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When set with the task of summing up the essence of *The Nerve*, we have found ourselves, as we often do in the scientific fields, musing on the philosophers who are arguably responsible for the neuroscientists amongst us today. Their ambition and courage to ask what exactly it is that controls these fleshy containers of blood and bones has driven us to uncover the mysteries beneath the skull. And if they have gotten us this far, certainly they will have something insightful to say about our journal, right?

Our research (which may or may not have involved googling “Aristotle quotes”) has provided us with this gem that we found a bit too fitting to pass up: The whole is greater than the sum of its parts. This certainly holds true for the field of neuroscience. The brain is an emergent organ. We can reduce it to white and grey matter, a few billion microscopic neurons, but from it emerges the wonders of conscious life: language, culture, religion, philosophy, and The Office, to name a few. We find it quite enthralling that all of the Einsteins and Kerouacs, the Monets and *The Nerve* staff-members of the world can be boiled down to a bunch of cells and we hope you do too! And yet, when a few of these neurons malfunction, the whole brain can go on the fritz (or recover astonishingly well, but we'll disregard that for the sake of this analogy).

*The Nerve* is also an emergent organism. We are simply made up of a few writers, editors, and artists and the majority of the work that we do is done individually. However, each plays a crucial part of the whole that is this journal. And when a broad range of topics, ideas, and beliefs come together to form an incredible display of creativity and passion for the mind and brain, we remind ourselves that we are nothing short of emergent. So we, as the staff of *The Nerve*, hope that you, as the reader, will be encouraged by the emergent properties of both our exploration of the brain and the brain itself.

To the staff of *The Nerve*—Finally! Let us be the first congratulate you on a job well done. This journal is nothing without your hard work and thirst for knowledge beyond the realm of academia. We cannot thank you enough for your support, flexibility, and, most importantly, ideas. Every year, we are sincerely impressed with the drive and passion you have committed to your work. Stay inspired and, please, never cease to be amazed at the wonders of the mind and brain, especially your own!

To Paul Lipton, Ashley Hoesing, the Undergraduate Neuroscience Program, the Mind and Brain Society, and the professors involved in the external review process—thank you for your constant support. We work to our fullest capacity to produce this journal, but at the end of the day, it simply would not be possible without you all. We hope for the sake of the journal and its supporters, and the quest for knowledge that both inspire, that there are many more issues to follow. Good luck to future staff, and keep in mind that together you are much more than the sum of your parts!

Shelbi Ferber and Kameron Clayton

*Editors-in-Chiefs*
Approximately 575,000 people suffer from an upper limb loss. Thousands more do not have use of their arms due to paralysis. Due to the increase in limb loss due to war, a focus has shifted toward improving prosthetics, and thereby quality of life for those without functioning limbs.

Currently, many types of prosthetic limbs are available to amputees. Many of them work by using movement of remaining and functioning muscles. For example, someone who has their arm amputated just above the elbow may flex and twitch their biceps and triceps to make the prosthetic limb move in certain ways. It is quite an improvement to having nothing and seems fairly easy to use. One can imagine needing to curl the prosthetic so they would flex the bicep as if curling their arm. However, it takes a lot of patience and skill to control the prosthetic in this manner. Additionally, the less remaining muscle there is, the less precise the prosthetic. Now take the example of a completely amputated arm. One would have to flex their chest muscles to move the arm. It is a lot harder and less natural to get the hang of flexing the chest to make a prosthetic arm bend.

While much research has been focused on moving mechanical limbs through the use of surrounding nerves, researchers are shifting toward prosthetics controlled by the brain. The ability to record spiking rates of neurons in the cortex, electroencephalographic signals on the scalp, or electrocorticographic signals from the surface of the cortex, can be used to control mechanical limbs or a computer cursor.

BMIs, or Brain Machine Interfaces, are used to manipulate prosthetic limbs via control from the brain. Of the three types of brain recording types commonly used in conjunction with prosthetics (EEG, ECoG, and cortex-penetrating microelectrodes), ECoG has emerged as the most practical. ECoG is recorded from the surface of the cortex, which is more accurate than EEG recordings from the scalp. Additionally, ECoG is less invasive and more reliable than the cortex-penetrating microelectrodes.

An ECoG map or grid is placed on the surface of the cortex and measures activity. The signals received are sent to a computer and decoded to reduce noise and unimportant frequencies. This information is then mapped into three-dimensional virtual or physical space. This technology paired up with a highly functional and precise limb results in almost perfect limb movement.

The Modular Prosthetic Limb has seventeen degrees of freedom in twenty-six articulating joints. The movement, speed, and directionality of the limb are the most advanced seen thus far in the prosthetics. Even so, many factors still need to be considered and improved upon. To increase precision, localization of signal, and dexterity, both the computer decoding and ECoG array can be im-
Abnormal Amygdala Function Associated with Autism Spectrum Disorders

Chioma Amenechi

The social implications of autism spectrum disorders (ASD), such as difficulty maintaining eye contact and perceiving emotions in others, have been well documented over the years. Researchers at the University of Michigan, Ann Arbor, have found that decreased amygdala habituation in youth with ASD may be related to their impaired ability to perceive emotions in others, a concept known as cognitive empathy. However, their affective empathy, or being able to respond to what another person is feeling, does not differ from those without ASD. This indicates that an autistic person may have trouble identifying the emotion another person is feeling, but is capable of feeling that emotion. Amygdala habituation is the decrease in activation of the amygdala (which is involved in processing emotion) accompanying repeated exposure to a certain stimulus. This activity is mediated by the ventromedial prefrontal cortex, which activates inhibitory interneurons in the amygdala.

To investigate the differences in this VmPFC connectivity between ASD and non-ASD individuals, both groups of children underwent fMRI while completing a gender identification task and an emotion recognition task for faces that were neutral, sad, happy or fearful. In the control group, the amygdala responds to faces initially, and then habituates to the repeated presentation of faces quickly.

However there is increased amygdala activation in individuals with ASD, indicating that they may find these expressions more arousing or ambiguous. Furthermore, decreased amygdala habituation to sad and neutral faces was correlated with higher autism severity. This suggests that youth with ASD most likely process facial expressions (particularly sad and neutral faces) differently than normally developing individuals. Furthermore, the control group exhibited more VmPFC activity than the ASD group while viewing faces to which they habituated (sad) than those to which they did not habituate (fearful). This indicates that the VmPFC may have a role in habituation (which could be clarified in future studies).

In summary, overstimulation by social stimuli may be partly behind autistic individuals’ impaired ability to behave appropriately in social situations. A method of early intervention for children with ASD could be to expose them more frequently to faces in order to enhance emotion recognition.


proved. Another focus in the continued development of BMI is its functionality and mobility. This system needs electrodes, circuits, telemetry interface to the limb, and power all implanted in order to be fully portable and functional. Currently, the BMIs are usually plugged in to an outlet built in to the scalp via surgery.\(^5\) Once this technology is improved, the next step is to make information flow in both directions. This means sending information back to the brain about the limb. Not only will this improve movement by letting the user know how tight to grip, position of the limb, and improve stability but, it may lead to full sensation experienced by the prosthetic limb which would completely restore what was lost in amputation.

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As people age, cognitive abilities once taken for granted become more difficult. Healthy adults may begin to experience a general cognitive decline that can occur in parallel with age. Despite the prevalence and consistence of cognitive decline, there is no universal explanation for this phenomenon. Atrophy of different brain regions and reduction of certain brain activity during sleep often occur in simultaneously with aging, though they are not directly linked. Independently, these factors cannot explain the various aspects of cognitive decline that people experience in old age. Together, however, they could form neurological correlates behind specific cognitive impairments. Researchers at the University of California, Berkeley, have focused on memory impairment to model late-in-life cognitive decline. They found evidence that gradual gray matter atrophy in older adults disrupts deep sleep, which leads to worsened long-term memory.

Bryce Mander and Matthew Walker and their group at UC Berkeley discovered this relationship between cell loss, poor sleep quality and long-term memory decline in older adults by using a word pair task that was sensitive to sleep-dependent episodic memory retention. The task was administered to a group of older adults and a group of young adults. All subjects were deemed healthy and cognitively normal. Initially, all participants were trained to
the same standard on a set of word pairs. The first recognition memory test incorporated a short delay, administered only 10 minutes after the initial training. Participants were then allowed to sleep for eight hours, which was recorded using EEG. The next morning, the second recognition memory test (long delay) was administered during a functional magnetic resonance imaging (fMRI) scan session to assess differences in retrieval activity. A different subset of the initially trained pairs was used in the short and long delay tests but each subset was the same across all participants.

The study revealed that the difference in memory performance between the short delay and long delay tests was significantly greater in older adults. EEG recordings performed during the study revealed that the older adults exhibited significant reductions in slow wave activity (SWA) during non–rapid eye movement (NREM) sleep as compared to the young adults. This is consistent with prior findings that deep sleep quality diminishes with age. A structural MRI performed after the long delay test revealed a marked difference in the grey matter volume of the two groups. The largest difference in grey matter volume between older and young adults was found in the medial prefrontal cortex (mPFC), also consistent with prior findings.

This study was notable because of the relationship that was discovered between long delay memory task performance, SWA during NREM, and grey matter volume. Researchers determined that, across both groups, age alone was not associated independently with SWA or with grey matter volume. Instead, they revealed a more complex relationship between age and the two neurological factors: the decrease in SWA with age was dependent on the level of reduction in mPFC gray matter. The group’s final conclusion was that age-related changes in SWA are mediated by regional changes in gray matter volume. The formation of such a specific model opens the door for further study and brings researchers a step closer to helping prevent cognitive decline.

tumors versus healthy brain to determine if a section of tissue is cancerous. This method employs a microextraction of a small section of tissue, which can be evaluated in the ambient environment by mass spectrometry with minimal pretreatment. Results can then be obtained in under a second. It is a considerable improvement on previous techniques and when compared to the histopathology assessment of the same tissue, has proven accurate at determining tumor presence.

Testing and validation of the DESI-MS method were performed on a group of five patients under care at the BWH neurosurgical clinic. The research team first developed a classification scheme based on common lipid fragments found in the mass spectrometry analysis of diseased tissues to differentiate between both gliomas (glial cell tumors) and meningiomas (brain tumors developing in the meninges), as well as healthy brain. Then tissue samples from the patients were tested using DESI-MS and lipid profiles were obtained to determine tumor grade, tumor cell concentration, and cancer subtype (e.g. oligodendroglioma versus astrocytoma). These results were then compared to histopathological examination of the same tissue and results from both assessments consistently produced the same conclusions. DESI-MS is even able to reliably characterize tumor subtype, even though for tumor resectioning purposes, grade and cell concentration are much more important. This method of tissue analysis and identification was not entirely error free, with some discrepancies arising between tumor concentration and classification results, but overall it reliably determined the presence of diseased brain tissue in a very short time frame. One final characteristic of the DESI-MS technique that increases its potential value for future use in cancer treatment is its ability to identify small foci of tumor embedded in larger regions of normal tissue. This not only helps surgeons locate all possible areas of the brain affected by the cancer, but also sheds light on the growth patterns and behavior of different types of brain cancer.

The DESI-MS technology seems to have great potential to help neurosurgeons more accurately and efficiently treat patients affected by cancers of the brain. The present study has inspired efforts at Purdue to produce a small mass spectrometer capable of being used commonly in the operating room. This is promising technology that will hopefully improve cancer treatment around the world as the scientific community continues to work toward finding a cure.


Bilingual Children Show Advantages in Non-verbal Auditory Executive Function Tasks

Katherine Callaway

Are the advantages of bilingualism restricted to language? The results of a study published in January of 2013 in the International Journal of Bilingualism suggest that young bilingual children demonstrate better executive functioning for nonverbal tasks. The findings support a growing literature on the domain-general advantages of bilingualism.

Researchers tested Spanish-English bilingual and English monolingual children on two auditory executive functioning tasks: a verbal task and a nonverbal task. The “Go/No-Go” activities tested the children’s ability to respond to a “target” stimulus and ignore the “distractor.” Subjects were asked to hit a keyboard only when they heard the target. For the verbal task, both stimuli were phonemes; for the nonverbal task, they were sounds like a dog’s bark or a bell. Subjects’ scores were based on their number of correct “hits” and response times.

Researchers tested the children’s executive functioning in a second trial that switched the “target” and “distractor.” For example, if a child had previously responded to /ba/ as the “target” and ignored /pa/ as the “distractor,” she was now asked to respond to /pa/ and to ignore /ba/. Both bilingual and monolingual children demonstrated an increased number of mistakes and longer reaction times when the targets were switched. However, when the targets were nonverbal, bilingual children were less affected by the switch than were monolinguals. For the switched nonverbal trial, monolinguals demonstrated significantly more mistakes (p=0.02) and significantly longer reaction times (p=0.039) than bilinguals. No significant difference between the groups for the verbal task emerged.

The study therefore suggests that, although
the acquisition of bilingualism is associated with verbal experiences, its impact is observed in non-verbal tasks. In other words, the benefits of bilingualism are not necessarily mediated by language. Bilingualism may also improve overall executive function through some more general mechanism, though further research must be conducted to understand its full implications.


Pathways to alcohol-induced brain impairment in young people: A Review

Alicia Van Enoo

The risks and long-term effects of alcohol dependence in adults have long been understood, but the rapid increase in drinking among young people (13-24), has prompted scientists to investigate the possible biological causes of alcohol abuse in teens and the implications those could have on treatment and prevention of alcohol-related brain damage (ARBD). The Clinical Research Unit of the Brain and Mind Research Institute at the University Of Sydney analyzed research done on the neuropsychological and neurobiological effects of alcohol abuse in young people. Researchers hoped to investigate neurobiological markers that would either show predisposed (genetic) vulnerability to alcohol dependence, or early warning signs of ARBD in alcohol-abusing teens. Understanding these markers would lead to earlier diagnoses, as well as intervention using cognitive remediation to prevent or even reverse the onset of ARBDs in young adults.

Harmful drinking patterns, coupled with an underdeveloped brain, puts adolescents at a much greater risk for Alcohol Use Disorders (AUD) compared to adults. Although most current research is conducted on long-term alcohol-dependent subjects, binge drinking now recognized as a form of alcohol abuse. Binge drinking is generally defined as the consumption of five or more drinks during one event. This drinking pattern has shown to lead to a similar level of neurological harm in young adults as long-term drinking. Adolescents, specifically college students, who binge drink frequently are exponentially more likely to develop an AUD leading to irreversible alcohol-induced brain damage.
Alcohol abuse in young people is shown to have detrimental neuropsychological effects. A series of nine different studies all point to the same conclusions, AUDs in young adults lead to visuospatial and executive functioning deficits, along with weaker controlled processing of attention and working memory, as well as poorer language skills. These deficits parallel those seen in older, alcohol-abusing subjects with ARBD. These findings support the theory linking the extent of cognitive impairments to earlier and more chronic onset of AUDs.

Cognitive deficits are not the only harmful effects of alcohol abuse. Numerous studies show neurobiological changes in young adults with alcohol dependence issues. These changes, primarily affecting activity in the Prefrontal Cortex, Hippocampus, and Corpus Collosum, mirror the changes seen in adults with chronic alcohol misuse. In both, these changes involve increased functional anisotropy and decreased mean diffusivity, revealing augmented myelination growth, which may prove to be a sign for the early onset of AUDs in young adults.

The investigation of both neurobiological and neuropsychological effects of alcohol abuse in teens provides insight into pathways leading to ARBD. In understanding the areas in adolescent brains affected by alcohol abuse, scientists are better able to diagnose whether these changes are pre-existing (genetic) or alcohol induced. A study by Norman at al. in 2001, revealed that reduced neuronal activity, during a task requiring high amounts of inhibition processing, is a precursor for possible alcohol abuse. These pre-existing vulnerability factors could locate alcohol abusing or binge drinking young adults who are at high risk for ARBD.

The implications of these findings are widespread. Early treatment of young adults with alcohol problems could lead to the prevention of irreversible brain damage due to alcohol abuse. While the brain structures and biochemical processes which indicate the susceptibility for alcohol dependence remains for the large part a mystery, findings about which neurobiological areas are affected by alcohol misuse during brain development in adolescent years will allow scientists to understand and identify factors leading to a greater risk for the development of ARBD. In deciphering between predisposed and alcohol induced changes in adolescent brains, scientists hold the ability to prevent alcohol abusing teens from developing irreversible, chronic neurological conditions.

Our need to eat is more primal than our desire to have sex. We must eat several times a day and our survival depends on it. Our choices of what we eat affect our health and the functioning of our mind and body. We have all heard the expression, “you are what you eat,” but why do we eat the foods we do? How do they affect us? In fact, there are strong psychological and physiological factors that underscore the dependencies we have on food. Nutrition affects the health of the brain and the body as a whole. We use nutrients obtained from our diets to provide energy to our calorie-demanding brains, which require more energy than any other organ in the body.¹

Nutrients found in food are the antecedents to neurotransmitters and the amount of nutrients affects the amount of neurotransmitters produced. Since different foods are made up of more than one nutrient it cannot easily be stated that an increase in the amount of one nutrient will increase the production of a specific neurotransmitter.² When proteins from foods are digested, they are broken down into their constitutive amino acids. Tyrosine, for example, is one particular amino acid that has been implicated in the increased production of dopamine, norepinephrine and epinephrine. These neurotransmitters are known for increasing alertness and energy. Thus, eating foods that are high in protein like fish, poultry, meat and eggs can temporarily increase mental capacity.³ In the case of epinephrine and norepinephrine, the release of these two neurotransmitters is triggered during emergency situations when our bodies need to be alert and self-preserving. The epinephrine binds to cell receptors and causes the breakdown of glycogen into glucose for immense amounts of energy.⁴

Carbohydrates are another major biological macromolecule that has a different effect on the brain. The breakdown of carbohydrates triggers the release of insulin into the blood stream, which then causes an increased uptake of amino acids in the extracellular environment of the brain. An exception in this case is tryptophan, which is normally out-competed by other amino acids attempting to cross the blood-brain barrier.⁵ However, when other amino acids are absent, tryptophan can easily enter the brain and be converted into serotonin.⁶ Serotonin is a neurotransmitter that reduces pain, decreases appetite and can produce a sense of calmness. When serotonin is sent from one nerve to the next it triggers a response in the receiving neuron to send a
message to the brain. The serotonin is consequent-
lly reabsorbed by the sending neuron. An imbalance
in serotonin may be caused by low serotonin levels
or reabsorption into the sending neuron too
quickly. Serotonin deficiency is a main reason
why many diets fail within two weeks and
why dieters become depressed in the initial
weeks of dieting. This is around the time se-
rotonin levels begin to fall due to a reduced
carbohydrate intake.7

Natural anti-depressants are found in
the nutrients available to us through our
diet. Deficiencies in folic acid, a form of vi-
tamin B, causes serotonin
levels to decrease,
which may lead
to various conditions such as
depression and cognitive impair-
ment.8 Psychiatric patients with
depression have much lower folic
acid concentrations than the general
public, suggesting a link between fo-
lic acid and psychological pathology.9
However, increasing the folic acid in-
take by as little as 800 micrograms in
the form of a cup of cooked spinach or a
glass of orange juice will relieve depression
symptoms.10 A retrospective study il-
lustrated this by shorter hospital stays
and better mood and social functioning
for psychiatric patients who received the folic acid
supplement.11 In addition, folic acid supplemen-
tation is effective in preventing cognitive decline and
dementia in old age.12 In the particular study illus-
trating this, men and women between the ages of
50 and 70 years were studied between 1999 and
2004. The 818 participants were randomly as-
signed 800 micrograms of folic acid or a placebo
for three years. Cognitive performance was mea-
sured through changes in memory performance,
information processing speed, sensorimotor speed
and word fluency. Even caffeine from coffee, tea
and other foods can perform as a low-grade anti-
derpressant for mild cases of depression that do not
require medical intervention.13

Choline is an additional B complex vitamin that
is concentrated in high cholesterol foods such as
eggs and liver. In an effort to reduce our cholesterol
intake, many of us
lack appropriate
amounts of cho-
line in our diet.14

Choline is a precursor to the neurotransmitter ace-
etylcho-
line which is linked to memory. Choline
circulating in blood can readily
cross the blood-brain barrier and
is taken up by cholinergic nerve
terminals. Inside these cells, choline
can be converted into acetylcholine
by enzymatic processes. In the hip-
 pocampus, an area of the brain asso-
ciated with mem-
ory, acetylcholine
is associated with memory strength.
Thus, a lack of choline can cause im-
pairment of memory and concentra-
tion.15

Omega-3 fatty acids have many
health benefits and are considered
“essential fatty acids,” meaning that
they cannot be synthesized by the
human body, but are nevertheless
vital for normal metabolism. Ome-
ega-3 fatty acids are dietary lipids
that were originally thought to affect
the brain through their effects on car-
diovascular health.16 However, they are
now recognized for their direct actions on
the brain, as they are components of the
cell membrane and are essential for normal
brain function.17 Omega 3-Fatty acids
contribute to membrane fluidity at the
synapses by maintaining membrane
integrity, neuronal excitability and synaptic func-
tion. Additionally they maintain membrane ionic
permeability and the function of transmembrane
receptors that support synaptic transmission and
cognitive abilities. Dietary deficiency of omega-3
fatty acids in humans has been associated with in-
creased risk of several mental disorders, including
attention-deficit disorder, dyslexia, dementia, de-
pression, bipolar disorder and schizophrenia.18

On the other hand, high amounts of saturated
and trans fats can have negative impacts on brain
function. Digestion of foods high in saturated fats
and sucrose has been shown to adversely affect
cognitive function.19 In a UCLA experiment, rodents
fed with a diet rich in saturated fats and trans fats
performed worse in learning tasks due to an in-
creased neurological burden that correlated with
experimental brain injury.20 Increased caloric in-
take has similar effects on the brain itself. Excess
calories can reduce synaptic plasticity (or the abil-
ity of the synaptic connections between neurons
to strengthen or weaken) because mechanisms
that regulate cell metabolism are integrated with mechanisms that control synaptic function. Thus, controlling our caloric intake can then be used to protect the brain by reducing oxidative damage to cellular proteins, lipids and nucleic acids.\textsuperscript{21}

Antioxidants are a class of molecules that prevent the oxidation (loss of electrons) of other molecules that can cause chemical chain reactions that lead to cellular death. One such antioxidant, alpha lipoic acid, can be obtained from meats such as kidney and liver as well as vegetables, e.g. spinach, broccoli and potatoes. Studies have shown that intake of alpha lipoic acid alleviates memory deficits and reduced cognitive decay in a small group of patients with Alzheimer’s disease.\textsuperscript{22} In fact, elderly patients with poor memory performance can improve cognitive function by increasing vitamin E intake. Vegetable oils, nuts, green leafy vegetables and fortified cereals are excellent sources of vitamin E. Ingestion of this coenzyme has been shown to extend lifespan and improve neurological performance and mitochondrial function in aging mice.\textsuperscript{23} Although it is not fully understood how Vitamin E affects cognition neurobiologically, it is likely related to its support of synaptic plasticity through protection of the synapse from oxidation. Curcumin, a traditional curry spice of India, has been shown to reduce memory deficits in mammals with Alzheimer’s and brain trauma as well. Curcumin is a strong antioxidant that can protect the brain from oxidative degeneration of lipids and nitric-oxide-based radicals. So it is probable that the low rates of Alzheimer’s disease in India might be due to their high consumption of curcumin.\textsuperscript{24}

Even if we know what foods are good and bad for us, why do we have tendencies to make unhealthy diet choices? It turns out that there are strong physiological and psychological forces that make us crave certain foods that may not be healthy for us. In terms of physiological influences, our bodies release trace amounts of opiates when we eat our favorite foods, elevating our mood and providing the feeling of satisfaction. Food rewards can strengthen a preference for foods that are associated with these good feelings and it is for this reason that certain foods can have addictive qualities depending on the individual.\textsuperscript{25} Additionally, environmental factors and social context can influence conditioned responses to food consumption. Often times, hunger can be induced by a certain time of the day as our meals are regularly consumed at these typical times during the morning, afternoon and evening. Mealtime can thus be the reason for eating instead of hunger itself because social signals that precede mealtime become associated with hunger during those specific situations and elicit a “hunger” response.\textsuperscript{26}

Moods, emotions, context, hunger and expectations also have a major impact on the way we perceive food. This is because the decision to eat certain foods directly impacts our survival. Odors and appearances play an important role in taste perception because they affect our expectations. Sugar is not just sweet, and bitter is not just disgusting. Sugar is both sweet and good while bitter is both disgusting and bad. Evolutionarily speaking, we use our sense of taste to perceive what might be good to eat and what is a poison.\textsuperscript{27} These senses are associated with the insular cortex of the brain, an area that is responsible for many diverse functions including emotion and homeostasis. In fMRI images, the insular cortex “lights up” when humans feel anything from good and bad emotions to thirst and hunger. We then use these senses of taste to learn the full story of what we are eating. Further, our sense of sweetness and umami indicate to us foods that are dense in energy and protein, while sour tastes give indication of spoiled foods, and bitterness signals the presence of toxins that can lead to death.\textsuperscript{28}

Taking a look at our taste buds allows us to understand what our brain is telling our body about what we are eating. The umami receptor for example, allows us to taste and be attracted to eating proteins. The human receptor for umami responds best to the amino acids aspartate and glutamate, which explains the intense sensation we feel when eating MSG (monosodium glutamate). Tastes from sweet foods indicate high energy food sources. A sweet responsive cell’s DNA codes specifically for a sweet receptor gene. By this, someone with a sweet tooth may have a gene that codes for a low affinity for sugar, so they may need more sugar to depolarize the neuron to the threshold potential and activate the corresponding brain area for sweet tastes.\textsuperscript{29} Consuming low to moderate amounts of salt satisfies a primal craving that dates back to when salt was rare as far as diet is concerned. Addition of salt to food was most likely one of the first additives to improve taste when the first Homo sapiens decided to add cooked food to sea salt deposits. Since that
time, salt has become important in human civilization as a preservative and a flavor booster. As we now know, sodium plays an important role in neurotransmission. Sour taste cells have acid sensors for the hydrogen ions that characterize acidic foods. They are useful in warning us against eating foods that are spoiled or unripe. The remaining of the five elemental tastes is bitterness. Bitter cells have 30 different bitter receptor genes, which are meant to signal the presence of toxins that plants use to protect themselves from being eaten. Despite these physiological indicators that drive our food eating decisions, psychological forces can overwhelm them. It is interesting how adult humans enjoy drinking bitter black coffee even if it is decaffeinated.

Tastes and nutrition have a significant impact on what we eat and the health of our mind and body. The brain itself is a calorically demanding organ. Evolutionarily, as brain size and brain architecture became increasingly complex, the cost of improved intelligence and cognitive function came at the price of the need for a more substantial, calorie rich diet. According to the “expensive tissue hypothesis”, early humans began to eat more energy dense foods to provide energy for our ever increasingly large brains. These changes in diet are the cause for the development of taste, as are the physiological and psychological dependencies we have on specific foods that drive the decisions we make while choosing what to eat. Using this molecular biological view of the way nutrition affects our body and brain, the true importance of proper diet and health becomes clear.

Justin Tepe is a junior majoring in biochemistry and molecular biology as well as concentrating in epidemiology as a MPH student at the School of Public Health. He is generally interested in neuroscience and plans to continue onto medical school after his graduate studies.

The image “Brain Corn” is a derivative work of the image “human brain on white background” by DJ, available under CC BY-SA.

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Five years ago, then eleven-year-old Laurel Fontaine suffered from an ischemic stroke that caused her devastating damage, leaving about 80 percent of the left side of her brain—her language-dominant hemisphere—completely destroyed. Following the stroke, doctors told Laurel and her family it was unlikely that she would recover motor function. She would also likely never walk, talk, or do any other typical motor activities of children her age.

Conventional speech therapy, a typical part of a patient’s recovery process following stroke, showed only marginal benefits in Laurel’s ability to talk. After a year, she still struggled with speech production, speaking only several words at a time. However, she was soon left in the hands of researchers studying the effects of singing therapy on speech production in stroke patients. After only four months of treatment, Laurel could perform with nearly 100 percent accuracy on one test. Talking to Laurel now, one would hardly recognize that just over five years ago she was completely unable to speak.

The puzzle of how music therapy may improve speech motor function in stroke patients is still being researched. Just how is it that something such as music could cause such noticeable behavioral improvements and what neurological changes are the bases of their recovery?

Understanding the linguistic and motor side effects of stroke

A stroke occurs as the result of rapid changes in blood supply to the brain. If lack of blood supply persists, it can cause irreversible damage, leaving the affected brain tissue dead. While the extent and type of damage incurred varies widely between patients, one common abnormality arising from stroke damage is aphasia. Aphasia is a disorder affecting the comprehension and production of language, making it hard for those affected by it to speak, write, or understand what others are saying. The disorder is caused by damage to areas in the language-dominant hemisphere of the brain that are commonly associated with language, especially in the left hemisphere. Structures in this region include Wernicke’s area in the superior temporal gyrus and Broca’s area in the inferior frontal gyrus. Some studies estimate that aphasia can occur in as many as one quarter of patients following a stroke. Even with extensive rehabilitative intervention from speech therapists, the prognosis for recovery is not always optimistic.

Like any other function we carry out, the use of language does not just rely upon a few localized areas, but rather entire networks of the brain that...
interact with and feed back to one another. Production of speech not only requires Broca’s area, but also requires involvement of motor control areas. Some studies estimate that as many as 50 percent of stroke survivors experience impaired muscle function even 6 months after their stroke.\textsuperscript{5} While this does not necessarily mean full paralysis of the body or of a single limb, it does mean that some stroke patients will suffer from motor impairments. These impairments may interfere with their ability to carry out simple tasks in their daily lives, including speaking.

An estimated 750,000 – 800,000 stroke cases occur in the U.S. every year.\textsuperscript{6} Because there is no standardized or completely efficient way of treating stroke-induced impairments such as motor deficits and aphasia, it is important that we search for new and innovative means to help patients recover from such disorders.

**Song as a Solution**

Stroke patients who are unable to speak are still able to sing their words, suggesting the possibility of multiple networks for vocal production.\textsuperscript{7} If there is more than one network that contributes to vocal production, then the possibility of rewiring undamaged networks for language use could allow non-fluent aphasic patients to speak once again.

Gottfried Schlaug and fellow researchers at the Music and Neuroimaging Laboratory at Beth Israel Deaconess Medical Center have directed their focus toward answering this question in recent years. Much of their time has been spent studying the effects of melodic intonation therapy (MIT) on stroke patients with aphasia. Developed as an alternative to traditional speech therapy, MIT requires that patients sing a phrase that they would typically speak while simultaneously producing rhythmic tapping with their left hand. Previous studies have shown that processing of musical components, such as melodic contour, tends to occur in regions in the right hemisphere. Contralateral connections would mean that tapping of the left hand creates more activation in the right hemisphere as well. The researchers believed that MIT could help patients by recruiting right-hemisphere structures analogous to the language structures in the left-hemisphere that had been damaged.\textsuperscript{8}

Evidence suggests that the therapy is successful. In one study conducted by Schlaug et. al., some patients saw an improvement of over 200% on measures of spontaneous speech.\textsuperscript{9}

Similar music therapies now exist for treating only the motor side effects of stroke. Music-supported therapy (MST) was created in order to help chronic stroke patients regain movement of paralyzed upper limbs. Patients received daily treatment in which they were required to mimic tones, simple melodies, or scales produced by an instructor. They used either an electronic piano to improve fine motor skill or an electronic drum set that emits piano tones to improve gross motor skill. The therapy made use of massive repetition and immediate auditory feedback of movements, allowing patients to hear whether they were making the correct movement at the correct time.\textsuperscript{10}

Studies testing the efficacy of MST have shown that partially paralyzed patients receiving MST made statistically significant improvements in fine and gross motor skill when compared to similar patients receiving standard rehabilitation for the impaired limb. Patients receiving MST showed higher scores in both frequency and speed of finger and hand tapping. They displayed both a wider variety of possible movements as well as an increased quality of movement.\textsuperscript{11}

**Neural Pathways to Recovery**

Why might music therapies work? Language and music share many of the same pathways in the brain. This could, in theory, allow some pathways to become more adapted for language use if pathways normally used for language are damaged. Furthermore, because music performance requires the integration of visual, auditory, and sensorimotor information, it has been suggested that the simultaneous use of the functional brain networks with the impaired motor networks could produce rapid changes in motor regions.\textsuperscript{12}

When Schlaug and his colleagues began studying Laurel Fontaine, they had the added bonus of being able to study her twin sister, Heather, as a control subject. Because Laurel and Heather share 100 percent of their genetic material, it would be more likely that any neurological changes Laurel experienced between the beginning and end of the treatment were due to the effects of MIT. Following treatment, researchers noticed increased activation in Laurel’s right frontal areas as compared to her own pre-treatment functional magnetic res-
onance imaging (fMRI) results and to her sister’s fMRI results. Using diffusion tensor imaging, the researchers also found that Laurel’s arcuate fasciculus (AF) grew to nearly three times its original size, while her sister’s AF did not increase in size. In another study, one patient receiving MIT also experienced increased AF volume post-treatment. In yet another, lesions to the left AF were shown to cause speech impairment. In healthy individuals, the left AF has been shown to connect language areas to areas that are responsible for motor speech and linking certain sounds to movements. Schlaug and colleagues hypothesized that Laurel’s increase in right-hemisphere activation during language tasks, and her increased AF volume, might reflect the recruitment of right-hemisphere regions for language use and increased connectivity between sensory language and motor areas. These changes could be responsible for Laurel’s improvements in speech production following melodic intonation therapy.

Patients undergoing therapy for stroke-induced motor impairments seem to experience similar neurological changes. After undergoing MST, patients in one study showed increased auditory-motor circuit connectivity. This appeared most prominently between premotor areas and the inferior frontal gyrus (IFG), an area believed to be involved in processing structural elements of music. Interestingly, the left IFG also houses Broca’s area, and also shows activation to semantic processing in language.

The audio-motor coupling hypothesis attempts to provide a theoretical framework for the efficacy of music therapy. This hypothesis claims that the constant feedback between auditory and motor regions during music performance allows for faster and more efficient correction of movements that are paired to specific sounds. Since MIT and MST both pair specific movements to specific sounds, this theory could explain why patients have undergone such a strong degree of improvement. These therapies require constant practice, in some cases totaling

untitled. Artwork by Emily Horton.
up to several hundred hours of therapy over the course of a year. As Laurel Fontaine admits, recovery is “hard at first,” but her speech gets “better all the time.”

Music has already proven itself instrumental in helping patients to recover from aphasia and motor impairments following stroke. And its benefits do not stop there; certain music therapy has also been theorized to help non-verbal autistic children produce spontaneous speech. Consdering the hope that music-based treatments have already given to many patients, it will be interesting to see where future research goes in terms of discovering the neurological benefits that music may have to offer.

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Speech in Parkinson’s Disease

Carolyn Michener

Parkinson’s disease (PD) is one of the most common neurodegenerative diseases, trailing only behind Alzheimer’s disease. PD is caused by a lack of dopamine producing cells, resulting in tremor, rigidity of body, bradykinesia (slow movements), and problems with balance. Degeneration of a midbrain area called the Substantia Nigra leads to inhibition of the motor cortex; the midbrain degeneration “has the effect of a stuck brake on an automobile or a bicycle.” The effect PD has on motor control can affect basic functions such as walking and speech production, which will change the lifestyle of numerous patients with Parkinson’s disease as the size of the elderly population—who have the highest incidence of PD—increases. In particular, PD affects speech quality through associations with several types of speech disorders that cause difficulty in the ability to communicate with others; because no cure for PD exists, these speech effects are permanent, but therapies that allow patients with PD to manage loss of speech control rather are emerging.

Healthy speech involves communication from the brain to the muscles that produce speech. A portion of the brain called Broca’s area in the left frontal lobe controls speech production. It collaborates with other areas of the brain to signal movements in the vocal folds of the larynx, commonly referred to as the voice box. As humans speak, they exhale, causing small vibrations in the soft tissue vocal folds as air moves from lungs to the oral cavity. After the air leaves the larynx, the articulators—the teeth and tongue—shape it, which in combination with vocal fold vibrations creates the formation of different sounds.

As Parkinson’s disease affects the brain’s control of muscles, patients with PD often have difficulty controlling phonation, and therefore speech production. Speech is affected in approximately 70% of patients with Parkinson’s disease, commonly lowering pitch and loudness, causing quick bursts of speech, and creating a harsh voice. Overall, patients with Parkinson’s disease speak with a very soft and monotonous voice. These changes are a result of hypokinetic dysarthria, which is a speech motor disorder resulting from rigidity and akine-
sia of the muscles. As fine muscle motor control is critical in speech production, this impacts speech in various ways.

A laryngeal disorder, which can result from atypical vocal fold movement, is one example of disordered speech in patients with Parkinson’s disease. Such a change in voice includes abnormal pitch or loudness. Typically the rapid passage of air between the vocal folds when speaking allows the larynx to function and speech to be created. For this process to completely take place, the vocal folds must successfully undergo adduction and abduction—joining and separation respectively. However in the case of many patients with PD, the vocal folds do not completely adduct, allowing extra air to escape the airway, and creating the breathy voice quality observed in PD. This phenomenon is often referred to as bowing, when instead of creating a straight line during adduction the vocal folds bow out, similar to the shape of parentheses. It was also found that the PD tremor principally affects the muscles controlling vertical laryngeal motion, creating bowing of vocal folds.

Improperly functioning larynxes in PD can also modify the production of particular sounds. For example, the production of /b/ and /p/ sounds involve the same muscle movements, except /b/ is voiced and /p/ is voiceless, meaning the /b/ involves vocal fold vibrations. If the vocal folds are affected by tremor, a patient with PD could unintentionally produce the wrong sounds during speech production. A 1987 study showed that 89% of participants with Parkinson’s disease showed signs of such a laryngeal disorder.

The dysarthria associated with Parkinson’s disease can affect not only the larynx, but also speech articulators: lips, tongue, and facial muscles. Each sound produced in human speech requires a particular combination of articulator placement. An articulation disorder is associated with errors in speech production that often make it difficult for audiences to understand the speaker. The inability to control the movement of the articulators will cause sounds to be improperly produced, particularly consonants such as: “stop /p/ and /b/, affricates /sh/ and /ch/, and fricatives /s/ and /f/”. The rigidity of jaw muscles, one of the symptoms of Parkinson’s disease, also affects the articulators.

Although there is no cure for speech impediments in patients with Parkinson’s disease, a form of intensive therapy known as the Lee Silverman Voice Treatment (LSVT) has been shown to help patients learn to control their speech. The LSVT is a regiment of exercises a patient completes under the care of a speech language pathologist at least four times a week for a month for maximum results. All of the exercises work to improve aspects of affected Parkinson’s speech such as increasing the loudness of spoken speech, “calibration” of sensory information and effort, encouraging high levels of participation from patients, and utilizing the benefits of intensive treatment. The LSVT can also assist patients in aspects other than the intelligibility of produced speech, such as learning to control facial expressions and creating less monotone speech. Numerous studies have reported considerable improvement in patients with Parkinson’s disease who have undergone LSVT.

In addition to intensive therapy, other treatments can improve vocal fold tremor. In particular, patients with Parkinson’s disease can benefit from collagen injections, which can help strengthen muscles and, when injected straight into the muscles of the larynx, prevent the vocal folds from adducting when talking. The product of choice is AlloDerm, also known as Cymetra; it provides temporary relief—about 6 months—but patients can receive subsequent doses if the treatment is deemed effective.

However, if patients do not want medical treatment, or if it is ineffective, other methods exist to help them communicate. One example is using an assistive communication device. Types of communication devices can range from personal microphone systems to help project an individual’s voice to language boards where individuals with PD can point at pictures or words. These types of devices do not treat Parkinson’s disease, but can assist an individual struggling to communicate with others.

Boston University is home to its own group of researchers and clinicians who treat the speech difficulties of Parkinson’s patients. The Boston University Medical Campus houses the Parkinson’s Disease & Movement Disorders Center, which dedicates some of its resources to treating speech impediments in patients with PD. The Parkinson’s Center for Voice and Swallowing includes several clinicians, all of whom are certified to conduct the LSVT. Moreover, various research labs, such as the Stepp Lab for Sensorimotor Rehabilitation Engi-
neering in Sargent College, also investigate speech disorders in patients with PD.

Parkinson’s disease and its symptoms are of utmost interest because as the life span and the median age of the population increase, more people will be at risk for developing PD. There is a greater chance that everyone will meet an individual with PD in their lifetime and experience his or her troubles with communication firsthand. Although Parkinson’s disease indeed limits communication, the speech community has clearly developed methods to counteract deteriorating laryngeal function. Speech therapy, collagen injections, and augmentative communication devices have clearly assisted speech impediments in patients with PD but there is vast room for improvement. Dedicating time and resources to treatments such as the Lee Silverman Voice Treatment and more efficient, lower cost assistive communication devices are necessary to prepare for the expanding number of people with Parkinson’s disease. Future discoveries in the fields of speech production and neuroscience could not only lead to continued progress in the study of speech impediments in Parkinson’s patients, but also in other neurological causes of speech disorders.

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6. Ibid.
12. Ibid.
15. Ibid.
17. Ibid.
21. Ibid.
24. Ibid.
27. Ibid.
Review of “Towards a Cognitive Computational Model of Music Composition”

Kameron Clayton

The intersection of music and the brain can be approached in many ways: some researchers would want to know how waves of air pressure are synthesized into a cohesive sound in our brains, others may desire to understand the neural learning processes or innate wiring by which a musician becomes a stunning virtuoso. However, among all the facets of music, there is one aspect upon which the entire musical world is dependent, the role of the composer.

Inevitably when the word composer is mentioned, some assume that composers are an exclusive club of white males from the eighteenth and nineteenth century who wrote profound masterworks. This couldn’t be further from the truth. Anyone, from the Beatles to Skrillex or yourself can be considered a composer, the only criteria is the creation of an original piece of music. And thus, without composers, we wouldn’t have music.

At a fundamental level, however, and of most interest to neuroscientists, composing is an enormously complex task that requires a multitude of different brain areas. At one level, one must possess all the skills any musician must possess, that is, a propensity for distinguishing pitches, timbres (sound quality), and the development of very specific muscle groups for musical performance. Additionally and perhaps most importantly, the composers and musicians in general must possess the capacity to produce musical imagery in the mind, i.e. to hear a piece in one’s head. We’ve all experienced this with songs that get stuck in our head, but for musicians and composers it is critical to have a developed capacity to hear a piece before even singing and playing. On top of this, the composer’s brain must recruit areas responsible for creativity (to produce original works), learning (to determine what works and what doesn’t against their desired aesthetic) and compute algorithms (music is at some level governed by mathematics, discussed in much greater detail below). It is clear that we are dealing with an incredibly complex neural system that virtually spans the entire cortex.

Having observed generally the various processes involved in the creation of musical work, it then falls to the neuroscientist to answer the question of how the brain accomplishes this task. Currently, we possess many tools to investigate this question; one could perform brain imaging studies on musicians in the act of composition to see which areas of the brain are implicated. One could poten-
tially study the effect of lesions and other brain abnormalities on the act of composition. For instance, the legendary twentieth century Russian composer Shostakovich reportedly heard melodies when he tilted his head due to a piece of shrapnel embedded in his brain during the World War II. Generally, such studies are both expensive and hard to design, as the act of composition can be broken down into a variety of component neural processes.

Instead, a great frontier in understanding music composition is the use of computational modeling. A computational model of music composition attempts to theorize precisely on the cognitive mechanisms that underlie the process and then replicate this process with a computer model, in such a way that the computer model achieves the same result as the cognitive process. One of the fundamental principles of computational investigation is that the literal replication of the actual system is impossible. Hence, the goal becomes to create models that approximate the cognitive phenomena and then continually optimize these models to achieve closer and closer approximations.

Computer models of composition (albeit in very specific genres) are nothing new. The CHORAL program, developed by Kemal Ebcioglu, was designed to produce four part realizations of Bach Chorales based on a given soprano. Ebcioglu created hundreds of rules that informed the construction of new chorale harmonizations informed by theoretical principles of analysis in the idiom of the Bach chorale. “The general approach of this research was to select a relatively fixed style, the Bach chorale, attempt to approximate the extension set with a precise definition, and then use the precise definition in a computer algorithm for generating music in that style.” Ebcioglu acknowledges that absolute rules can only really be found in artificial musical forms, such as fugue, and that problems with applying absolute rules to real music emerge (as composers tend to “break” the rules quite often). Thus, any absolute rule set will simply produce an approximate version of a Bach chorale, not an exact model. However, CHORAL is more complex than simple rules that generate music, Ebcioglu incorporated heuristics (rules that are followed when possible), which “estimate, at each step, which among the possible ways of extending the partial chorale will lead to its best completion.” Heuristics act as a sort of shepherd, directing the composition in a more musical direction than it would go based on absolute rules alone. Examining some of the harmonizations produced by CHORAL provide by Ebcioglu, they do seem to at least approximate a Bach chorale, idiomatic in harmony and (for the most part) voice leading.

David Cope purposed a different system, the “Experiment in Musical Intelligence” that relies more on the principle of recombinance than novel design. Essentially, the idea is that if the music is broken up into small enough chunks, you can arrange the chunks in such a way that they form a new piece of music. This computational model relies on a large data set and the smallest chunks possible. There are also some rules in Cope’s program, but they are much more limited than in that of Ebcioglu. Cope’s program is adaptable; the EMI has produced hun-
hundreds of works in the styles of composers from Bach to Chopin.\(^8\)

When we look at these models, they are successful at producing an end result that closely approximates the works that inspired their creation. In these models, no answers as to how human composition occurs can be answered. Cognitive modeling, of the sort that researchers at the University of London propose, attempts to get at the how question. In this case, Geraint A. Wiggins, Marcus T. Pearce, and Daniel Mullensiefen asked if they could potentially produce a model that was capable of creativity with respect to composition.

### A Model of Music Perception

Before discussing the perceptual component of the research, it necessary to understand how this model serves the ultimate goal of a cognitive computational model. Essentially, Wiggins et al. are operating with the understanding that a model of human perception of music underlies any cognitive model of music composition. From a practical perspective, this makes sense; hearing and the resultant perception of music are critical to any sort of secondary response to it. Perception allows us to grasp the concept of idiom, an aesthetic construct in which the composer determines what musical elements should go where in a given composition and additionally which musical elements are not appropriate within that specific construct. This set of experiments conducted by Wiggins et al. represents an attempt to create a perceptual model that can later be used in a generative capacity.\(^9\)

Any perceptual model of music will be subject to constraints that limit the number of elements involved, as one would imagine that musical perception is a complex neural process involving pitch and rhythm recognition among many other elements. Wiggins et al. limited the parameter of their study to focus on tonal melodies (short single voice compositions that are centered around one pitch, something that one could whistle).

Wiggins et al. propose a model, named IDyOM (the Information DYnamics Of Music) that can predict pitch expectancy (what note will come next) and phrase segmentation (boundaries between group of pitches) through training with existing data (i.e. music). The model relies on multiple viewpoints to account for different elements of music perception, isolating each element.\(^10\) What this means is that the model treats every element of a single note event (what we would consider a single note, composed of pitch and duration among other factors) separately.

For each given feature, the model creates a statistical distribution of the likelihood of any given event based on n-gram models. N-gram models, commonly used in computational linguistics, are simply a collection of sequences (each sequence being n-symbols long) that can be organized into a frequency count and used to predict the next event in a data set.\(^11\) For example, if a given data set consisted of (ABABAB) and we considered n=2, the set would be divided into groups of two (AB,AB,AB), and from examining these groups we could see that the sequence AB occurs three times. Therefore, we would predict based on this distribution that the next sequence would also be AB.

IDyOM considers n-gram models for every order within a given data set in order to obtain the most accurate possible end result.\(^12\) For the example given above, this would mean considering n=1 (A,B,A,B,A,B) through n=6 (ABABAB). IDyOM would then predict the next event in a series by
taking a weighted sum of the distributions for all values of n, with weight given to higher order predictions as they generally are more specific to a given context (notice that the distribution of n=1 would yield a much less accurate prediction than n=2). In the context of examining melodies, frequency counts are obtained from existing melodies in the same idiom as that of the melodies that will be examined. This initial process of division of elements must then somehow be brought together. Essentially, predictions of each individual element of a given melody are combined using a scheme in which greater weights are placed on models with less uncertainty. Using the results of this scheme, IDyOM will predict the next note in a given piece.

All of this sounds fairly logical, albeit complex, but IDyOM’s efficacy must be tested on two levels: at the level of melodic pitch expectancy and at the level of melodic segmentation. To test the degree to which IDyOM could predict pitches, Pearce and Wiggins tested the degree to which IDyOM could predict the next pitch at various points in British folk songs and in the context of single intervals and in chorale melodies. The study found that IDyOM could predict the expectations of listeners with some degree of success, notably much better than previous models.13

A more complex metric of the success of IDyOM is its success at predicting melodic segmentation. To test this element, the team conducted two studies. In the first, 25 expert judges (musicologists) were asked to indicate melodic segments within 15 popular melodies, comprising a data set of 1250 note events, on a score while continually listening to the melodies. When compared to the human ground truth data (essentially accepted values), IDyOM was in agreement with the human evaluators 58% of the time. In the second study, a large set of German folk songs was used, comprising a data set of 78,995 note events. Importantly, phrase boundaries (ground truth data points) were indicated by a single musicologist. In this case, IDyOM was in agreement with the human evaluator 74% of the time.14 This shows a marked correlation between size of the data set and accuracy of the predictions. Further, this result demonstrates the relative success of the IDyOM in predicting melodic segmentation. This success suggests that peaks in unexpectedness in a given melody are strongly correlated to the boundaries of phrase segments as follows from the procedure of the model.

A Model of Music Composition

The enormous challenge researchers then faced was the question of how to utilize this perceptual model to compose music. However, when the question is reframed in terms of how one uses a model that predicts the next note to a compositional system, the challenge becomes more manageable. “Predicting”, as IDyOM does, approximates composition. A composition could easily be obtained in any idiom, simply by training IDyOM with a data set, choosing a starting note, and then using the prediction power of IDyOM to generate the rest of the melody through choosing the highest probability note events.15 Unfortunately, previous research showed that the most highly probable music is syntactically correct, but musically dull.16 Therefore, some other scheme must be utilized.

In creating a scheme, Wiggins et al. were faced with the problem of combining multiple variables (recall that IDyOM broke melodies down into many components) to generate a single note event. Because of this, the researchers used the Metropolis-Hastings algorithm to predict single note events using the multi-element model, IDyOM. Essentially, the Metropolis-Hastings algorithm is a means of obtaining a sample (read: a new melody) from a
trained multi-element system by specific method of random sampling.\(^\text{16}\) What is important is that the application of this algorithm allowed the researchers to generate melodies based solely on the statistical models they had created. At this point, one may wonder how this methodology could possibly result in a cognitive model, but it is important to recognize that the statistical models are designed to approximate human musical perception.

Three different systems were created for experimental evaluation. Three different systems allowed the researchers to examine what elements of the multi-element statistical model, IDoYM, are needed for successful melody generation. The hypothesis for all three systems was that “each System can generate melodies rated as equally stylistically successful in the target style as existing, human-composed melodies.”\(^\text{17}\) Each system was designed to exhibit a greater degree of sophistication: System A generating predictions based on chromatic pitch (a single element), and was expected to refute the null hypothesis. System B is a multi-feature system which attempts to closely approximate human expectancy through three features related to tonality, rhythm and phrase structure. System C is another multi-feature system that the researchers believed would yield the best performance of all three, as it had nine features. It was expected that the null hypothesis would be retained for both System B and C.\(^\text{18}\)

Using seven randomly selected chorale melodies by J.S. Bach as a base data set, Wiggins et al. generated seven new melodies using each System, for a total of twenty-one new melodies. The effectiveness of each melody was then tested by sixteen expert human judges. To clarify, as J.S. Bach is without equal as composer, the “effectiveness of each melody” was based solely on if the chorale melody was in the style (i.e. idiom) of J.S. Bach’s chorales. The experiment consisted of the judges listening to and rating twenty-eight melodies (consisting of some of Bach’s original works and some melodies generated by the system) in a random order. To limit the influence of order, the researchers split the judges in half, with eight judging the melodies in the reverse order of presentation compared to the other group.\(^\text{19}\)

**Results of Chorale Melody Evaluations**

The results of the judges’ evaluations indicated that the Systems were only marginally successful in producing successful chorale melodies. System A melodies received an average rating of 2.9 out of 7, system B melodies received an average rating of 2.49, and system C melodies received an average rating of 3.17, compared to the Bach Chorale melodies which received a rating of 6.02. The experimental expectations were largely dismissed, system A and system C received a very similar rating, although the researchers had expected A to perform much less successfully than C. System B had also dismissed expectations, as it received the worst rating of the three. As the Systems performed on average only half as well as the Bach Chorale melodies, it suffices to say that these systems were not viable models. It is important to note, however, that some of the individual melodies generated by the systems garnered much higher ratings than the average; one melody generated by System C received a rating of 5.0 out of 7.\(^\text{20}\)

**Discussion**

While the ultimate results of this series of studies were not encouraging, the studies should be noted for its approach to the issue of creating a cognitive computational model of music composition. The approach, namely reaching a cognitive model of music composition through a model of music perception, makes a large statement on its own, and is yet to be proven. If it is true, however, one would have to ask whether the act of music composition is simply a composer choosing pitches and rhythms based on expectations of the listener (which are created through the constructs of the idiom and are based on perception). Further, would this mean that creativity is the degree to which the composer plays off of these expectations in unique and interesting ways while staying true to the context of the idiom?

This study relied heavily on artificial intelligence at all stages; unfortunately there is a lack of literature regarding purely neuroscientific computational approaches (modeling neural networks, etc.). Studies with this approach could lead to an exponentially greater understanding. Regardless
of the outcome of future studies, considering music composition on a level deeper than “artistic inspiration” will yield deeper insight into this incredible human capacity to create music that can almost universally evoke emotion. Any answer will no doubt shed light on the various facets of the process and most importantly how creativity works at a neural level. The importance of this research is not that the models these studies propose ultimately fail as a consistent model of music composition, but that they raise the question of how the human brain accomplishes it and begin to shed light on the process.

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Rachel Franklin

“I cannot live without brain-work. What else is there to live for?”

-The Sign of Four

“A man’s brain originally is like a little empty attic, and you have to stock it with such furniture as you choose."

-A Study in Scarlet

Sherlock Holmes, the fictional detective created in 1887 by British novelist Sir Arthur Conan Doyle, remains a recognizable and celebrated character in modern media due to his indisputable case-solving genius, and yet, relatable humanity. Holmes’ ability to observe objectively, think clearly, and work through problems in his own head lead him to solving mysteries that confused his more instinct-driven sidekick, Dr. John Watson. The two characters intellectual interplay drove the plot lines which inevitably led the guilty party to justice and the truth to light in each of Doyle’s stories. The story remains familiar due to countless reinterpretations; however a recent resurgence in Holmes’ popularity attests to his modern relevance. Just to name a few takes on the character: Sherlock Holmes, the American film starring Robert Downey Jr and its sequel Sherlock Holmes: A Game of Shadows, Sherlock, the BBC mini-series with the actor Benedict Cumberbatch, the American CBS television series
(featuring a woman as Joan Watson) Elementary and finally the popular Fox show House M.D. which is centered around a main character of a Holmes-inspired complex.

Holmes is more popular than ever in pop culture right now. But why? Maria Konnikova, a Russian-American psychology writer, recently published an entire book on how we, as normal, confused humans could work to become more Holmes-ian in our day-to-day thinking and approach to our own mysteries of daily life. Her intentions and findings can be summed up as such:

1. Be mindful.
2. Control and actively engage your attention.
3. Learn to observe.
4. Give your creativity a chance.

The most exciting part of these Sherlockian lessons? They are supported by modern neuroscience, due in part to a recent explosion in research surrounding the effects of mindfulness training and meditation on the brain.

To start, a proposed “operational definition” of mindfulness from a 2004 paper from the Journal of Clinical Psychology

“We propose a two-component model of mindfulness. The first component involves the self-regulation of attention so that it is maintained on immediate experience, thereby allowing for increased recognition of mental events in the present moment. The second component involves adopting a particular orientation toward one’s experiences in the present moment, an orientation that is characterized by curiosity, openness, and acceptance.”

Mindfulness is exactly what Sherlock Holmes, the designer of his own mind’s “attic”, was an expert at. Mindfulness and meditation go hand in hand and the evidence of their benefit is mounting. A preliminary study of twenty meditators (9 years of 1 hour/day on average) vs non-meditator controls out of Massachusetts General Hospital conducted by neuroscientist Sara Lazar showed an increased thickness in the prefrontal cortex and the insula. The prefrontal cortex is often associated with higher “executive” functions like decision making while the insula is thought to play a role in integrating sensation and emotion. The goal in these practices is simply to reign in one’s thoughts from the natural tendency they have to wander.

The suggested benefit (becoming more accepted with each subsequent study) is that practicing mindfulness leads to increased ability to understand the perspective of other people- the combined roles of the prefrontal and insular cortex- thus increasing social empathy. In terms of Holmes’ ability to objectively assess situations and the motivations of others (read: guilty persons) this makes perfect sense; he is practicing mindfulness in his capacity to investigate the inner workings of his own brain while improving his mystery-solving powers.

Attention is Sherlock’s forte; he is able to command his cognitive intent like a robot on Ritalin; but does it actually help him find the murderer? Experience says yes: if the only way to remember something is to take note of it in the first place, then attention is vital to encoding memories. Additionally, this type of focused attention is only one component. Many more mindfulness studies have shown that increased attentional control (through training) additionally improved subjects’ short-term working memory. This would have an enormous impact on Holmes’ 19th century sleuthing; keeping the details intact in his head was crucial to his case-solving.

“‘It has long been an axiom of mine that the little things are infinitely the most important.’”

-A Case of Identity

Further support for the idea that Holmes’ ability to train his focus would have improved his job performance is the headline-making recent neuroscience finding that multitasking doesn’t work (DiGirolamo and npr). Holmes’ approach? He doesn’t attempt it: better to focus on one problem at a time.

One of the core aspects of Sherlock’s cognitive prowess is his keen observational power. I would argue, that this ability is yet another extension of his precise control over his attention to internal and external stimuli. When sleuthing about London, Watson at his side, Holmes takes silent note of every detail, seemingly without making the effort to do so: it’s as if even the simplest or minute information is simply flowing into his memory without being filtered out. An exchange with Dr. Watson from “A Scandal in Bohemia” demonstrates how Holmes under-
stands the difference between seeing and observing (all stories told in Watson’s first-person perspective):

“When I hear you give your reasons,” I remarked, “the thing always appears to me to be so ridiculously simple that I could easily do it myself, though at each successive instance of your reasoning, I am baffled until you explain your process. And yet I believe that my eyes are as good as yours.”

“Quite so,” he answered, lighting a cigarette, and throwing himself down into an armchair. “You see, but you do not observe. The distinction is clear. For example, you have frequently seen the steps which lead up from the hall to this room.”

“Frequently.”

“How often?”

“Well, some hundreds of times.”

“Then how many are there?”

“How many? I don’t know.”

“Quite so! You have not observed. And yet you have seen. That is just my point. Now, I know that there are seventeen steps, because I have both seen and observed.

While simply knowing the number of steps (or windows or chairs) encountered in daily life (or even given a sole occasion) as Sherlock seems to know, may be beyond any normal person’s ability, there may be ways to improve. Evidence is mounting that undergoing training such as the University of Massachusetts developed Mindfulness-based Stress-Reduction (MbSR) program seems to improve awareness, which leads to more accurate perception, as shown by a 2003 meta-analysis out of Freiburg, Germany. The study looked at 20 published research reports which included MbSR in their methods and found demonstrable benefits across cognitive and affective domains post MbSR training. Perhaps Sherlock was just an early adopter.

Finally, Sherlock Holmes’ enviable creativity can possibly be credited to his approach to difficult problem-solving, a task which requires out-of-the-box thinking. He unwittingly utilizes the psychological principle of “incubation,” that is, the period “during which a person turns to other matters after failing to solve a problem.” to his benefit by allowing himself to switch away from a problem when the solution is not immediately forthcoming. This gives underlying mechanisms in his brain time to process the problem’s parameters, providing him with answers upon revisiting the question. As Watson laments, it remarkably difficult to do: (from The Adventure of the Bruce-Partington Plans)

“One of the most remarkable characteristics of Sherlock Holmes was his power of throwing his brain out of action and switching all his thoughts on to lighter things whenever he had convinced himself that he could no longer work to advantage. I remember that during the whole of that memorable day he lost himself in a monograph which he had undertaken upon the Polyphonic Motets of Lassus. For my own part I had none of this power of detachment, and the day, in consequence appeared to be interminable.”

The technique appears to improve creativity among a range of thinking tasks when the “incubation” period consists of some kind of alternate activity. Amazingly, this concept has been recently re-demonstrated in the realm of sleep science in a study that presented dramatic increases in problem-solving insight among participants that had been able to “sleep on it” and then return to the task. Apparently, regardless of what the alternate activity actually is, it seems that taking time away from a problem may be a way to find the solution.

So it seems that if you want to be able to think like Sherlock Holmes, in a way demonstrated by modern neuroscience to be effective, there are four key takeaways:

1. Be selective- don’t try to set your focus on multiple tasks at once, this will eat up your limited attentional resources and detract from your ability to think.

2. Be inclusive- while this may seem the opposite of #1, they can be practiced simultaneously. Being inclusive involves being open to stimuli in any sensory channel you have, regardless of whether or not you actively act upon it. Much like the internal/external mental balance that occurs during a game of chess, you must pursue a strategy while remaining aware of the strategies of your opponent.

3. Be objective- try to pull yourself out of the
equation when considering possibilities, this will reduce the likelihood that you’ll make an error with regard to your own perspective.

and finally:

4. Be engaged- discover and focus on the real reason you want to complete a task or find an answer- this will motivate you to not only finish it, but to complete it with zest and passion.

Overall: practice mindfulness, your own ability to self-regulate your attention, focusing always on the present moment in an objective, unbiased manner and you will be solving murder mysteries in no time!

Rachel Franklin is a senior studying neuroscience. She enjoys curating the nerve blog (sites.bu.edu/ombs), beautiful data, riding her bike and reading. Her research interests include neuroplasticity in the adult brain, metamodalities and connectivity studies.


2. Baime, M., (2011, July). This is Your Brain on Meditation. Shambhala Sun, 44.


The Undergraduate Program in Neuroscience is an interdisciplinary major leading to a Bachelor of Arts in Neuroscience that takes advantage of the rich neuroscience mission of multiple departments and campuses of Boston University. As a field, neuroscience has grown considerably over the last few decades through its integration of multiple disciplines; and, a current understanding of the field requires knowledge that spans traditional approaches while moving into the intersection between far-reaching technologies and new computational methods. This program combines breadth of exposure to the field as a whole with the opportunity for depth of experience in one of three central domains of neuroscience: Cellular and Systems, Cognition and Behavior, and Computational Neuroscience.

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The Mind and Brain Society (MBS; formerly known as the BU Organization for the Mind and Brain Sciences) was founded in the fall of 2008 in concert with BU’s new undergraduate program in Neuroscience. The group aims to create a network for undergraduate students who wish to take an active role in current issues and research. MBS serves as a hub for not only Neuroscience majors, but all students interested in Psychology, Biology, Philosophy, Computer Science, etc. Our goal is to support an eager multidisciplinary undergraduate community with the conversations and resources fundamental to Neuroscience today.

Throughout the academic year, MBS hosts events spotlighting many different facets of Neuroscience. We hold discussion sessions during which we informally discuss a topic of interest over coffee; previous topics include “The Neuroscience of Religion” and “NeuroEthics.” The group also hosts research presentations by BU professors and screenings of thought-provoking films pertaining to neuroscience.
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