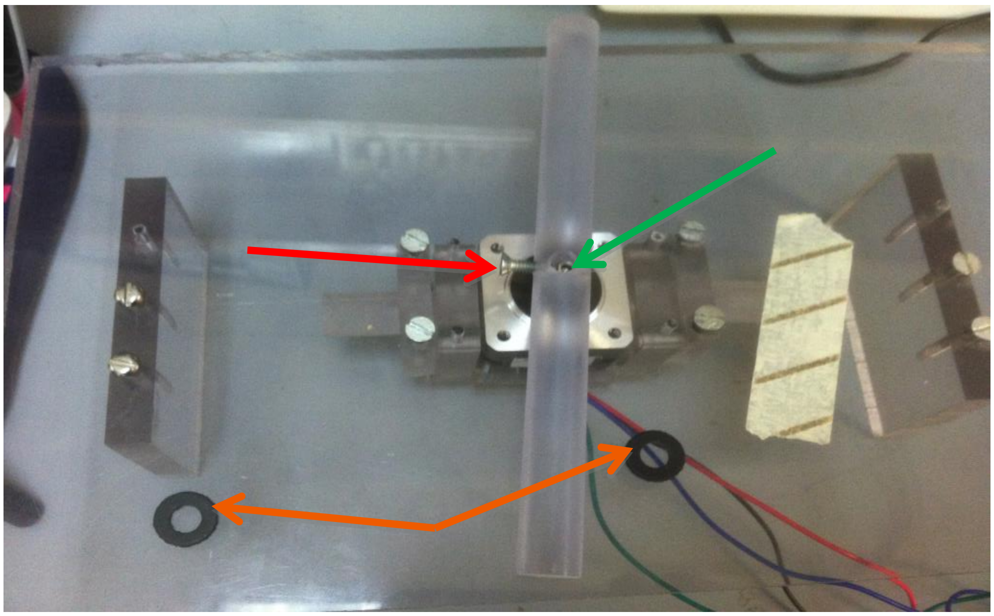

Figure 13: The propeller rests atop 2 **rubber washers** (pictured for reference) and is centered by the **shaft of the stepper motor**. The stepper motor itself has a semi-circular shape which allows for a **screw** to be tightened against its flat surface through the propeller. This allows for the propeller to be set firmly in place.

The motor housing design for the stepper motor consists of four square pieces of polycarbonate 1.4”x1.2” with a .5” diameter hole through them. Two of these pieces are screwed under the base of the cage to act as the female component of the housing. The remaining two are connected to a 1.4”x1.4 square of polycarbonate to act as the male components which can be removed and complete the housing for the stepper motor. A portion of the .5” diameter polycarbonate rod is then inserted into the respective holes to act as the key and hold the respective elements in place. The easy removal of rod segments allows for the stepper motor itself to be easily separated from the cage as a whole (Figure 14).

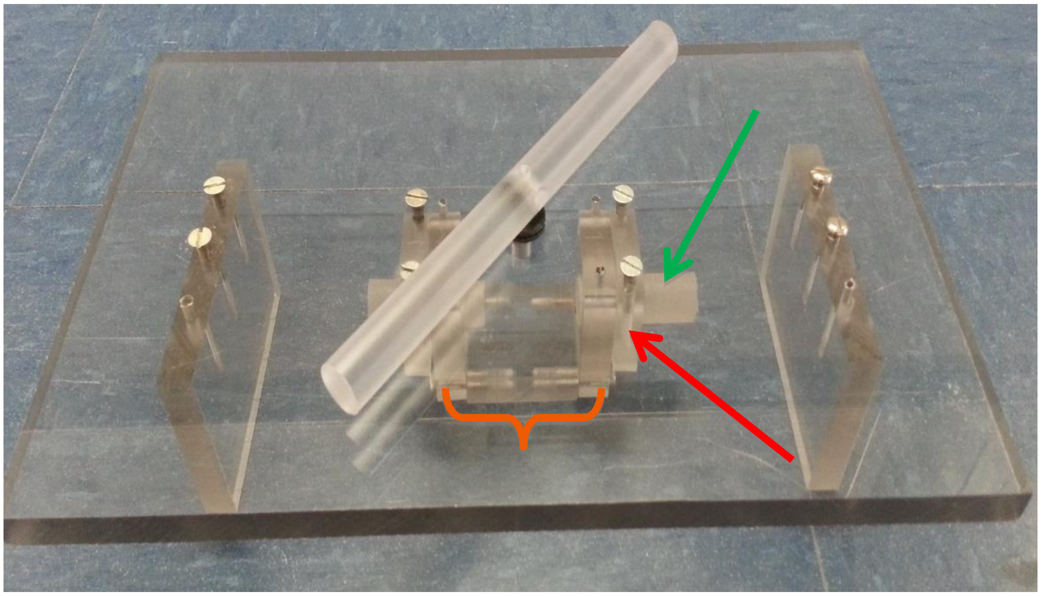

Figure 14: The stepper motor housing consists of three parts: **two blocks** with .5” diameter holes screwed to into the cage, a **smaller unit** of two blocks with .5” diameter holes connected to a center block matching the dimensions of the stepper motor (1.4”x1.4”), and two **segments of rod** with diameters of .5” on each end. Once in place, the stepper motor can be removed from the cage by sliding out the sections of rod from the holes.

Circuitry

Circuit components of the final design are three-fold: the stepper motor, the driver chip, and the arduino. The stepper motor is a bipolar, DC motor connected to the arduino through the bipolar stepper motor driver. RedBoard-the arduino-is very similar to the arduino UNO, but with some Sparkfun tweaks and upgrades.

The stepper motor is a brushless, DC electric motor. This motor was chosen for its precise control of rotatory movement. Stepper motors divide full rotations into an equal number of steps. The stepper used has 200 steps or 1.8 degrees per step. At each step there is a toothed electromagnet that is energized by an external control circuit, in this case, the arduino. The motor used in the design is bipolar, which means that the current in the winding needs to be reversed to reverse direction, but it is more powerful than a unipolar motor of the same weight. The motor performance is strongly dependent on the circuit. For example, if the poles reverse quicker than the torque curves extend to greater speeds. Based on a 40g mouse and the cage radius of 2.875 inches, the torque needed (assuming the entire mouse weight is at the edge of the cage) is 292.1 g-cm. Based on a 70% efficiency the motor needed to be rated at over 417.3 g-cm of torque. The chosen stepper motor is rated at 7.4V, 230mA with a holding torque of 650 g-cm. The stepper motor also has four leads that connect to the stepper motor driver.

The stepper motor driver carrier is the interface between the arduino and the stepper motor. The driver, the A4988, has an 8V operating voltage (near the stepper driver’s) with a max current of 2 amps. The logic voltage range is from 3-5.5 volts. The driver also has four microstep settings and chopping control. Each stepper driver can only control one stepper motor. The stepper driver connects to the stepper motor through four pins: 1A, 2A, 1B, and 2B. This driver is ideal for the circuit because it has chopping control so it can run the motor at higher voltages than rated safely which provides more power. Also it has a variety of safety features: over temperature shutdown, under voltage lockout, crossover-current protection, and short to ground/shortened load protection. Plus the driver chip is only 0.6 by 0.8 inches. The driver carrier provides two functions: it separates power and smooths function. The arduino and motor run at different powers, and the ardunio cannot provide enough voltage to power the motor directly. The driver chip separates these two levels of voltage and prevents the power supply to the motor from overloading the arduino. Microstepping acts to reduce the vibration and noise caused by the interworkings of the motor. This allows the user to choose full, ½, ¼, 1/8, or 1/16 step sizes-which converts the stepper motor from 200 steps/rev up to 3200 microstep/rev at the 1/16 setting.

The final piece of the circuitry is the arduino. The arduino platform is what connects to the computer and transforms the code from LabVIEW into signals sent to the stepper driver. It is a modified Arduino Uno that can be programmed by a mini USB and features an ATmega328 microcontroller with Optiboot bootloader, FTDI USB programming, 14 digital I/O pins, 6 analog inputs, 32 kb flash memory, and 16 MHz clock speed. The arduino runs on 7-15 volts and connects to the DIR, STEP, GND, and VDD pins on the stepper driver. The VDD pin is where the logic power supply from the arduino attaches. The arduino processes the code and sends it to the stepper driver in a specific sequence through the STEP and DIR pins. Each pulse to the STEP input corresponds to one microstep in the direction specified by DIR. Then the driver outputs voltage pulses to the stepper motor through the four leads to move the motor the desired number of steps. The arduino was previously being powered by the computer and the stepper driver through an alternate power supply, but in the final design the stepper driver and motor are powered through a power adapter and the arduino will be powered through the computer.

Final Prototype

The final prototype connects the three components described above. To do this, the motor is placed in the housing below the bottom of the cage. The stem of the stepper motor sticks up through a small hole cut in the bottom of the cage. The propeller can then be attached to the cage by tightening a small screw. The circuitry connects to a computer that has the program on it through a USB cord (USB to mini-USB).

The entire setup then works in the following manner. The LabVIEW program sends a signal to the Arduino IDE software, which translates this into language that is readable by the Arduino. It then sends this information to the Arduino which passes it along through the driver chip to the motor. A 12-V power cord connects to the driver chip in order to power the stepper motor while the USB supplies the power to the Arduino itself. The final prototype can be seen in the figure below.

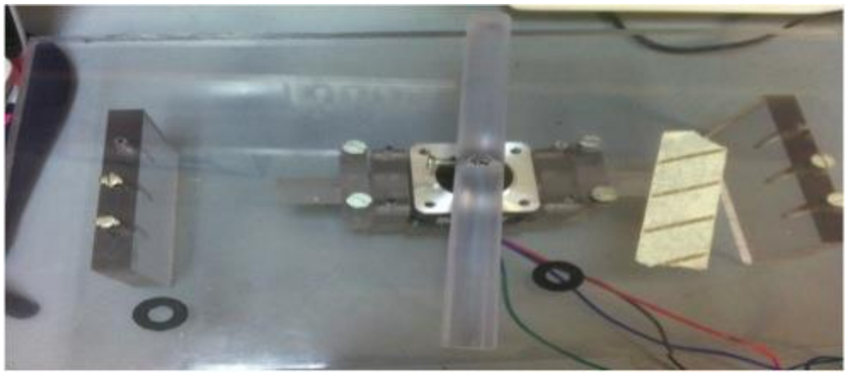

Figure X: Final assembled cage prototype – This image of the final prototype shows how the motor fits into the final cage design. Not shown in this figure is the circuitry or software, which are shown in the individual component sections above.

Testing and Results

For the first phase of testing our program, it was decided that we should conduct user testing to learn about the perception of our program from a perspective that was not immersed in the project. The test was designed and administered in the following manner: it was determined that the test should involve subjects reading a short introduction to the project and the program, outlining a bit of background on the project, the main goals of the current design, and the function of the program being tested. After this, a series of four increasingly difficult questions were asked of the users. These questions were designed to progressively introduce the user to the different aspects of the program. The first question is based solely on properly using the time stamp feature of the program. The second question asks users to put in all components of a "session," but the manner in which they are supposed to do so is very blatant. The third and the fourth question mimic experimental design in the objectives they ask the user to achieve. Next, the users were asked to fill out a short survey, in which they rated the program on a one to five scale in terms of its ease of use and intuitiveness. This survey also asked them to express at least one positive comment and one negative comment about the program. Finally, the survey asked some personal details about the participants such as their year in school, their major, and their perceived computer ability. An example of the letter read, the questions asked, and the surveys completed can be found in Appendix II.

The survey was administered by Kyle and Rebecca over a period of two days. 21 individuals participated in the survey, ranging in majors from art to engineering and in years from freshman to graduate students. During each survey administration, Kyle or Rebecca wrote down brief observations as well as how many tasks the participant correctly accomplished. Each participant was asked to complete the first task without help. If they failed to complete or incorrectly completed the first task, Kyle or Rebecca showed them how to correctly complete the task before the participant moved onto the next task.

The data accumulated from the testing surveys showed that the average user gave the program a 3.88/5 rating for its ease of use and a 3.90/5 rating for its intuitiveness. The average user also successfully completed 3.24/4 tasks correctly which translates to a success rate of 81%. Perhaps more revealing than these figures are the facts that 38% of participants correctly completed all four of the tasks without any outside assistance and that 85% of participants completed at least 3 of the tasks correctly. In the latter case, participants most commonly struggled on the first task, but after being shown how to complete it, easily completed the remaining tasks.

The comments given on the surveys reflected a relatively positive response towards the program. The most common positive comment stated on the survey reflected a variation of the statement "the program is easy to use." This was observed in 11/21 of the users. Another common positive comment stated that participants "liked the time stamp feature." This was observed in 7/21 testing participants. Additionally, the most common negative comment was not directed at the program structure, but rather the lack of direction associated with the testing. This was observed in 5/21 of the participants. Another common negative comment was directed at making the units clearer or defining the variables better in the program. This was also observed in 5/21 participants.

These testing results show a relatively positive response to and outlook for this program. The ease of use, both perceived by the users and demonstrated by their ease in completing the tasks, shows that the program can indeed be learned easily. It is also important to note that the greatest flaws in the program that were identified by the users were not flaws in the program itself, but rather in the testing administration or the program interface design. To correct these negatives, the team will create an instruction manual that clearly defines the variables used as well as provides a thorough introduction to the use of the program.

It is important to note here that this testing does not provide a quantitative comparison to the current client software. Because of software constraints, this was not possible at the time of testing. However, this is something that would be completed in the future. Additionally, it is important to note here various imperfections of this experimental design. First, the sample size is relatively small. Therefore it would be unwise to draw widespread conclusions about the program from this relatively small sample. This test provided a good "first look" into the thoughts that people had but larger-scale testing is needed in the future. Second, this testing does not do a good job of looking into the target user of the product, that is, scientific researchers who are relatively unfamiliar to programming and circuitry. In this test, it was desired to gain a broad scale overview of what the general public thought of the program. However, in future testing, this should be better tailored to the target client.

Budget

The client initially specified a budget of $1000 for the creation and manufacture of eight cages. This translates to a budget of $125 per cage. The cost for this prototype was $118.51, which was within the estimated budget per cage. However, some of these costs are not repeated for each new prototype. The Arduino can program up to 4 stepper motors, and more than 1 cage can be made out of each polycarbonate sheet and rod. It was estimated that, for 8 prototypes, 4 orders of polycarbonate, 8 driver chips, 2 Arduinos, and 8 stepper motors would be needed. This results in a cost of $560 for the creation of 8 prototypes. This is very positive, as the current cost of a single commercial product of this nature ranges from $3,000 to $7,000 dollars (5, 9, 10)

Item	**Cost**
Polycarbonate Sheet and Rod	$38.77
Stepper Motor	$19.90
Driver Chip	$24.90
Arduino	$24.95
Shipping for Circuit Components	$10.01
Nails, screws	Donated
Total Cost	$118.51

Figure X: Itemized Budget for Final Prototype: This budget list shows the cost of each of the components used in the final design. It is important to note that not all of these costs will be repeated in the creation of future prototypes.

Ethics and Animal Welfare

This design project contains several elements that could be potentially considered ethically objectionable if not addressed properly. The following presents a series of ethical considerations that must be taken into account considering that this product will be used with a live animal.

First, the inclusion of a live animal into scientific research poses a need to care and maintain the basic level of health of the animal. All animals used in this research must be provided food and water in order to not create unwanted stress for the animal, for both humane and research reasons. Additionally, the animal habitat must be sanitary. Therefore, the cage that the animal lives in must be properly sanitized between uses as well as cleaned and the animal bedding changed on a regular basis. Proper sanitation will prevent animal odors and disease, and this, in turn, will prevent unwanted stress in the animal as well as provide a humane living place for it. Considerations for animal care according to the Guide for the Care of Research Animals, such as the size of the device and ventilation associated with the needs of the animal, have been taken into consideration in the device design. Additionally, these factors have been considered in the design matrix for the selection of the final design.

Secondly, this research involves the deprivation of sleep to an animal. This could be conceived as a seemingly ethically questionable research method. However, an animal research regulatory board must approve experimental protocols in order to begin experimentation. Our clients have extensive training in animal handling and their experimental protocols have been approved and are fully within the limits outlined by the IACUC. This fact notwithstanding, it is important for the team to consider any changes in the ethicality of the experiment posed by the use of this device. Therefore, in the final design, it will be important to minimize any pain or discomfort this design may inflict on the mouse, and, because of this importance, this consideration was one of the first steps taken in the refinement of the final design: the minimum torque required to move a mouse has been calculated and the team will take steps to ensure that the design does not implement a torque that is much greater than this.

One aspect that is known to be an indicator of stress in mice is an increase in blood corticosterone levels. While several studies have shown different exact figures for this increase, it is can be concluded from this data that chronic stress will increase corticosterone levels in mice by at least 80 micrograms/mL. (26,27) Furthermore, 80 micrograms/mL is an acceptable increase in corticosterone levels in mice. This means that it is considered ethically acceptable for causing stress in mice that increases corticosterone levels by 80 micrograms/mL in tests that involve "chronic stress" under which sleep deprivation is classified. In future testing of the device that involves animals, corticosterone measurements should be taken to ensure that the mice are not being subject to stress that is beyond the ethical limit.

In the further refinement of the final design as well as the building of the prototype, there are many other important considerations to take into account when designing a device that comes into contact with animals and should not increase this animals' distress any more than necessary. For example, steps will be taken in order to ensure that the animals do not have access to hazardous circuitry components, and care will be taken to ensure that there are no sharp edges in the final design that could harm the mouse. In our current prototype, animal contact with circuitry is avoided by the fact that the mouse is separated from all circuitry elements by the circular tube surrounding the cage and the rubber washers that line the aperture at the bottom to the motor. However, the current mechanism that attaches the propeller to the motor (the screw) is problematic in this area and will need to be changed to fit this ethical requirement. It will be paramount to continuously consider the Care of Research Animals Guide and maintain open communication with the UW-RARC upon continuation of this design (28,29,30)

Future Work

There are many areas in which the current prototype can be refined, verified, and expanded upon in order to be improved.

First, the design can be improved by making minor modifications to the current prototype to correct some of its current shortcomings. This includes an alteration of the current propeller design, a creation of a permanent place for the circuitry, and incorporating the control of multiple cages into the LabVIEW program.

The current propeller does not accurately reflect the size and ability of the mouse, and more research and design is needed on the creation of a propeller size and shape that a mouse can step over with relative ease on a consistent basis. The propeller can also be improved by altering the mechanism by which it attaches to the propeller. Currently the propeller only attaches to the propeller by means of a small screw. This could be problematic if the mouse tries to eat the screw.

The creation of housing for the circuitry also presents an area in which the current design could be improved. The current circuitry is simply sitting beside the cage and the wires can easily be removed from the Arduino pins. It is necessary that we better secure these wires as well as proved a place for the circuitry to reside while in use so it does not clutter the client lab space.

The client stated in the initial stages that he runs experiments on many cages at once. Therefore, for better use by the client, the LabVIEW program should be changed to better reflect running 8 cages at one time. This could be achieved by the client simply running 8 LabVIEW programs at once, but it would be better for CPU use if this change was made within the LabVIEW program.

Second, the design could be much better validated in the future. This includes testing the strength and stability of the prototype, testing the accuracy and longevity of the current program, testing extremes and possible errors involved in using the device, and testing that incorporates animals into the prototype.

The device should be tested for strength as well as impact in order to hold up the claim that this prototype is stronger than the current client prototype. The current prototype and program should be used for two weeks continuously with a complex program in order to see if the program performs as expected as well as if the circuit materials can perform continuously for the length of time needed without their failure. It is also pertinent to test the possible errors involved in the use of the device. This means that the program created should be able properly alert the user if the user enters a data type that is out of range or presses a button incorrectly. For example, if the user enters a negative number for the number of rotations desired in the turning of the propeller, the program should prompt the user to enter a variable that is within the desired range. Tests are also needed to ensure that this device works with animals and actually performs as designed, that is, awakens a mouse when the propeller turns without hurting the mouse.

Finally, there are several ways in which large changes can be made to the device in order to better suit the client needs. These include mechanisms that the client desired but were not attainable in the time scale of the semester. Specifically, this includes the incorporation of a motion sensing system, the creation of a wireless operating system, and the incorporation of the clients' current data acquisition methods to our device.

The client's current device features a mechanism that is based on a piezoelectric resistor mesh that shows the movement of the mice. However, this system is very flawed and the clients cannot rely on it with accuracy. Our prototype can be improved by incorporating a system such as this that better senses mouse movement and causes the propeller to move when the system detects a lack of mouse movement for a specified amount of time.

The client also specified that it would be desirable to operate the device wirelessly. This wireless communication between the circuitry and the computer program is also something that could be created in future semesters. Finally, the use of the device could be better streamlined if the current method for client data acquisition was incorporated into the prototype so that all controls and data could occur in one program.

Conclusions

Current mouse sleep deprivation devices contain several key flaws that make them undesirable for use in experimentation. The prototype created improves on current devices in several key areas, including greater ease of use, greater customization, greater stability, and lower cost. Despite these gains, there is still much to be done in terms of improving the product, and future work is needed in the areas of testing, streamlining the device, and better catering the device to the client needs.

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Appendix I: PDS

Project Title: Mouse Sleep Deprivation Device

Team Members: Kyle Anderson, John Diaz de Leon, Peter Guerin, Rebecca Stoebe

Client: Rama Maganti
Advisor: Chris Brace

Date: 2/5/13

Problem Statement: A research group intends to study the effects of sleep deprivation in pubertal and epileptic mice and how this affects learning and memory. To accomplish this research, a device is needed that can awaken mice as they are beginning to fall asleep. The device should be easily programmable by a user and should monitor the mice and deliver a non-painful stimulus to awaken the mice as well as allow arbitrary control of this function.

Function: This group intends to create a device that can awaken mice without harming them. This device will ideally be operable for up to 2 weeks at a time and will be controlled by user inputs into a program.

Client Requirements:

- Stable housing for 1 mouse that provides access to food and water, fits within a 20 by 35 cm area and is able to deliver a stimulus that will awaken the mouse.
- Intuitive user interface for programing speed, frequency, and duration of mouse stimulus.
- Feedback system that can monitor the mouse and deliver a stimulus if the mouse is falling asleep
- System must be able to operate continuously for up to three weeks and should be able to operate and store mouse data without being connected to a computer
- System must be able to be sterilized between uses and should be able to withstand 82 degrees Celsius

Design Requirements:

1) **Physical and Operational Characteristics**

   a. **Performance Requirements:** Device will be used on a weekly or semi-weekly basis and will house one mouse at a time. The mouse will weigh, on average, 25-90 g and can escape through an aperture of 6 cm^2. The stimulus delivered by the device will occur several hundred to several thousand times over the course of the experiment (720 – 60,000).

   b. **Safety:** All materials and systems used in contact with mouse will be subject to IACUC regulations. Additionally, it is vital to note that any exposed electrical or chemical elements in the mouse housing are a safety hazard to the mice. Finally, since the device will be operating continuously for extended periods of time, careful consideration must be given to ensure that the device does not overheat.

c. **Accuracy and Reliability:** Mice should not be able to sleep at all during the course of the experiment (ideally the device should promote 100% sleep prevention). In practice the device will prevent sleep at least 97% of the time and will be able to do so over a period of up to 3 weeks.

d. **Life in Service:** Experiments using the device range from 6 hours to 3 weeks in length. Therefore the device should be able to deliver up to 60,000 stimuli over the course of one experiment (1 stimulus every 30 seconds for 21 days). Additionally, the product should be able to be used for at least 2 years.

e. **Shelf Life:** While storage of this device will occur in normal environmental conditions, materials and circuit components will be chosen such that no component of the device will degrade within the 2 year minimum life of the product.

f. **Operating Environment:** Corroding could result from mouse bodily fluids, and materials will be selected such that this does not occur.

g. **Ergonomics:** Any stimulus used should not cause lasting physiological or psychological damage to the mouse. Additionally, mouse housing must provide reasonable space for mouse bedding and general habitability in accordance with IACUC regulations.

h. **Size:** Housing must be able to fit in pre-existing 20 by 35 cm mouse cage.

i. **Weight:** Must be able to be carried easily by researcher (<4.5 kg) but must also not be able to be lifted by mouse to allow escape (>0.45 kg)

j. **Materials:** As stated previously, any materials used must follow IACUC guidelines. Additionally, materials should be able to withstand 82 degrees Celsius for 15-20 minutes. Finally, materials should not be able to be chewed through or degraded by mouse action.

k. **Aesthetics:** Mouse cage should be transparent.

2) Production Characteristics

a. **Quantity:** 8

b. **Target Product Cost:** $1000 for 8 mice sleep deprivations devices plus software and circuitry

3) Miscellaneous

a. **Animal Restrictions:** All materials used, sleep deprivation mechanisms, and cage conditions are subject to IACUC regulation because of the involvement of live mouse specimens.

b. **Client Specific Information:** Mice can sleep for as little as 30-90 seconds at a time. Even this much sleep is unacceptable. Therefore, the device must either be extremely precise in monitoring the mice or must be able to deliver a stimulus every 30 seconds for the duration of the experiment.

c. **Sterilization:** Materials will be sterilized between use and should be able to be autoclaved (withstand 82 degrees Celsius for 15-20 minutes)

d. **Competition:** Many rodent sleep deprivation devices are currently available in market. Examples of these can be found below. The aim of this project is to create a cage coupled with a software that is more widely applicable (is not product specific) and less expensive than current devices.

Appendix I: Links to current devices and IACUC guidelines:

Current Devices:
https://www.lafayetteneuroscience.com/product_list.asp?catid=120
www.limef.com/downloads/sleepscience_2009.pdf
www.limef.com/downloads/FV_2008.pdf
http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2982737/
www.sciencedirect.com.exproxy.library.wisc.edu/science/article/pii/50165027011000409
www.pinaclet.com/sleep-deprivation.html

IACUC Documents and Guidelines page:
http://www.iacuc.org/usa.htm

Appendix II: User Testing Documents

Mouse Sleep Deprivation Cage User Testing

Thank you for participating in our device testing! Here is a little background on our project and our device:

We are working with Dr. Rama Maganti of the Neurology department here at UW-Madison. They are researching the effects that sleep deprivation has on epilepsy and memory in epileptic patients in order to better predict and prevent epileptic seizures as well as to better understand what effects seizures have on the brain. One of the ways they do this is by depriving mice of sleep and having them complete certain tasks.

Cages that deprive mice of sleep are already available from scientific device makers, but these are very expensive and have very limited functionality. Our team worked this semester to make a cage that has more options for researchers.

The program that you see in front of you is our software that we developed for running the cage. It allows users to select time and date ranges over which the experiment will run (termed "sessions"), the amount of times that a small propeller will turn (in order to wake the mouse) every time the cage activates, how often the cage should activate (frequency), and the speed of the propeller. The software is able to program the cage to activate over ten "sessions", and also shows the user when the propeller is turning. It also is able to save the data that the user inputs to a file and has an emergency stop for turning off the system.

We are going to ask you to complete a series of 4 short tasks that increase in difficulty involving our system. We will then ask you to fill out a short survey about the software and your impressions of it. For each task, if you don't know what to do just give it your best guess. We are trying to find out how intuitive our system is to a people with a variety of technological backgrounds. If you get the question incorrect Kyle/Rebecca will show you how to input the correct answer before you move on to the next question, but you cannot ask them for help while you are inputting your guess.

Also, please do not press start after you put in your answer. Since we do not have the hardware with us today this will cause us to have to restart the program.

If you have any questions at all, about our system, our project, this testing, or anything else, please ask us before we start. Thanks again for participating!

Mouse Sleep Deprivation Cage User Tasks

1. Set up the system to start a “session” now and end it five minutes from now (don’t worry about speed, frequency, or number of turns right now)

2. Set up the system to start at 9 pm tonight and end at 8 am tomorrow morning. Your system should set “rotations per frequency” to 5, “frequency” to 20, and “speed of rotation” to 1 rotation every 4 seconds.

3. Lets say you wanted to run an experiment on sleep deprivation in mice where you were going to deprive the mice of sleep for 4 hours, starting at 9 am tomorrow morning. In this experiment, in order to ensure the mice stay awake, you want the propeller of the device to turn 3 times every 90 seconds with a speed of 1 rotation every 2 seconds.

4. In the experiment outlined in number 3, lets say after that “session” was over you wanted to give your mice a 4 hours break and then repeat the “session” with the same parameters. How would you change your answer from 3 so you didn’t have to come back to the computer later to input something else? Hint: you should not erase anything from your input in question 3

Mouse Sleep Deprivation Testing Survey

Year:
Major:
How familiar are you with computers (circle one):

I can barely use email   I know how to operate my computer pretty well but I'm no expert

People ask me for help with computers often   I can program with ease

On a scale of 1 to 5, how easy do you think our system was to use?:

(Super hard) 1 2   3   4   5 (Super easy)

On a scale of 1 to 5, how intuitive do you think our system is?:

(Very un-intuitive)   1   2   3   4   5 (Very intuitive)

What is one thing you liked about our system?:

How do you think we can improve our system?:

Is there anything you think we should add to our system?: