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COLLECTED WORKS ON FUNCTIONAL VARIABILITY

REED COLLEGE

"OWING TO THIS STRUGGLE FOR LIFE, ANY VARIATION, HOWEVER SLIGHT AND FROM WHATEVER CAUSE PROCEEDING, IF IT BE IN ANY DEGREE PROFITABLE TO AN INDIVIDUAL OF ANY SPECIES, IN ITS INFINITELY COMPLEX RELATIONS TO OTHER ORGANIC BEINGS AND TO EXTERNAL NATURE, WILL TEND TO THE PRESERVATION OF THAT INDIVIDUAL, AND WILL GENERALLY BE INHERITED BY ITS OFFSPRING."

CHARLES DARWIN, *ON THE ORIGIN OF SPECIES*

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Introduction

In this paper, you'll find the essays I wrote and the self-experiments I conducted for Psychology 374: Functional Variability. Throughout the course, we searched for variability in its many forms. Nestled under foreign terminology of different academic disciplines, we found a wide perspective of views on the subject. Beginning with B.F. Skinner's operant conditioning, we saw how variability could be reinforced in humans and animals. Then came stochasticity in quantum physics, evolution in biology, probability in mathematics, consciousness, volition and free will, creativity in the arts and sciences, and much more. In this collection of papers, I hope to convey a little of what I learned.

The works are split into three chapters: *Why is Variability Functional?, Miscellaneous,* and *Self-Experiments.* A brief summary at the beginning of each chapter will tell you what you should expect to find. The underlined sentences throughout the collection denote modification from their original versions (submitted to Allen earlier in the year).

After all of the physics courses, taking a semester of psychology was refreshing. Thanks Allen, for organizing this fascinating and unique class, and for hosting us at the Ridge.

Miguel Conner
December 2014, Portland OR

Why is Variability Functional?

Summary

Throughout the class we studied and read about many examples in which variability can be functional. With my first and final papers, I decided it would be interesting to see how my perception of variability changed throughout the year. By constraining myself to the same topic: "what makes variability functional?" I hoped to summarize the main points I got out of the course, at two different times. Below you will find the first paper I submitted (written after a week of class), and the final paper (completed hours before the last class). I was able, I think, to predict reasonably well what the main points of the course would be, though by the end my understanding was much deeper.

First Paper: After One Week of Class

What makes variability an effective tool? For a person faced with a problem, varying behaviors and thoughts might help one arrive at a solution more effectively than not varying. Perhaps by varying one's approaches, one might uncover a more effective strategy. Or, by trying different things one will familiarize oneself with the problem, and might use their knowledge with confidence. Finally, when faced with an adversary, variable strategies succeed due to their unpredictability. Among many reasons, these seem the most beneficial, and are outlined below.

Discovery

Even when one is successful, trying a variety of strategies might lead a person to a new, significantly more effective solution to his or her problem. Take for example, the cornerstone of Biology: evolution. An essential aspect of evolution is the fact that genetic variation benefits a population by increasing the probability that some members of that population might survive sudden changes in selective pressures. Examples for this sort of behavior are numerous, from the stickleback fish to Darwin's finches. But evolution is not the only important concept that rests on variability; a fundamental phenomenon in psychology, operant conditioning, also operates under a similar model. As Neuringer (2004) explains: "Before his owner can reinforce Fido the dog for fetching a ball, Fido must approach the ball and perhaps accidentally touch it, as he bounds around the yard." In a lab, the reward might take the form of a pellet or a treat, in real life however, the reward could be nutrients that mean the difference between life and death. Even at a less general level, many day-to-day human activities can be made more efficient by trying different things and finding a better method. Examples would include finding new ways to drive to work or trying different methods in solving math problems. However, varying only to discover a better path can be harmful if one stumbles upon a worse path. Does the risk of potentially wasting time and energy on a less efficient strategy outweigh the benefit gained from (possibly) finding a more efficient strategy? In the long run, variability in evolution has uncovered more effective methods, but at the cost of some mutations that render a subset of the species unable to survive. While varying might uncover a better strategy, it is by no means free of casualties. The presence of diverse life today illustrates that these casualties are the cost of adaptation.

Learning

Variability can be more than just a tool to make discoveries; under certain conditions it seems to exhibit a beneficial mental or physical effect through an increased learning rate. In an experiment designed by Arnsen (2000), a group of rats were reinforced for varying reactions to test objects. These rats, when placed in a new room with 30 new objects (inside of each a food pellet was hidden), found many more pellets in 20 minutes than did the control group (which was not reinforced for varying). Quoting from Neuringer (2004): "the experimental rats explored more–they seemed bolder–and interacted more with the objects than did the controls, many of whom showed signs of fear." In this particular experiment there wasn't an obvious "new path" that was easily discovered by varying; instead the reinforcements promoted a "discovery" mentality which the rats used to quickly explore the object. The increased success that the exploring rats found can also be modeled with muscle memory and coordination in preschoolers. In an experiment discussed in class, two groups of children were told to throw a beanbag into a trashcan. The first group practiced on trashcans that were 3 feet away, while the second group practiced with trashcans that were 2 feet and 4 feet away, but not 3 feet. After both groups practiced for the same amount of time, every child in both groups underwent a test where the trashcan was placed 3 feet away. Surprisingly, the children from the second group were more successful! Somehow, practicing aiming at varying targets gave the children in the second group a better "feeling" of the dynamics of throwing the beanbag. The two examples have subtle differences; in the first, a variety of information improves the mental pathways involved in the creation of a strategy, while in the second the information improves physical coordination. The beanbag example is interesting because the children trained their muscles to be more effective, not only their minds. Taking an example from the previous paragraph, varying one's path to work would familiarize them with the area. It seems as if trying a variety of things gives the subject more feedback about the problem at hand, which allows for improved effectiveness.

Competition

Oftentimes in nature, an animal may be forced to compete with another animal for territory, mates, or some valuable resource. A mixture of economics and mathematics known as Game Theory can be used to model these sorts of competitions. Game Theory operates under the principle of analyzing all possible outcomes so that one can deduce the most effective choice(s) and expected reward(s). When playing the same "game" multiple times, sometimes the most effective

strategy might be employing a *mixed strategy*, so called because it involves playing a few select strategies at specific ratios to one another and generating these responses probabilistically. For example, lets say that Rose and Colin are competing parties and they each have two choices, A or B. After a numerical analysis, Rose could discover that her best option would be to play A 2/5 of the times and B 3/5 of the times. As long as the ratio of A's to B's remains 2 to 3 and the string of responses has no apparent order, Rose can expect the highest payoff independent to what her opponent Colin does. This way Colin has no way to guess which strategy Rose will play because her play is unpredictable. Here, variety (albeit a very specific kind of variety) is what provides the largest payoff specifically because it prevents the opponent from countering the strategy. Similarly, a bear might defend its territory from an intruder by jumping up on its hind legs, roaring, or charging. These aggressive and unpredictable displays might intimidate the attacker into thinking that this bear would do anything to defend its territory, and that the attacker should retreat. Behaving unpredictably can be a successful strategy.

Conclusion

One might have a few reasons for thinking variability is beneficial. Like in evolution, variety might allow for a discovery of a new strategy. Or as in the experiment with the rats or beanbags, variety may give more feedback (and therefore more information or knowledge) than a constant repetitive strategy. Finally, a variable approach is unpredictable, and can prevent an opponent from outsmarting a subject because it is impossible for them to predict the subject's actions. There may be a slew of other reasons as to why variability might be functional, but these are the first impressions that have come from thinking about examples from the readings or examples I have come across in other areas.

Last Paper: After a Semester of Class

Variability is still, I believe, functional. In the previous paper, I argued that variability had three central benefits: first that it encouraged discovery of a more efficient pathway; second that it aided in the learning process; and third that it was valuable in competition. There is one more critical point aspect of variability that I missed in my first paper: degeneracy. Degeneracy is a property that makes an organism or technology much more robust, and arises naturally from variability.

Supplementing Arguments: Discovery, Learning, and Competition

The idea that variation might uncover a better solution is a large part of Campbell's (and Simonton's) conception of the Darwinian model of creativity (Simonton, 1999). Just as behavioral psychology operates under a Darwinian model (elucidated in the first paper), so too can the generation of ideas, acts, works, etc. An idea is judged to be creative when it is adaptive and original. An idea with a low probability distribution (one that has not likely to be conceived) is one that is original. But how does one conceive of something that has never before been conceived? Campbell argues that blind variation is responsible. Whether we call it blind variation or random combinations, we're talking about the same idea. Any Darwinian theory that operates under the principles of first variation, then selection, is benefitting from variability because it allows for the creation of what before did not exist. Thus, it may be suggested that variation at all levels uncovers hidden solutions through a system of trial and error.

Variability seems to aid in learning. As another example, consider Langer's conception of mindfulness, which is described as an "opening up" to variability; a "flexible state of mind;" and an "openness to novelty" (Langer, 2005). When being mindful, according to Langer, "we are actively varying the stimulus field." Langer and others have conducted research that shows that mindfulness has positive effects on well being, learning, and other attributes. How might this process work? Imagine somebody is explaining something you don't understand. The words that this person says to you will activate and create new neural pathways in your brain, as they tell you their thought. One must "open up" to the concepts and ideas they are being told, to understand these ideas. In conjunction with the reinforced rat exploration and beanbag tossing examples, these ideas seem to imply that learning and discovery are measurably aided by variation.

Variability prevents the opponent from predicting and countering a strategy. In the previous paper I mentioned the idea of a mixed strat-

egy in game theory, a sort of "controlled variability," that maximized the outcome. It turned out that I was right on the mark; Glimcher brings it up as an example of how uncertainty or indeterminacy can be the best course of action in a typically deterministic system (Glimcher, 2005) . Another example that I had not considered is the unpredictable and variable escape patterns prey animals employ to evade capture by predators (Humphries and Driver, 1970). This "protean" (i.e. unsystematic) display can take the form of zigzagging, looping, spinning, or in groups scattering, and is an adaptive feature. The prevalence of protean defense speaks to its importance, and to the importance of variability as a means of besting an adversary.

New Argument: Degeneracy

Degeneracy is an artifact of variability (Edelman, 2001). We may consider a degenerate component to be one that achieves the same goal through different means, not one that is a redundant or exact copy. If an important degenerate component experiences a failure, one of the other components will step in to take its place. If an important component supported by redundant components experiences a failure, then the exact copies will also experience the same failure, and the entire system will fail. This makes systems with degeneracy much more robust because they can withstand failure from "all angles," so to speak. From multiple nucleotide sequences encoding a polypeptide at the genetic level, to uncountable paths of connectivity in neural networks, to equivalent body movements using different patterns of muscle contraction, examples of degeneracy exist at all levels. Though at first it may seem unintuitive, degeneracy is a product of natural selection. Because degenerate organisms are selected for (they are more likely to withstand environmental pressures), it can be said that they arise from the variable process that is Darwinian evolution. But the overarching lesson is that having a variety of ways of doing something will be more resistant to failure than having just many of the same backups. Though we only discussed examples in a biological setting, it's easy to see how the principle of degeneracy could be extended to engineering, technology design, or many others in which system toughness is critical.

Conclusion

To conclude, variability is crucial to almost all aspects of life as we know it. It arises in the most fundamental process of life: evolution. Within this struggle, it forms a part of every level: learning, competition, and success. With these arguments, the case for the adaptive nature of variability is convincing.

Miscellaneous

Summary

The next three papers are not thematically tied in any way (other than that they were covered in class). The topics range from looking at Campbell's model of creativity in soccer, to trying to get pigeons to vary under constraints, to outlining a model of the mind that allows for free will. The soccer one has highlights, so make sure to click the links.

An Argument for Creativity in Soccer

Simonton argues for Campbell's Darwinian model of creativity using evidence from a variety of backgrounds. Simonton discusses creativity in regards to art, science, and other areas, but fails to make much more than a passing mention about creativity in sports. In this paper, I summarize Campbell's model of creativity, and then explain why it is relevant to sports. I will then discuss the different levels in which creativity can arise in soccer, and end by presenting some famous "creative plays" in professional soccer.

Campbell's Model

Campbell advocated for a model of creativity analogous to Darwin's theory of evolution. In evolution, traits are hereditary, with some variety in the genes due to recombination and some random "noise" due to mutation. The environment then selects for a few "adaptive" traits, and they thrive. The traits that are not beneficial are tossed from the gene pool. The main idea is that from a variable group of options (some new some old), many are tested. Most of these options fail but a few succeed, many are neutral and remain unaffected, and the "popularity" of the successful ones grows. Campbell argued that the same sort of process exists in the process of generating ideas, art, or solutions to problems, etc., and that this sort of process can explain how creative acts arise. In Campbell's model, "blind" variations (i.e. unguided by anticipated needs) in thoughts are generated when approaching a problem. These variations have a certain probability distribution associated with them; certain thoughts might be more likely to arise than others. The environment then selects for the thoughts: by one's own brain, by other's opinion, and by the utility/truth/beauty of the thought or act itself. A creative act or thought is one that is both adaptive and original (i.e. has a very low probability associated with it).

Creativity in Sports

Variable plays are highly adaptive in all sports. A successful play in an athletic competition has two components. First off, it must cause the opponent to make an error or it must exploit an error already made by the opponent (though going back in time, one can always find a point where that error could have been prevented). A player can lead their opponents to err by being unpredictable or "inventing" a new play, thus making it difficult for the opponent to correctly guess the next move. The second important element of a successful play is that it must move the team forward or have some overall

positive effect. The variable play is one that is hard to predict because is always changing, and the creative play (a subset of variable plays) is the one that involves inventing something that the opponent and others believed to not be available.[1] Our conception of creativity here matches the definition given by Simonton as something with a low probability distributions associated with it (i.e. original), and something that must useful in some way (i.e. adaptive). Variable plays are adaptive for many reasons, but among them is the reason that they lead to creative plays. This is analogous to the idea of blind variations in Campbell's model.

Variability will be selected for in sports[2] because usually the opponent is an equally skilled competitor, and his or her expectation of the probability distribution roughly matches its true nature. It has been shown that competition can encourage true random sequence generation because it's the best way of being unpredictable (Rapoport & Budescu, 1992). Athletic competitions also foster variation for the same reason, but because of all of the variables and possibilities in soccer, unpredictability in soccer takes on a different form than in Rapoport et al.'s study. One way to behave unpredictably is to vary between expected plays, and another is to create a play. This isn't too difficult since in sports there are enough possibilities[3] that it is impossible to prevent all actions even if they are anticipated. An opponent will act on the plays he or she believes benefit him/her, and will remain ready to act on the plays that he or she anticipates, but can do nothing about.

Selection is the other important factor in a Darwinian process, and it arises organically in all sports. In short selected plays are those that are successful. Depending on what the player is trying to accomplish, he or she might be reinforced for that type of play, or he or she might be reinforced for trying new plays (i.e. varying). Every interaction is a selection event, and from these events a player's style is born.

[1] This is difficult to explain. Because each play is different, it allows for a variety of options. A creative play is "original" because the player did something nobody else predicted. But it's not just that the play is unpredictable, it's that nobody else believed the play could have existed. When a player creates a play, he or she is inventing a novel solution. Doing something like a simple pass would not be creative, because it is the expected action. A variable play is not always creative; one can alternate between doing the most predictable thing and least predictable thing. A creative play, however, is always unpredictable because of it's *newness*.

[2] Variability, not creativity. Creativity cannot be selected for, for the same reasons Simonton makes in his paper. Domain expertise is not correlated with creativity.

[3] But not too many; constraints make sports like soccer interesting!

Creativity in Soccer

From sports, lets narrow it down to soccer. In soccer, creativity can exist at two scales. At the larger scale, a team could be "creative" in their formation or their tactics. At the individual level, a player can be creative in his or her passes, "moves" for one-on-one encounters, feints, defensive style, runs (without the ball) into space to encourage a pass from a teammate, or even in ball control / passing / shooting techniques. What governs the players' probability distribution at every new situation? Physical inputs (i.e. position of other players, location of the ball, etc.), and previous encounters that have been selected for. The form of selection can change depending at what

scale being analyzed. At the tactical level win percentage is what selects, but at the individual level, a good pass, a good move or any minor success in individual effort will act to select.

Creativity can forever change the way to look at a situation. In 1976, Czech soccer player Antonin Panenka's creativity led to his country's victory over West Germany in the 1976 European Championship. A penalty shootout in soccer is used to determine the outcome of a tied game, and involves shooting the ball at a point 12 yards away from the opponent's goal with only the opposing goalkeeper standing in the way. The close proximity makes this much easier for the shooter than the goalkeeper. The usual tactic for the shooter is to make a hard shot towards the four corners of the goal, but of course this is risky because aiming near the edges might end in missing the goal altogether. Because the goalkeeper starts in the center, he must dive before the shot is taken if he is to have a chance at stopping the ball. In a moment where everything depended on Panenka's penalty,[4] his brilliant creative insight was to chip it lightly, straight down the middle. Easy enough for anyone standing in place to stop, it was a risky, and completely new idea. That style of shooting is now referred to as "a la Panenka" and is still an effective strategy in penalty shootouts, though not as effective as it was for Panenka because goalkeepers are aware of it now. A creative play like this one is useful because its unpredictable, but once it has been performed it is just another thing to expect. Either way, it has had lasting impact.

[4] If he scored, his country was the best in Europe, if he missed, the game would go on and the West German giants would probably have defeated his team.

Creativity can arise in cases where an obvious outcome seems inevitable. A player who can "make things from nothing" is a valuable asset. On such player is ex-Real Madrid player Guti, who was the master of the assist. The assist is the pass right before the goal, usually a clever pass that puts an attacker in a favorable position allowing the player to score a goal. Being "one on one" with the goalkeeper is one of the most favorable positions with a high scoring percentage. In a league game in 2009, Guti finds himself in front of the opponent's goal; the only thing standing in his way is the opposing goalie. This situation occurs about 5 or so times every game, and the outcome is (almost) always one of the following: the shooter misses, the shooter scores, or the goalkeeper blocks the ball. Instead of choosing any of those options, Guti creates his own. Without looking, he uses his heel to pass the ball directly behind to his teammate (Benzema), who kicks it into an open goal. After all, the only position more favorable than having one person in the way of the goal is having an open goal! It's important to note that even though defenders surround Benzema, none of them expected the pass and so they don't have time to react when he gets the ball. Watch the defenders care-

fully, had any of the defenders been able to predict what was going on they could have easily stepped in and intervened. This is just one example of Guti's assists. He thrived because he constantly looked for passes that nobody else saw, and was good at seeing them. In the years I watched him play, I saw many of his great passes and also many of failed attempts. The highlights that remain are his successful plays, but if we were to look at his failed plays or his successful "not creative" plays, we might see that Guti also had a fixed creative ratio just as Campbell predicts.

Players must know each other very well to play well together. They must be able to predict each other's "probability distribution," when the make a leading pass. A player might make a provocative run, drawing the attention of the passer to make the pass. Other times, the person making the pass might encourage the person making the run, to run to a particular place. Either way, we have one person actually initiating the creative act, but other person must be on the same page so that they can quickly react and benefit from the situation.

Conclusion

Soccer breeds creative actions. Even if an action has been performed before, a player may create something they had never seen or done before. Campbell's model of creativity can be extended to cover creativity in soccer and in sport.

Neuringer vs. Schwartz

Here is a problem that perhaps you can help me solve. I've argued - in class and in many published papers - that when variability is reinforced, the animal or person doesn't learn to "do anything" but rather learns to vary within a class (or set) of defined behaviors. However, Page & Neuringer maintain that Schwartz was not successful in reinforcing variability in his pigeons because he "constrained" the birds to 4 responses on each key. Explain the apparent inconsistency; and propose an experiment to test your explanation.

Response

The inconsistency mentioned is that Page & Neuringer (Page & Neuringer, 1985) criticize Schwartz's experiment (Schwartz, 1982) because he had the 4-max-response constraint, yet they ignore the fact that fundamentally, the idea of reinforcing variability requires constraints! Why were Page & Neuringer able to train pigeons to respond variably under their constraints, while Schwartz failed using his constraints? The answer, I think, lies in the difficulty and the timing of the constraint.

In both experiments, the pigeons were given the same type of pre-training which familiarized them with reinforcement coming from pushing both left and right keys. Page & Neuringer then demonstrated using an ABA design that the pigeons succeeded in varying like a random generator without Schwartz's constraint (A), but failed to adapt when Schwartz's constraint was imposed (B). But even without Schwartz's constraint in (A), the pigeons have to behave variably under other constraints like: varying left and right keys, varying within eight sequences, and avoiding the 3.5 second timeout, just to name a few. If the pigeon's were able to follow all of the other constraints without a problem and not Schwartz's, then we might suspect the difficulty of the constraint can vary or that somehow the other constraints were learned during pre training.

When training an animal to perform a complex task, one must guide the animal through the process using shaping. In *Don't Shoot the Dog*, Karen Pryor presents a list of ten laws of shaping, of which the first two are particularly relevant:

1. Raise criteria in increments small enough that the subject always has a realistic chance for reinforcement.

2. Train one aspect of any particular behavior at a time; don't try to shape for two criteria simultaneously.

Are these criteria being followed in Page & Neuringer? In both pre

training and the experiment, the expectations for behaviors were increased in small increments, pushing keys and later pushing the same keys randomly. Also, in both phases the pigeon is being trained to perform one particular behavior at a time.

If we examine the experimental condition with Schwartz's constraint using these two laws, we see that the second law is not violated since Page & Neuringer reward the pigeons for varying and then later for varying under the four key constraint. In each case they are shaping one criteria. But if the pigeons are failing to operate under Schwartz's criteria, then the problem must be with the first law: that the increment is not small enough. If this really is the problem, then one could teach the pigeons to vary under Schwartz's constraint by breaking the difficult constraint[5] down into more manageable increments.

A study to show this would start out as Page & Neuringer's did. In the first experiment, the pigeons would be rewarded for varying within four sequences. Then in the next experiment pigeons would be rewarded for pushing two left keys and two right keys. The expectation here would be that the pigeon settles on one combination. Then in the third experiment, the pigeon would be rewarded for behaving variably under a two-right-two-left constraint. The experiment could be repeated with six and later eight sequences. This order ensures that variability and the equal key constraints are being taught separately, and that the equal key constraint is being taught at its most basic level. Only after both behaviors have been learned, does the requirement increase from four to six to eight keys in a sequence. If the pigeons failed to learn this constraint using the method outlined, that might indicate that the 4 left and 4 right constraint combined with varying is too difficult.[6] Then the question becomes: at what point do the constraints become impossible for the birds to keep track of? What constraints don't work? The benefit of building from 2 by 2 to 3 by 3, and eventually 4 by 4, is that we'd see where the pigeons fail. Or perhaps, we'd see that they wouldn't even make it past the 2 by 2 case.

[5] And this constraint is difficult, I think. Neuringer claims that some animals are equipped with a "stochastic random generator" that seems to better approximate true randomness as memory decreases (we mentioned in class an experiment in which people were able to behave more randomly after drinking alcohol, which hinders memory). If this is really the case, then behaving randomly with a 4 left and 4 right key constraint would be very difficult because one process calls upon memory (how many left keys have been pressed?) and the other (generating a random sequence) calls for a lack of memory.

[6] After writing this, Allen pointed out that Schwartz tried shaping performance in another experiment, and even still was unable to get the birds to behave as he wanted. Maybe it is too hard?

The Nonlinear Cogito Model

Propose and argue for a theory of volition (or free will). The theory can be, but need not be, original to you, i.e. you can argue for previously suggested theory. A combination of your own ideas with previously presented notions is also acceptable. Is your theory testable, either now or potentially in the future? If so what is test? If not, offer some other reasons to accept or entertain your theory.

Response

In the standard argument against free will, determinism is refuted on the basis that it relieves one from all moral responsibility. The aim of this paper is to present a model that champions determinism while maintaining an individual's moral responsibility. The paper will begin by reviewing the Cogito Model, then discussing why the QM (indeterministic) portion of the model must be thrown out. Then, we propose a nonlinear model and discuss its implications.

The argument for and against free will has spanned centuries and has focused around two camps: determinism and indeterminism. To begin with, we will use Bob Doyle's definition of determinism, that "the philosophical idea that every event or state of affairs, including every human decision and action, is the inevitable and necessary consequence of antecedent states of affairs" (Doyle, 2009). Indeterminism, then, occurs when opposite is true: every action is not the inevitable consequence of prior events. The standard argument against free will contests that neither full determinism nor full indeterminism can hold true, because in both cases moral responsibility is taken away. For determinism, this conclusion is reached because all actions are determined, so one can only will what has been determined, and thus has no choice in the matter. Indeterminism prevents a causal flow of events, so that one cannot be held accountable for actions whose effects could not have been predicted. Doyle's Cogito Model combines the two, keeping the benefits of both while tossing out the drawbacks. The model has two levels: a Micro Mind which operates through indeterminate quantum randomness and a Macro Mind that retains adequate determinism. The Micro Mind generates noise (which means that one's actions are not totally determined because chance is at the source) while the Macro Mind logically and deterministically selects from this noise (so one is held accountable for their own actions). The Cogito Model elegantly sidesteps the standard argument against free will while at the same time accounting for the vast amount of "new" ideas that humans generate.

The quantum aspect of the Micro Mind seems difficult to fathom,

and the dust has not completely settled about what exactly Quantum Mechanics entails. To begin with, this alteration is warranted because, for the author, any level of true indeterminism is incredible.[7] The foundational component of all of science is it's determinism, and it has famously made the indeterminacy of the standard Copenhagen interpretation Quantum Mechanics hard to swallow for many.[8] In the current state of affairs there are other formally developed (but not nearly as popular) descriptions of Quantum Mechanical phenomena that make the same predictions as the Copenhagen interpretation. The benefit of some of these alternative theories is that determinism is maintained, but one must pay the price of breaching a fundamental law: the universal speed limit. If one accepts a so-called (deterministic) "hidden variable theory" then the "quantum effects" seen in the quantum realm are still the same, the difference is in the interpretation. For example, let's take some of the astounding behaviors at the quantum scale and apply them to macroscopic objects, as an analogy. Imagine that I pulled a ball out of a hat of five red balls and five green balls. Without looking at the ball, I hide it in a covered box. The Copenhagen interpretation asserts that until I open the box and look at the ball, it is in a "superposition" of both colors. The hidden variable interpretations suggest that the ball is red the whole time. Both theories predict that I could get a green ball 50% of the time and a red ball the other 50%; the distinction occurs when that probability translates to reality. In the hidden variable model we get determinism, while in the standard Copenhagen interpretation we get indeterminism. Now lets imagine that the Copenhagen interpretation is the correct one, and that indeterminacy does exist at the quantum level. At this stage it is still unclear whether or not the brain is even governed by these quantum effects (though Doyle and Glimcher are convinced and Brembs points to a few provocative studies) (Brembs, 2011). Since indeterminism in Quantum Mechanics is still up for debate, and the uncertainty in whether or not the indeterminacy in quantum effects affects operation of the brain, one can see why other models could be considered.

A nonlinear chaotic model is proposed to govern the Micro Mind because it essentially produces the same "noise" achieved by the quantum system, without the indeterminacy. The hallmark of a nonlinear system is that an infinitesimal change in input creates a major change in the output, and this can make it very hard to distinguish between a random dataset and a dataset produced by a nonlinear operation. Justin Miller presented on a paper that looked at the probability of mutations in DNA (Caporale, 2003). It was found that some areas of the DNA strand were more likely to mutate than other areas. One could argue that this effect is constrained randomness,

[7] This may seem like a strange argument to make: I don't believe it because it doesn't make sense to me. (Especially for an undergraduate Physics major.) I understand what the Copenhagen interpretation implies and I've read about the experiments and taken the class and all of that. But I can't really comprehend the belief that the world is indeterministic; that everything I've ever observed is deterministic except for in this one realm that I can't really see, makes it a hard sell.

[8] So is it possible that with a majority of the Physics community is wrong about QM? Sure. Is it likely that they are wrong about QM? No. But still, the possibility of determinism at the quantum level cannot be completely ruled out.

or that it is nonlinear. Distinguishing between the two can be very difficult,impossible even, depending on the number of inputs or variables governing the system. I believe that at the foundation these systems, the noise is nonlinear rather than random. So why would the Micro Mind benefit from a nonlinear modification? If all of the inputs in the system are so complex that the many equations governing the system will never be found, then the system has the appearance of randomness, while maintaining determinism. A nonlinear Micro Mind creates a pool of variety based on inputs and parameters. Inputs could include things like environment [9] and genes. Every brain would have its own set of parameters that would vary slightly from brain to brain. Because so many things influence thought and decision making, this model would account for variability of all kinds, just like the Cogito Model would.

[9] For example: what you are thinking about now, what you read yesterday, who you talked to and what they said, the time when you, etc.

A nonlinear Micro Mind means that the system is deterministic. And since we will leave the Macro Mind unchanged (it's function is still to pick out of the pool of options, now generated through a nonlinear process) then we are left with fully deterministic system. However, I propose that this model is really the same as the Cogito Model. Simply put, I think that the nonlinear model explains where the "random" information comes from, whereas the quantum model doesn't. The result is still the same. The complexity of the system, the potentially hundreds of inputs and parameters, make the causal flow impossible to follow, in a practical sense. Theoretically this system could exist, but testing for it with current technology is impossible. If some equations do in fact govern this system, then they could only be found by incredibly powerful super computers in the very distant future. However, advances in nonlinear dynamics or in quantum mechanics might yield great insight into the problem. If quantum systems turn out to be indeterminate, then I might have to alter my allegiance to the Cogito Model. But I will remain held to the determinate position as long as I can.

In summary, my model is functionally similar to the Cogito Model, but ideologically distinct. The model suggests that free will does not exist. However, the complexity of the system at the very least allows for the illusion of free will because it so closely matches a system in which free will does exist.

Self Experiments

Summary

Self-experimentation is not the most objective method of collecting data, but it is a quick and fun way to test small observations. In this chapter you'll find four of my self-experiments conducted for this class. My ideas came from things I had been wondering about (unconsciously) for years, and had never thought to test. The first involves waving hello to people to test their response classes. In the second, I examined what effect exercise had on my cognitive abilities on the day *following* exercise. The third experiment I look for behaviors that affect my sleep quality. And the fourth and final self-experiment measures reading comprehension of upside-down text.

When brainstorming experiments, I was able to come up with more than I had time to test. Here are some my other ideas, in rough form:

- How do notifications on my phone affect my concentration? Use an ABA design with an experimental condition allowing notifications every two hours on the hour. Test concentration with random alerts: was I focusing on the task at hand when the alert came up?
- How does setting time limits (a schedule) affect the quality of my work? Am I more efficient? Do I work for fewer hours?
- How does reading a novel for fixed amounts of time every day affect my concentration?
- How does concentration change before and after lecture? What about creativity?
- What are some techniques for implementing things I learn about in Psych into my everyday life? What will help motivate and remind me when they are relevant?

Maybe I'll work on these in the future. For now though, I'll leave you to read the four experiments I conducted!

Waving Hello

Every day at around noon, I take a 6 minute walk from my thesis office in the Physics sub-basement to Commons. Before telling you about the specifics of my walk, I should mention that taking a walk across the Reed College campus is not like walking down the streets of downtown Portland or the local mall. The faces I see when walking around town are unknown; people I have never seen and will probably never see again. But at Reed, I do recognize most people. After all, I have been living on campus for the past three years, and there are only about 1400 students. Most people I have not talked to, but I would say I recognize (know of them or know them by face) at least 60% of the student population, am acquaintances with about 25% (know them by name), am "friends" with 10% (actually have had extended conversations), and then I have a few friends who I know really well and I would estimate that to be about 10 to 20 people.

So, what does this mean about my walk? Well, if I run into the 10 to 20 people I know really well, then I will usually stop and talk to them or at the very least exchange a few sentences as we approach one another. Crossing paths with a friend or acquaintance requires less of an engagement, but still we must still exchange a dutiful nod or a one-word acknowledgement. Finally, the last 60 % of students I recognize often doesn't require acknowledgment, except in rare cases. All in all, I exchange acknowledgements with about half a dozen students on my walk to the cafeteria, I think about saying something to another three but in the end remain quiet, maybe about 1 to 2 professors, and in about one in every 2 walks I run into someone who I stop and talk with. That is of course, if I escape the Physics building without walking past any other Physics majors (very likely, since our offices are all in the same place), any professors, or anyone else who works in the department.

My description might lead you to think that I am a social butterfly (I am not) or that I am hyper-aware of social cues and requirements (I am). I mention this to give the reader an idea of how many times a day I have to wave hello to people! Many, many times! Over years of practice, I have developed a variety of phrases, [10] tones,[11] and physical motions[12] that I can mix an match to create a variable acknowledgement.

One interesting thing that I've noticed over the past few years is that if I wait until the last second to say hello to someone, they will repeat the word I use. If I really wait until the last second, they will even repeat the tone that I use. I've noticed something similar with a wave or a nod.

This experiment hopes to probe at how the system of social re-

[10] "hey," "yo," "what's up?" "how's it going?," etc.

[11] the "cool guy" start-high-end-low tone, the attention grabbing start-low-end-high tone, the eager-beaver tone, the mono-tone, etc.

[12] the barely-lifting-my-hand-wave, the regular-wave, the cross-campus-exaggerated-ironic-wave, the head-nod-up, the head-nod-down, the smile, the eyebrow-lift, etc.

sponses might work. The idea is that every person draws their response to an acknowledgment from a possible class of responses. Even though variability of a response is usually rewarded (no one wants to repeat exactly what was said to them) sometimes a mirrored response occurs anyways. It is hypothesized if within-class response probabilities differ, then it may take more time to access an intermediate or low probability response than a high (or strong) response, meaning the subject will produce a mirrored response for last second acknowledgments.

Experiment 1

There are three possible dimensions to an acknowledgment: the word choice, the tone, and the physical component. In Experiment 1, word choice and tone are held constant and the physical component is eliminated. The question was: At what distance is a mirrored response more likely to occur?

Methods

The word "hey" was used as the acknowledgement and was said in the same tone (as much as possible). Eye contact was avoided until the moment of acknowledgment, at which point eye contact was made and the acknowledgment uttered. The distance between the experimenter and the subject at the moment of exchange was varied, in the hope of finding a "critical distance," though what really matters is the critical time[13] (i.e. a response time). The approximate distance (1 and 4 meters), the subject, and the response (matched tone and word) were recorded on a note taking application on my phone (often what served as the "distraction" when avoiding eye contact upon the approach), and later transferred to a sheet of paper. It should be noted that there were many situations in which the data was not recorded explicitly, but the experiment was performed many times (20 times) and a general impression was formed.

[13] Though one could systematically vary time and distance in order to test this conjecture

Results and Discussion

The data presented in Table 1 shows that almost no one used the same tone, and only about six of the 20 or so subjects repeated the same word (it's also a pretty common greeting, so its not unexpected). Furthermore, the response rate of a mirrored word and the distance to the subject did not seem to be correlated. That is, the people that did respond with a "hey" did so when further away and when close together. These results go completely against the predicted theory.

	1 meter	4 meters
Mirrored Tone	10%	0%
Mirrored Word	20%	40%

Table 1: The percentage of mirrored responses, broken down by tone and word, for acknowledgments at two different distances.

The results from the first experiment suggested an unfounded assumption was made in the methods-namely that by avoiding eye contact with the subject, he/she would not be expecting the acknowledgment. While the experimenter was looking at his phone hoping to surprise the subject, the subject recognized the experimenter and prepared (unconsciously, probably) an acknowledgment. In fact much to the frustration of the experimenter, many of the times when running this experiment, the subject was the first to acknowledge the experimenter!

Another trend that appeared was that people that were not as close were more likely to have a mirrored response. Almost all close friends showed a variable response, whereas a much higher percentage of the people who may not have been expecting an acknowledgment showed a mirrored response. Both of the above points suggest that the idea is still valid, but that this experiment was not the best way to go about it. There are two clear extensions to this experiment.

The first is to fix the issue of the subject preparing a response when seeing the experimenter off at a distance. The problem could be avoided by positioning the experimenter in such a way that the subject would be unable to see him. In fact, on the handful of times this was attempted,[14] the word and tone were mirrored in most of the cases. Clearly many more data points must be taken before drawing a conclusion, but this seems like a possible direction.

[14] For example: unexpectedly encountering someone as they exited the bathroom, waiting by the doorway inside a building, leaning behind a column at the entrance of the library, etc.

The second way to investigate this might be to exploit the expectations of the unknown people who pass by. Because these subjects are not expecting acknowledgement they would not "prepare" for an encounter, and they might exhibit the mirrored response.

Experiment 2

In Experiment 2, a constant physical acknowledgment was used (no verbal component). What is the rate of mirroring?

Methods

A short wave was used as the constant acknowledgment in this experiment. It consisted of lifting my hand for about a second and making eye contact with the other person, and then bringing my hand back down. Usually a physical greeting is saved for when a verbal greeting is not appropriate, like across long distances (5 to

20 meters) or through the window of a classroom or something like that. Distance was *not* varied in this experiment, based on the idea that a physical greeting is not as dependent on distance as a verbal one. Results were again recorded or remembered with about 20 total trials.

Results and Discussion

The rate of mirrored responses was much greater for the physical acknowledgment than for the verbal acknowledgment. In almost 75% of 20 trials, people responded with a wave similar to the one made by the experimenter. There was also a notable difference in response time: the wave was reciprocated almost immediately as if it were a reflex or an instinct, whereas subjects tended to take their time when responding verbally in Experiment 1. This finding supports the theory that with less time to react the subject must draw upon a limited class responses, so in most cases that class consists mostly of greeting that she just witnessed and may be one of her go-to greetings. In comparing the two experiments, an interesting question arises: why does the subject feel like they must respond more quickly with a wave than with a word? In other words, why are the responses faster, thus more likely to be mirrored, in the second experiment? One reason might be that a physical greeting can be reciprocated immediately across all distances (within reason), where as there is a much greater delay involved in verbal recognition due to the time of travel and the complication of the task (i.e. processing language vs. a motion). Another possible cause is that because subjects were further away during experiment 2, they may not have been expecting the wave. The subject may have been preparing for a verbal exchange when closer together, and the wave was totally unexpected which meant they had to draw from the limited class. One limitation of this study was that the wave that was used is pretty standard, and the subject might have responded with the same wave whether or not the experimenter used a nod, a smile, or some other form of physical acknowledgment. I think the results were pretty conclusive, but just how conclusive remains to be seen. One way to combat this would be to have two or three standard acknowledgements (wave, nod, and smile), and then the percentage of mirrored responses in each group (percent wave, percent nod, percent smile).

General Discussion

It was hypothesized that waiting until the last second to greet someone means that they must draw their response from a more limited

class than if they were given more time. What was found was that an unexpected acknowledgment, which can in some but not all cases be a late response, is what caused the narrowing of responses. While performing the experiment, there were a few other ideas I had. For example, might we expect that someone with more experience might have a larger response class? If this were the case, we would expect people who spend a lot waving or walking by people on campus (professors) to be more likely to respond variably. After trying in this experiment to find mirroring, it might be interesting to consider what kinds of situations bring about variable responses in students. One could try using non-standard acknowledgments and see if those were mirrored. That is, will a novel response be mirrored if it is not in the short-term response class of the subject, or will the subject only mirror acknowledgements if they are within a certain class of acknowledgments that have been seen before and that the subject is expecting (as shown in Fig. 1)? Testing this would involve repeating experiment 2 with a brand-new or rarely-used acknowledgment. Any mirroring in that case would disprove the overlapping classes theory.

What relevance, if any, does an experiment analyzing greetings have to the real world? Because this process works by drawing from a class, it suggests an inherent variability in human responses because a particular response is never guaranteed. Whether this is a "chaotic process" in which one response from the class is chosen based on small encouragements from the outside world, or a completely random one, is unknown. Does this apply to other aspects of social human interaction, like finding topic of conversation at the water cooler in the work place? Does this apply to opinions we hold about things like political parties (as was suggested in conference in The Nature and Origin of Mass Opinion, by John Zaller)? As we see, there might be more variability in our world than we like to imagine.

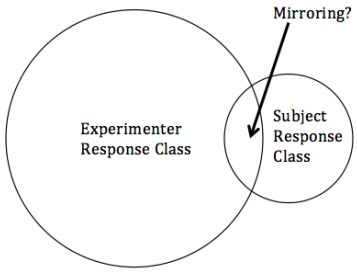


Figure 1: The response class of the experimenter and the subject. The response class of the experimenter is much larger because he has time to prepare an acknowledgment, whereas the subject will be forced to respond quickly and will therefore have a smaller response class (though given more time, it could grow larger). Will mirroring occur only if the acknowledgment made by the experimenter lies in the response class of the subject?

Self Experiment: How does Exercise Affect Cognitive Ability on the Following Day?

Miguel Conner
Reed College

It is commonly thought that exercise imparts a variety of positive effects, both on the mind and the body. A self-experiment was conducted to investigate specifically the cognitive benefits exercise might provide. By taking a series of small tests every morning after waking up, I hoped to establish some measure of cognitive ability. The data from these tests were to be tracked and grouped into one of two options: data after having exercised, and data in which I didn't exercise before. The results were mixed and indicated that while exercise improved some test scores, it decreased scores on others. Overall, the conclusion seems to be that exercising increases scores, though better cognitive tests could yield more insight into the problem.

Introduction

Research in a variety of fields indicates that regular physical activity can have multiple positive effects on mental functions (Hillman et al., 2008). Since I perform physical activity of the aerobic variety a few times a week, I thought it would be a great idea to compare my cognitive abilities before and after exercise.

How does one actually measure "cognitive" abilities? There are a variety of tests I could take, but the longer the tests, the more cumbersome it becomes to take the tests, so I need one that will be relatively quick (15min). Also, I couldn't really use an IQ or Wonderlich test, because there is a limited availability of these online, which would limit the number of data points. This constraint also means that these tests must be generated randomly under specific rules, so that the tests are about the same difficulty but remain unpredictable.

Of course, like anything, the more one practices something the better one will get. This means that after a certain period of time, I will be able to score better on these tests independent of my cognitive ability, because I've taken the tests many times. This problem is circumvented by averaging all results from the day of exercise, then averaging all of the results from the day without. As long as I more or less alternate the days of exercise with days of rest, I can expect these imbalances to average out. This will render the effect of my improved test-taking abilities negligible.

Studies in academic journals, common sense, and mothers have all said that sleep can have a significant effect on mental function. For this experiment to be successful, then sleep *must* be controlled. This includes the initial and final times of sleep as well as the duration.

As long as the diet is being varied mostly randomly, the effects should cancel out.

The independent variable is the amount of physical activity (either some or none), and the dependent variable is the test scores. The hypothesis is that on average, the scores on all three tests will be improved on days directly following exercise.

Method

This experiment was performed by the experimenter, Miguel Conner, on himself. The preliminary data only includes 4 days worth of data, though many more data points plan to be recorded by the time the final version of this report is due in December.

Here "exercise" is the usual 2 hour sports practice at Reed (either soccer on Wednesdays and Fridays, or ultimate frisbee on Tuesdays and Thursdays), from 4 to 6 PM. Games on the weekends, either soccer or ultimate, also count. I do not attend all of the practices for both teams, and expect that as the semester goes on I will be able to attend even fewer. I generally go to 3 or 4 of these events a week, which means I have 4 or 3 days, respectively, during which I don't "exercise." The exercise days will probably be picked pretty randomly.

Because sleep is an important variable that could easily affect results, sacrifices were made in order to accommodate a regular, 8-hour-a-night sleep schedule. In bed by 12 PM, and awake by 8 AM.[1]

Data was collected every day, on days that I exercised and on days that I didn't exercise.[2] The data collection portion of this experiment was incorporated into my daily morning routine. My day begins at 8:00 AM when the alarm clock next to my bed goes off. I remain in bed for 2 minutes until

[1] I tried to include two separate categories: hours slept and hours in bed, that way I can also see how easy it is for me to fall asleep. I also include a "sleepiness" rating in my data sheet: on a scale out of 5, how tired I feel after taking the test.

[2] Technically, a within subject design.

the alarm on my cell phone, on the other side of the room, goes off. After turning *that* off, I rest on the couch for about 5 minutes, slowly building the courage to shower. By 8:10 I am showering, after which I brush my teeth, shave, and put in my contacts. By this point it is 8:25, and I am ready to take my three cognitive tests.[3]

The first test is a reaction timer from the website Human Benchmark.[4] This test involves clicking the mouse as soon as the screen changes from red to green. The online test automatically averages the reaction times from 5 trials. I take this test twice and pick the best score, giving me a chance to get "warmed up" or in case for some reason I lose focus for an instant, I am not severely penalized. Hopefully, this test provides some insight into how quickly my brain is responding to outside stimuli, and gives some idea of cognitive response rate.

The second test requires solving 15 addition or subtraction problems, between two numbers between 0 to 5 digits. This worksheet is randomly generated online at SoftSchools.com, with the following settings: Rows: 3, Columns: 5, Min Number: 0, Max Number: 10,000, Bottom Min Number: 0, Bottom Max Number: 10,000, Show answers (Check).[5] By timing how long it takes me to find 15 answers,[6] I can get a sense as to how efficiently my brain is going through these simple calculations.

The third and final test is a logic game involving a circle and a square. The game can be found on CambridgeBrainSciences.com.[7] A randomly generated sentence along the lines of "The square is not bigger than the circle," would appear and beneath it, a picture of an orange square with a smaller blue circle inside the square. One must choose either "True" or "False," (in this case, False!) and then the program tells the user whether they answered correctly or not, and then it spits out another question. The total time of the test is 1 minute and 30 seconds, and the idea is to answer as many correct questions as possible. Here, incorrect responses are already penalized with -1 and correct responses are rewarded with a +1. This test involves a few important elements: a very basic verbal comprehension, a spatial diagram that one must decipher, and a logic test which will combined, shed light onto some of the functions going on in my brain.

After each test, I record the relevant information in the data collection spreadsheet. I leave breakfast for after the test, and then I leave for Reed at around 8:40.

The raw data and data analysis are attached to the end of this document.

Results

The test results were averaged by days on which exercise preceded the test, and days which exercise did not precede the test. These are shown in Table 1. Note that in the first two tests a lower score (faster response) is a better result, while in the third test a higher score (more correct questions) is better.

Table 1
The mean test results with and without physical activity the previous day.

	Test 1 (ms)	Test 2 (min)	Test 3 (# correct)
Exercise	261.2	191.7	16.3
No Exercise	252.9	204	18.1

The data from Table 1 indicates contradictory behavior. The first two tests show that exercise improves scores. In the third test, scores actually improved on days after *no* physical activity, contrary to the hypothesis and the literature. And by a significant amount too; a difference of 1.8 questions. Figures 1 through 3 show the scores across the many days of experimentation.

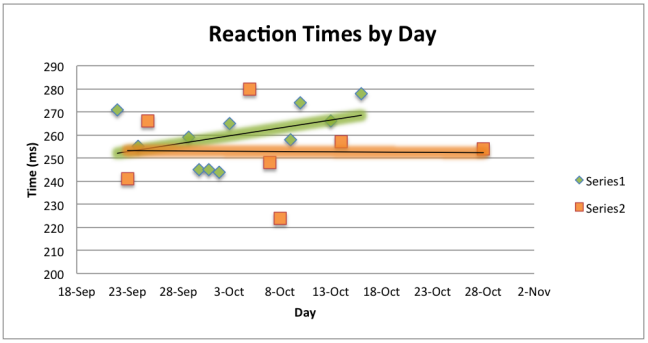


Figure 1. Results of the first test, length of reaction time, across the month. Green diamonds represent days after playing sports, and orange lines are days without exercise the day before.

In all three cases, there are clear improvements in scores for both conditions, though in some cases scores improved more in one condition than in the other. Scores improved for the "automated" tests, the tests that don't require much thinking, only instinct and training.[8] For the task that required really "thinking" on a deeper level, scores decreased. Does

[3] The description of my morning routine serves to emphasize regularity, and that conditions are as similar as possible in the moments leading up to the tests.

[4] `http://www.humanbenchmark.com/tests/reactiontime`

[5] `http://www.softschools.com/math/worksheets/addition_subtraction_mix.jsp`

[6] Incorrect scores are penalized with an added 30 seconds.

[7] `http://www.cambridgebrainsciences.com/play/grammatical-reasoning`

[8] By this point, five digit addition is instinctual...

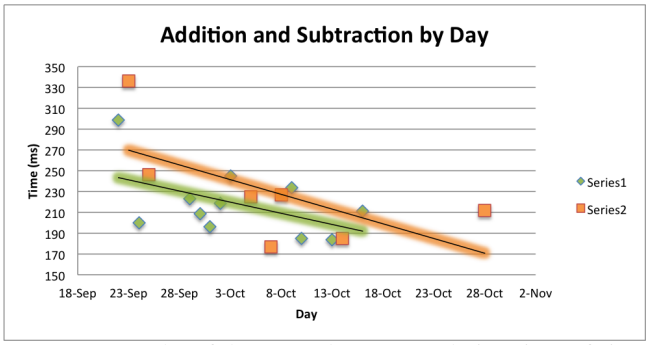


Figure 2. Results of the second test, completion time of simple math problems, across the month. Green diamonds represent days after playing sports, and orange lines are days without exercise the day before.

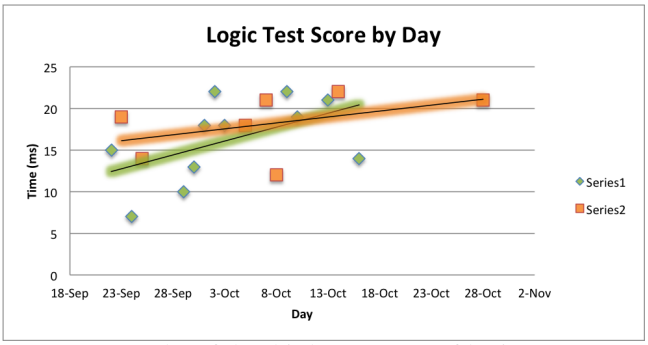


Figure 3. Results of the third test, score of logic test, across the month. Green diamonds represent days after playing sports, and orange lines are days without exercise the day before.

my tired body affect my mind's efficiency? This would be a troubling finding.

-Sleep was also a critical factor in this study, though the results will not be discussed here (check the section after the references for graphs).

It might be worth recalling some of the limitations of the study. First off, sleep cannot be completely controlled despite the best efforts of the experimenter. Another limitation might be the varying vigor of the physical activity, some days might require more running than others. This could be aided with an additional parameter, like a rating out of 5 describing the intensity of the activity. Also, because the time between the actual physical activity and the time of test taking is more than 12 hours, some of the effects of exercise might have worn off. While a test could be taken directly after exercise, the point of the study was specifically to investigate how the following day was affected. This way I hope to imitate how my learning in class may be affected by my exercise habits.

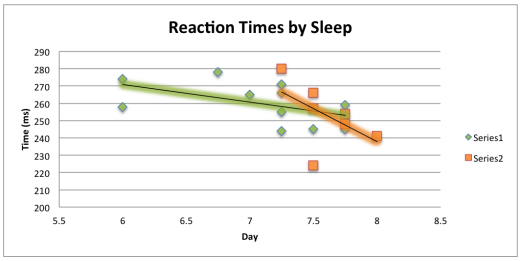
One major improvement that could be made would be in the design of the cognitive tests themselves. Perhaps more complex tests, or tests involving memory would be more instructive. [9] Another improvement could be made in measuring quality of sleep, in order to account for sleep as a possible variable in the study.[10]

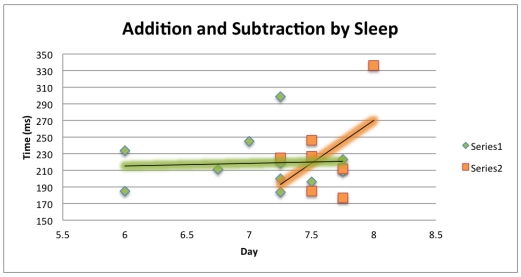
References

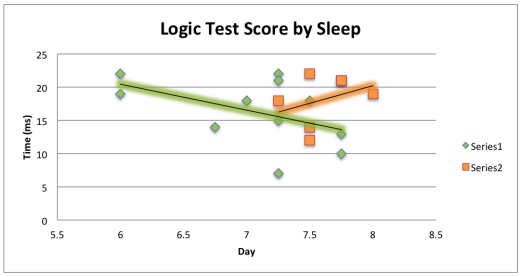
Hillman, C., Erickson, K., & Kramer, A. (2008). Be Smart, Exercise Your Heart: Exercise Effects On Brain And Cognition. *Nature Reviews Neuroscience*, 9, 58-65.

More Data

I was also curious to see how sleep affected the results of my test. The graphs below show that for different conditions, sleep had different effects on different tests! Good luck finding a pattern! (Note: where the x axis reads "Day," it should read "Hours of Sleep.")







[9] For example, a test that generates 4 random numbers and forces me to remember then input them. Any correct input would increase the number of digits in the sequence, and any incorrect input would decrease the number of digits.

[10] Use *Sleep Cycle*!

Self Experiment Data								
Date	Reaction Time of Fastest Test (ms)	Time of Addition Problems (sec)	Number Incorrect (+ 30 sec)	Score of Logic Test (in 1:30)	Hours in Bed	Hours Slept (night before)	Sleepiness (out of 5)	Sports Yesterday?
22-Sep	271	239	2	15	8	7.25	3	Yes
24-Sep	255	200	0	7	8	7.25	2	Yes
29-Sep	259	193.00	1	10	8	7.75	2.5	Yes
30-Sep	245	179.00	1	13	8	7.75	1.5	Yes
1-Oct	245	196	0	18	8	7.5	1.5	Yes
2-Oct	244	189.00	1	22	7.5	7.25	1.5	Yes
3-Oct	265	215.00	1	18	7.5	7	2.00	Yes
9-Oct	258	174	2	22	6.5	6	2.50	Yes
10-Oct	274	185	0	19	6.5	6	2.00	Yes
13-Oct	266	154.00	1	21	8	7.25	2.50	Yes
16-Oct	278	181.00	1	14	7.25	6.75	3.50	Yes
29-Oct	274	195.00	3	17	7.5	7.25	3.00	Yes
Average	261.1666667	191.6666667	1.083333333	16.33333333	7.5625	7.083333333	2.291666667	Yes

Date	Reaction Time of Fastest Test (ms)	Time of Addition Problems (sec)	Number Incorrect (+ 30 sec)	Score of Logic Test (in 1:30)	Hours in Bed	Hours Slept (night before)	Sleepiness (out of 5)	Sports Yesterday?
23-Sep	241	306	1	19	8	8	1.5	No
25-Sep	266	186	2	14	7.75	7.5	2	No
5-Oct	280	225	0	18	7.5	7.25	2.5	No
7-Oct	248	177	0	21	8	7.75	1.50	No
8-Oct	224	197	1	12	7.75	7.5	1.50	No
14-Oct	257	155	1	22	7.75	7.5	3.00	No
28-Oct	254	182	1	21	8	7.75	2.00	No
Average	252.8571429	204	0.857142857	18.14285714	7.821428571	7.607142857	2	No

Self Experiment: What Factors Affect My Sleep?

Miguel Conner
Reed College

As a student, it's easy for me to find myself staying up late doing homework, and not getting as much sleep as I know I should. What factors can I cut back on, so that I sleep better? What will increase my quality of sleep? Turns out stress makes sleep quality much worse, and eating late and working out make it better.

In my first self-experiment, I was curious about how the soreness I felt from the soccer game yesterday affected my cognitive performance today. By taking a few quick tests every morning, I sought to test this experimentally. Results were mixed.[1] On days after exercise, my simple math scores improved, my reaction time worsened, and my logic scores started poorly but over time got better. One critical constant was sleep. I knew that it has an important effect on cognitive abilities and recovery after physical activity, so I did my best to go to bed at 12:00 every night and wake up at 8:00 every morning. Though I remained fairly consistent in getting to bed on time I still found that on some nights I slept better than others. This was a variable that was hard to quantify. Hoping to improve this study, I came across the phone application *Sleep Cycle*, which inspired me to see what elements affect the quality of my sleep.

Sleep Cycle is an application that tracks movement during sleep using the accelerometer in a phone. By detecting movement during sleep across periodic intervals, an algorithm infers the state of one's sleep (either deep sleep or light sleep) at various points throughout the night. Factoring in both the movement and the duration of sleep, *Sleep Cycle* will produce a quality rating of sleep for the entire night. The application allows for various notes to be included; variables whose effect on sleep quality is recorded.

Methods

By noting variables before going to bed in sleep cycle, I tracked what effect these variables had on sleep quality. I looked at six different parameters: if I ate within the hour before bed, if I had a stressful day, if I exercised at all, if I had soda at dinner, if I read before bed, and if the following day was a weekend. The expectation was that exercising (more restful sleep), reading before bed (relaxing before going to sleep), and weekends (Friday and Saturday nights) would all correspond to a higher sleep quality. Eating right before bed (disrupting metabolism), drinking soda before bed (caffeine has makes going to sleep harder), and stress (makes everything harder) were expected to correspond to a decrease in sleep quality.

Figure 1. Sleep note effect on sleep quality.

Results

The main results are shown in Fig. 1. Matching expectations, we saw increases in sleep quality on a weekend night (+6%), working out (+4%), and reading before bed (+1%); and decreases in sleep quality for stressful days (-5%). Against expectations, both eating late and drinking soda at dinner increased sleep quality (+6% and +2%, respectively).

The most statistically significant finding sleep quality improves on the days after weekend nights, which makes sense since sleep quality depends largely on length of sleep, and I tend to sleep more on weekends. Next up is eating late; the increase is puzzling. Perhaps I tend to eat late on weekends? More thorough monitoring would need to be done in order to achieve certainty. The correlations of stressful days and working out are just large enough to not seem negligible, and fit expectations. The tiny effect of reading before bed and drinking soda seems too small and can be considered negligible (<2%).

[1] See previous self-experiment.

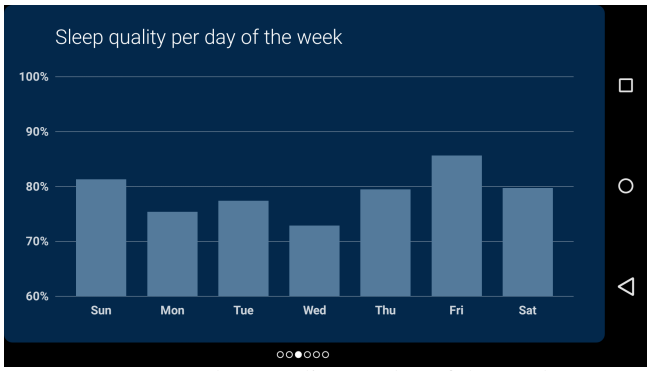


Figure 2. Average sleep quality per day of the week.

Finally, it is also interesting to look at average sleep quality for each day of the week, seen in Fig. 2.

It's easy to see the large increase in quality on weekends, and the effect would be even more significant had I included Sunday nights as well. We also observe the sharp decline on Mondays and Wednesday nights, when Miguel is hard at work reading for Psych class! Though Thursday is usually a late night spent working on Physics problem sets, I seem to have managed it well this past month, because quality didn't take a hit.

Conclusion

Overall, the data seems to fit our initial expectations, save for eating right before bed. Working on stressing less might result in better sleep. Additionally, though it might be hard to quantify, I felt that I almost always agreed with the sleep cycle rating. When I got above 90% I felt great, and anything below 70% meant a rough day ahead. This should be perfect for my original experiment measuring cognitive performance on the day after exercise.

Other Data

Other graphs collected from Sleep Cycle can be seen in Fig. 3; each description is in the top left corner of each graph.

Figure 3. More graphs.

Self Experiment: How Does Reading upside-down Text Affect Comprehension?

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Finding new ways of staying engaged with a long text would prove useful. In this experiment, I find that attempting to read text upside-down takes much longer, and proves to be ineffective in boosting comprehension. Comprehension decreases by 8%. Limitations are discussed.

Reading Upside-down

Often times while reading after a long day, I will find myself slowly drifting out of focus, only to realize at the end of the paragraph that I remembered nothing! I then have to start at the beginning again, and more often than not, the same problem occurs. I wondered if maybe the task was too easyâĂŤby that I mean that reading is too practiced a skill that I could perform it without giving much thought. If I made it a little harder I would wrestle with the text more and spend more time thinking about it, so that eventually I would understand it better. So, I wondered, would reading something upside-down increase my reading comprehension?

The idea seems sort of counter intuitive: that making something harder would help when the whole problem is that I'm too tired to do the easy thing effectively. After thinking about it for a while, I realized that the idea came from a famous Psychology experiment performed by Craig and Tulving in which they looked at word retention as a function of depth of processing (Craig & Tulving, 1975). Their experiment showed that "shallow processing" (e.g. typescript) was much less effective than "deep processing" (e.g. synonyms or category matching) in subjects' ability to recall words. Using this logic, I reasoned that reading upside-down provided a deeper level of processing than regular reading. Even though reading upside-down is still a "shallow" change (forcing me to think about the form of the word rather than it's meaning) I thought it might supplement my usual reading ability.

Methods

The experiment seeks to compare reading comprehension when reading upside-down against reading right side up. The passages chosen will be from an SAT practice test, typically a short passage with 2-10 comprehension questions. An effort was made to read through the passage, then try to answer the questions without looking at the passage. This was sometimes difficult to avoid because the questions asked one to look at specific lines. The time of initial reading was recorded, and the questions were read right side up. Because passages were of varying length, an effort was made to distribute length requirements evenly between the two experimental conditions. Finally, as a sort of control, all tests were done in one afternoon in the library with the order of control or upside-down passages randomized.

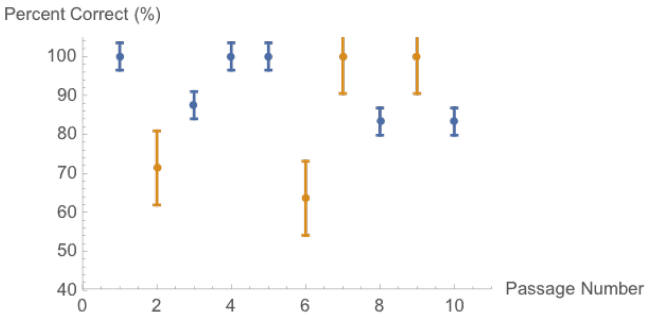

Figure 1. The percent of questions pertaining to each passage answered correctly.

Results and Discussion

The results showed that regular reading improved reading comprehension over the upside-down reading condition. The data are summarized in Fig. 1 and Fig. 2, and the raw data can be found after the conclusion.

The data seem to argue against the hypothesized result, but their 8% difference is not definitive since the error bars for the upside-down case stretch to at least 92%. Interestingly, one could note that there was significant improvement in the experimental condition over time, but it's a result of the final two passages being the easiest, not an increased facility or comprehension with the new condition. The qualitative experience of the subject also contradicted the hypothesis. What could have gone wrong in our prediction? It was assumed that reading upside-down would only supplement the meaning that was being obtained while reading. Explained differently: in the control condition, "deep processing" is already occurring since meaning is being obtained from the words as they give rise to complex ideas. When reading upside-down, however, the cognitive effort spent trying to decipher the text interfered with the meaning-extracting effort. Thus, we had a

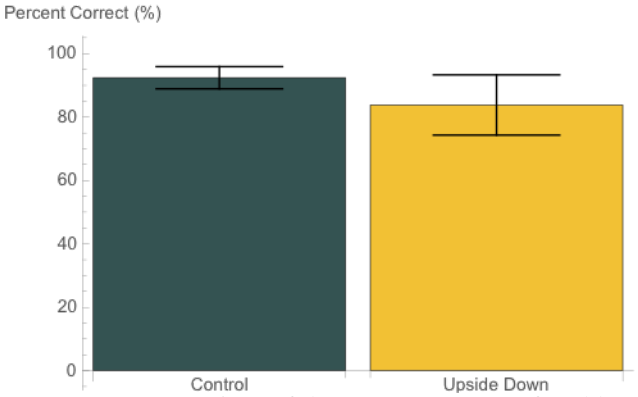

Figure 2. A comparison of the average percent of problems answered correctly on the SAT reading comprehension questions split into the two separate conditions. Reading upside-down corresponded to an 84%, while the regular control condition resulted in a 92%. The difference is not statistically significant.

shallow process replacing a deep process, and the result was poorer retention.

Additionally, reading the passages made the process much more frustrating. It was difficult to read at such a slow pace and to struggle with identifying relatively simple words.

There are a few important limitations to consider. The first is that there was difference in the average length of the passages in both conditions. Typically the questions are more difficult for the longer passages, and the control condition in this case had an average passage length of 30 lines compared to the experimental condition average of 42 lines (Fig. 3). This could be the cause of the 8% difference between the two conditions. Secondly, it is worth mentioning that many of the SAT questions were asking about things that were not just basic comprehension. Many of the questions involved going back to look at the passage for the context necessary to answer the questions. It might explain the statistically insignificant result when in performing the experiment the difference in comprehension felt like a lot more. Said another way, continually looking back might have boosted the upside-down experimental condition more than it boosted the control condition. Still, reading it normally the first time made answering the questions much easier, because when it took a longer time the process became more frustrating. Thus, a reworked study would make a stronger attempt at balancing both conditions and at choosing more relevant questions.

Conclusion

The data showed that reading upside-down had an insignificant negative effect on reading comprehension. Some limitations of the experimental setup could have skewed the data because the overall feeling of the subject is that the hypothesis was effectively refuted. The proposed description is

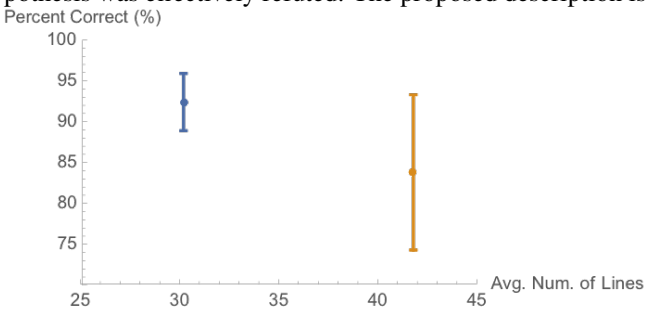

Figure 3. A depiction how the average number of lines in the passage may have influenced the percentage of correct responses. The blue corresponds to the control condition, and the orange to the upside-down condition.

that the mind is too preoccupied with deciphering each word to retain the entire meaning of the sentence. A more equalized set of passages between the two conditions would and more relevant questions would provide greater confidence in the result.

Raw Data

The raw data can be seen in Fig. 4, and was analyzed in *Excel* and graphed with *Mathematica*.

RIGHTSIDE UP	Passage 1	Passage 3	Passage 4	Passage 5	Passage 8	Passage 10	Average	Total	Standard Deviation
Correct Answers	4.0	7.0	2.0	2.0	5.0	5.0	4.2	25.0	
Total Questions	4.0	8.0	2.0	2.0	6.0	6.0	4.7	28.0	
Percent Correct	100.0	87.5	100.0	100.0	83.3	83.3	92.4		8.5
Time (sec)	77.0	180.0	25.0	30.0	180.0	45.0	89.5	537.0	
Lines	25.0	74.0	10.0	10.0	42.0	20.0	30.2	181.0	
Time/Line (sec/line)	3.1	2.4	2.5	3.0	4.3	2.3	2.9		
Computer?	No	No	No	No	Yes	Yes			

USPIDE DOWN	Passage 2	Passage 6	Passage 7	Passage 9
Correct Answers	5.0	7.0	2.0	2.0
Total Questions	7.0	11.0	2.0	2.0
Percent Correct	71.4	63.6	100.0	100.0
Time	588.0	632.0	75.0	90.0
Lines	60.0	82.0	11.0	14.0
Time/Line (sec/line)	9.8	7.7	6.8	6.4
Computer?	No	No	Yes	Yes

Average	Total	Standard Deviation
4.0	16.0	
5.5	22.0	
83.8		19.0
346.3	1385.0	
41.8	167.0	
7.7		

Figure 4. The raw data from the experiment.

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