Allendale Columbia School
Mission Statement

“At Allendale Columbia, we prepare students for the world they will inherit. In our trusting and responsive environment, students in nursery through grade 12 grow in confidence and develop scholastic independence. Together, our students and teachers imagine, design, and create in order to make a positive impact locally and globally.”
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COVER ART was created by Ava Gouvernet (Class of 2020)
When asked about the process of creating this illustration, Ava said, “I was holding a pencil before I even spoke a word. Illustrating and creating stories has been a passion of mine as far back as I can remember. This specific piece was created during my first time ever using Photoshop. My experience with Photoshop has since grown, but this particular assignment stirred my creative juices for future projects. That is the funny thing about art… it is never perfect and never done! I look at this piece now and see ways of improving it; pieces become like snapshots that forever capture an artistic moment in time. This was a character that just flowed from my brain into the computer”. Since graduating from AC, Ava has begun studying at Ringling College of Art and Design in the hopes of someday working in the animation industry.
From the Editors

It is with great pleasure that we present this first volume of Research & Discovery, a publication of Allendale Columbia School student research and scholarship. The research presented within this journal is the result of independent student research conducted as part of the Scientific Writing & Research class of the 2016-17 school year. Students worked with teachers Travis Godkin and Dr. Jeff Lawlis to learn many of the intricacies of independent scientific research such as, reading and interpreting scientific literature, methods of statistical analysis, performing literature searches, designing and conducting experiments, elements scientific writing style, and peer reviewing. Students began the school year by reading exemplary works from the fields of Biology, Chemistry, and Physics to increase their exposure to scientific writing in three of the main scientific disciplines. As students grew more comfortable with the scientific writing style, they began scouring databases to identify and read articles on topics of their own interest. Each student selected a paper to assign to the class and then facilitated a class discussion on the scientific merits and elements of writing style for the selected paper. As students’ expertise in the subject increased, they were able to identify their own research question, propose a hypothesis, and then complete a research proposal to present their research to their teachers and potential academic advisors. These advisors, whom they identified and solicited independently from the Rochester community and beyond, provided advice, material assistance, lab space, and in some cases, comments on the student’s written drafts. As students completed their research, they began to write and revise the various sections of their manuscripts. Starting with the Introduction, we went through the iterative process of submitting a rough draft, peer-reviewing each other’s work and revising. Students repeated this process for all individual sections of the manuscripts as well as a final, complete version of their work. Their final draft, submitted at the end of May, 2017, is what you will see in these pages.

We were continually impressed with the students’ curiosity, ingenuity, dedication, and independence throughout this process. For example, Luke Nicosia’s research arose from a college visit road trip when he first wondered if junk food, such as the chips he was currently eating, could affect a student’s ability to learn. Additionally, Alivia Martin built upon her life-long love of horses to look for scientific validation of a “rule of thumb” from the equestrian world. Nadia Linton showed real perseverance in her search for an advisor. After reaching out to many individuals for assistance, she was eventually introduced to a graduate student at Syracuse University who happened to live right down the street and whose interests aligned perfectly with her own! Others, like Cecilia Esterman and Nate Morse, were able to work alongside their advisors and graduate students in labs at the University of Rochester. Alternatively, Leeore Intrator and Dylan Dailor worked closer to home, using Allendale Columbia School students in their research. Similarly, Mason Grimes worked with Artie Cruz, an Allendale Columbia faculty member, as he attempted to write a program that would “evolve” through a process similar to natural selection.

While the students’ work was outstanding, it would not have been possible without a great deal of support from various individuals, who we would like to acknowledge. We would like to thank Dr. Jeff Lawlis for lending his experience and expertise to this process. We are likewise grateful for the work done by Amy Oliveri, Amelia Fitzsimmons, and Ava Gouvernet (Class of 2020) whose efforts made this publication a reality. Ava created the cover art and Amy Oliveri designed the layout for the actual publication, turning students’ Word and Google docs into the professional product seen within. Finally, we would like to thank all those who gave their time to help these students complete their research. In many cases, students’ work could not have been done without their generous donation of time and expertise. All those involved help create an authentic scientific experience that was very enlightening for the students, which we hope will continue for years to come.
Mixed Solvent Studies of Squaraines for Use in Organic Photovoltaics

Cecilia Esterman

Abstract

Squaraines are good molecules to study for organic photovoltaics because they have good absorbance in the near infrared region, high extinction coefficients, and they are easy to modify. Using mixed solvents, we were able to study different aggregates of different squaraines by worsening the solvent quality to force the squaraines to come together and form aggregates. We found that packing structure has a large impact on the absorbance spectra of the materials. The molecular structure affects the packing, which in turn influences the electric and absorbance properties. In particular, there were significant differences in spectra between squaraines with OH groups and without. This is most likely due to intramolecular hydrogen bonding.

Introduction

Organic photovoltaic (OPV) devices can contribute to a solution for clean renewable energy. These devices work by absorbing photons from the sun, which excite the electrons in the donor layer causing them to jump from the highest occupied molecular orbital (HOMO) to the next highest orbital, the lowest unoccupied molecular orbital (LUMO) (Heeger 2014). The exciton (electron-hole pair) travels to the interface between the acceptor and the donor layer where the charges are separated and are collected at their respective electrodes, which generates a current (Figure 1). This is different from silicon devices because the electrons in the organic molecules used in OPVs don’t separate from their atoms as easily as silicon. Therefore, OPVs need a donor and acceptor layer because the entire exciton needs to travel to the interface in order to generate electricity.

Fig. 1. (A) Light excites the electron and it jumps from the HOMO to the LUMO. The pink is the anode, the gray is the cathode, the blue is the donor material, the yellow is the acceptor material, and the purple circle is the exciton. (B) The exciton travels to the interface between the donor and acceptor materials. (C) The charges separate and travel to their respective electrodes.

Since OPVs are lightweight and relatively inexpensive they are currently ideal for a few applications such as providing electricity to African villages and chargers for electronics such as toys and mobile phones (Darling & You, 2013). However, their relatively low power conversion efficiencies (PCE) make it difficult for them to satisfy the global need for electricity as much as fossil fuels or even other types of solar panels can (Darling & You, 2013). For this reason, more research is necessary to either increase efficiency or reduce cost. Studying the role that the material plays on properties such as absorbance and charge mobility can help understand how to synthesize better molecules for OPV use.

One material that can aid in the understanding of how OPV materials affect device performance is squaraines. Squaraines are dyes that have a square arrangement of 4 carbons at the center of the molecule (Figures 2 and 3). They have high extinction coefficients (a measure intrinsic to a material of how much light it can absorb) and good absorbance in the near-infrared region. Because of this, they absorb more photons from the sun than some other commonly used molecules in OPVs (Roncali & Leriche & Blanchard, 2014). They also have good photostability
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us to start to understand the other properties for a particular absorbance spectrum in solution. Aggregate spectra also allow form. Each aggregate of the squaraine molecule has a distinct films, which is its form in OPVs, it is present in the solid aggregate more important than monomers because when the molecule is in aggregates structures are also small enough that they can pack closely for charge mobility. Also, studying the different aggregates can help in understanding the way that different aggregate structures affect the absorbance of the films. This is important because more photons absorbed leads to more charge generated, which gives greater device efficiency. This work could help with choosing device materials designed to optimize device performance.

This study uses mixed solvents to isolate different aggregates in order to study them one at a time. The objective of this paper

(they are resistant to chemical changes when exposed to light) so light will not degrade the film as easily. However, squaraine-based OPVs tend to be less efficient than other small molecule OPVs in part due to their limited capabilities to transport holes through the device (Roncali et al., 2014).

Nonetheless, squaraines are interesting materials with which to study OPVs because they absorb well in the near infrared (NIR) and that is one area where many OPVs fall short (Darling & You, 2013). NIR absorbance is important to study because in the solar spectrum there are more NIR photons than there are blue-green photons. So, if we learn more about NIR devices, that can contribute to more photons being absorbed from the sun, which could increase device efficiency. Squaraines by themselves do not make world record setting devices in efficiency but they are fairly simple molecules that can be used to study OPV principles before applying them to a more complex molecules that will drive the industry forward. Squaraines are also interesting to study because they have unusual intermolecular charge transfer (ICT) characteristics. The presence of ICT broadens the absorbance spectrum and gives a characteristic double-hump spectrum (Zheng & Hestand & Spano & Cody & Collison, XXX). More importantly, charge transfer between molecules is how these materials conduct electricity. Once electrons are generated they need to be conducted to the external load. Therefore the extent of ICT is likely indicative of the expected conductance of electrons through the material.

When these squaraines are present in solutions as monomers, they tend to have similar spectra regardless of side chain length. However, the side chain lengths have an effect on how the molecules pack in aggregate structures. Aggregates structures are more important than monomers because when the molecule is in films, which is its form in OPVs, it is present in the solid aggregate form. Each aggregate of the squaraine molecule has a distinct absorbance spectrum in solution. Aggregate spectra also allow us to start to understand the other properties for a particular family of materials. Spectra can give us a glimpse into a deeper understanding of the material in question.

Thin films of squaraines tend to exhibit multiple different aggregates throughout the film. Since multiple possible aggregates are present in films, it can be difficult to study how the molecules behave in each aggregate because they’re all mixed together (Zheng et al., 2015). The films are spin coated in attempt to create a uniform thickness and it creates a random orientation of molecules and possible aggregates. One way to create solutions with only one type of aggregate present is through mixed solvents. Mixing good and bad solvent qualities in different ratios can yield different aggregates because when the solvent quality is bad the molecules tend to pack together and when it is good they tend to disperse and qualities in between can give different aggregates that only form in solvents of intermediate quality (Zheng et al., 2015). By varying solvent quality, it is easier to isolate each aggregate and study them individually. The solvent composition can also affect whether the squaraine forms a kinetically stable aggregate or thermodynamically stable aggregate. Thermodynamically stable aggregates retain their structure over time while kinetically stable aggregates try to find more thermodynamically favorable positions over time or with improved solvent quality (McKerrow & Buncel & Kazmaier, 2015).

Side chain length has a huge effect on how the molecules pack together in these aggregate forms. The longer side chains have the potential to create more J-aggregates since they are longer and may force the molecules to pack closer to end-to-end. The slip stacking angle is important because if the squaraines are packed such that their positive and negative charges line up, there is possibility of intermolecular charge transfer. Longer side chains are also bulkier, which force the molecules further apart which leads to less ICT.

Since the devices are processed from solution, the materials also need to be soluble in the solvents. Side chain plays a huge part in solubility. While longer side chains exhibit greater London dispersion forces, they are generally more soluble than molecules with shorter side chains. The increase in solubility with increase in side chain length is due to the fact that the side chains have more ways in which they can arrange themselves and this higher entropy makes dissolving more favorable (Collison, 2017). Squaraines with OH groups tend to be less soluble in water than deshydroxy squaraines because the OH groups form an intramolecular hydrogen bond with the oxygen. This hydrogen bonding makes the backbone of the molecule more rigid and so there are fewer ways for it to arrange itself and dissolve (Law, 1997).

We have found that side chain length influences absorbance and electronic properties of aggregates. This work is important in studying OPVs in order to optimize molecule side chain lengths for devices. There are trade offs in side-chain length because the molecules need to be longer to be more soluble for processing but also small enough that they can pack closely for charge mobility. Also, studying the different aggregates can help in understanding the way that different aggregate structures affect the absorbance of the films. This is important because more photons absorbed leads to more charge generated, which gives greater device efficiency. This work could help with choosing device materials designed to optimize device performance.

This study uses mixed solvents to isolate different aggregates in order to study them one at a time. The objective of this paper

Fig. 2. A deshydroxy squaraine molecule. The radical groups are chains of carbons.

Fig. 3. A dihydroxy squaraine molecule. The radical groups are chains of carbons.
is to study the effect that side chains have on aggregation and to study the properties related to OPV device performance of those aggregates. This will help us understand how materials behave when in films and can help with molecule selection.

**Methods**

All squaraines used were synthesized at Rochester Institute of Technology by Dr. Jeremy Cody. Squaraines used were either branched (ex. DiBSQ) or unbranched (ex. DBSQ) and were either deshydroxy squaraines (ex. DPrSQ) or dihydroxy squaraines (ex. DPrSQ(OH)2). Stock solutions of squaraines were prepared in cleaned glass scintillation vials. Between 0.80 mg and 1.6 mg of dry squaraine was measured and put into the vial. One milliliter of reagent grade acetone or dimethyl sulfoxide (DMSO) was added for every 0.01mg of squaraine using a 1mL-5mL VWR Signature Ergonomic High Performance Single Channel Variable Volume Pipettor and the solution was sonicated without heat in a VWR Model 75D ultrasonic bath until the squaraine was adequately dissolved.

All solution absorbance measurements were taken by placing the solutions in a 1 cm path length fused quartz cuvette (Starna) perpendicular to the oncoming beam and running them in a Shimadzu UV-2100PC UV-Vis spectrophotometer. Unless otherwise specified, scan speed was set to medium with a slit width of 2nm and a sampling interval of 0.5nm. Scan range was generally from 370nm to 900nm. Before scanning the squaraine solutions, the machine was calibrated with the appropriate solvent mixture.

Both a solvent that easily dissolved squaraine (good solvent) and ones that didn’t dissolve as well (bad solvent) were used in the solvent studies. The good solvent used was DMSO (Fisher Chemical) and the bad solvent was deionized H2O prepared from a Barnstead E-Pure Water Purification System to at least 17.0 megaohms per cm. Solvent blends of good and bad solvents were prepared in 10mL glass scintillation vials. The solutions ranged from 0% bad solvent to 100% bad solvent in increments of 10%. The solutions were prepared by pipetting the same amount of stock solution into each vial, after which the correct amount of DMSO for each mixture was added. The water was then slowly injected into the solution with a pipette over 1 minute while the solution was sonicated.

Solvent shift experiments were performed by starting with mixtures made to 100% water. Then DMSO was added stepwise into the solution, with sonication, with a spectrum recorded for each step. When a thermodynamically stable aggregate was observed to have formed, the process of stepwise addition of DMSO was carried out, essentially to confirm that the thermodynamically stable state had been formed. All measurements were taken with the appropriate blanks.

Heating studies were performed using a Shimadzu Model CPS-240A CPS Controller connected to the Shimadzu UV-Vis. The solution where mixed species of monomer and aggregate was found for each squaraine was heated to find an isosbestic point and demonstrate a stoichiometric relationship between the monomer and aggregates. Temperature measurements were taken from the readings on the machine immediately after the temperature display stabilized.

**Results**

After collecting spectral data on the aggregates, the absorbance data were plotted as a function of wavelength as shown in the figures below. All absorbance measurements for each aggregate were normalized by dividing by the maximum absorbance. This makes the maximum value 1 for all spectra to simplify spectra comparison.

The UV-Vis absorption spectra for DPrSQ are shown in Figure 4. The black curve represents the solution spectrum and is characterized by a single peak at ~655nm with a shoulder at ~595nm. The Full Width at Half Maximum (FWHM) is ~45 nm. The blue curve represents the absorption from an aggregate that

![Fig. 4. The absorbance spectra for DPrSQ. The black line is the monomer, the blue line is the aggregate in 0% DMSO, the green line is the aggregate in 10% DMSO and the red line is the aggregate in 20% DMSO.](image-url)

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is considered to be kinetically stable, since it is formed in a 100% water solution. It is a very broad peak with a FWHM of ~175 nm. There is also some fine structure that is clearly seen, with features at ~620 nm, ~660 nm, ~705 nm, ~735 nm, ~748 nm, ~758 nm and ~778 nm. As the solvent conditions improve, the aggregate moves towards a thermodynamically stable form, where some breadth is lost, while the fine structure seems to remain.

The spectra for DBSQ are shown in Figure 5. The black line is the monomer which is characterized by a peak at ~655 nm and a shoulder at ~590 nm. The blue line represents the kinetically stable aggregate. It is quite blue shifted from the monomer with a peak at ~520 nm and a shoulder at ~650 nm. The peak is more triangle shaped than a smooth curve. The red line is the thermodynamically stable form and it is characterized by two peaks of similar intensity. The low energy peak is red shifted from the monomer at ~630 nm and the shorter peak at ~750. The peaks are more rounded than that of the kinetically stable aggregate. There is also a small spike in absorbance at ~885 nm but that is at the edge of the instrument’s range detection. Few other spectra appear to show this as well (Figures 6, 9, and 14).

Fig. 5. The absorbance spectra for DBSQ. The black line is the monomer, the blue line is 0% DMSO and the red line is 40% DMSO.

Fig. 6. The absorbance spectra for DiBSQ. The black line is the monomer, the blue line is the kinetic aggregate and the red line is the thermodynamic aggregate.
The spectra for DiBSQ is shown in Figure 6. Black is monomer with peak at ~655 and a shoulder at ~590. The blue line represents the spectrum for the kinetically stable aggregate. It has a broad peak at ~610 nm so it is slightly blue shifted from the monomer. It has a FWHM of ~150. The red spectrum represents the thermodynamically stable aggregate and it has a broad peak (FWHM ~170) at ~655 (same as the monomer). It has a shoulder at ~740 nm. Both peaks are rounded but the thermodynamically stable form is slightly more pointed. There is also a slight spike in the red spectrum at ~885 and it appears that the blue has an even smaller one as well.

The spectra for DiPSQ are shown in Figure 7. The black line is monomer with peak at ~650 and shoulder at ~600. Red is thermodynamically stable aggregate and it has 2 peaks. The shorter one is at ~540 and is round and the taller is at ~740 and triangle-shaped. It also still absorbs light at 900 nm and doesn’t taper off to 0 absorbance. The blue spectrum is kinetically stable and also has 2 peaks. The higher peak is at ~550 and has a shoulder at ~500 and
The spectrum for DHSQ is pictured in Figure 8. The black line is the monomer. It has a peak at ~650nm and a shoulder at ~595nm. The red is thermodynamically stable and has a peak at ~735. The peak is somewhat broad with a FWHM of ~130. It also still absorbs at 900nm but not as much as DiPSQ. The blue spectrum is kinetically stable with a peak at ~645 and a shoulder at ~765. Both peaks are more triangular.

The spectra of DPSQ(OH) is shown in figure 9. The black line is the monomer. It has a peak at ~650 and shoulder at ~600. The red peak is thermodynamically stable. It has a slight peak at ~425, a large peak at ~520 with a fine feature at ~510, and a shoulder at ~645. The large peak is rectangular. The thermodynamically stable peak is blue shifted from the kinetically stable spectrum which is unusual. The blue line is kinetically stable and has a small hump at ~400 and a large, broad peak at ~525. The peak is rounded.

Fig. 9. The absorbance spectra for DPSQ(OH). The black line is the monomer, the blue line is the kinetic aggregate and the red line is the thermodynamic aggregate.

Fig. 10. The absorbance spectra for DESQ(OH)2. The black line is the monomer, the blue line is the kinetic aggregate and the red line is the thermodynamic aggregate.
The spectra for DESQ(OH)2 is shown in Figure 10. The monomer is black with peak at ~650 and shoulder at ~595. The thermodynamic and kinetic forms both have large peaks at ~510. The kinetic peak is slightly blue shifted relative to the thermodynamic form. They both have smaller peaks at ~660 but the thermodynamic is a little lower. There is very little difference between each form.

The spectra for DPrSQ(OH)2 is shown in Figure 11. The black line is the monomer and it has a peak at ~650nm and a shoulder at ~580nm. The red line is the thermodynamically stable aggregate. It has a peak at ~520nm and a second lower peak at ~730nm. The blue line is the kinetically stable aggregate. It has a peak at ~520nm and a second lower peak at ~670nm. The second peak is lower in the kinetic aggregate and the kinetic aggregate is blue shifted.

The spectra for DBSQ(OH)2 is pictured in Figure 12. The black line is the monomer. It has a narrow peak at ~650nm with a shoulder at ~580nm. The red line is the thermodynamically stable aggregate. It has a peak at ~550nm and a shorter peak at ~692nm. The blue line is the kinetically stable aggregate. It has a peak at
The spectra for DiBSQ(OH)2 is shown in Figure 13. The black line is the monomer. It has a peak at ~660nm and a shoulder at ~610nm. The red line is the thermodynamic aggregate. It has a broad peak at ~600nm with a lower, overlapping peak at ~540nm. The blue line is the kinetic aggregate. It is a broad peak at ~600nm. This squaraine is unusual because the thermodynamic form is blue shifted from the kinetic form.

The spectra for DiPSQ(OH)2 is shown in Figure 14. The black peak is the monomer. It has a peak at ~630nm and a shoulder at ~570nm. The red line is the thermodynamic aggregate. It has a short peak with some fine features at ~550nm and a larger peak at ~880nm. The blue line is the kinetic aggregate. It has a peak at ~660nm.
~540nm and a shorter overlapping peak at ~660nm.

The spectra for DHSQ(OH)2 are pictured in Figure 15. The black line is the monomer. It has a peak at ~650nm and a shoulder at ~590nm. The red line is the thermodynamic aggregate. It has a peak at ~560nm and a shorter peak at ~660nm. The blue line is the kinetic aggregate. It has a peak at ~540nm and a shorter peak at ~650nm. The short peak on the kinetic is shorter than the thermodynamic.

In developing an understanding of how side groups change the properties of the squaraines, it makes sense first to find common properties that apply to most of the squaraines regardless of branching or OH groups. In general, the solubility of the squaraine increases with increasing side chain length. However, their solubility in water decreases as the side chain length increases as shown by the fact that they aggregate at a lower percentage of water (Figure 16). Additionally, the smaller side chains tend to show greater differences in absorbance spectra between kinetic and thermodynamic aggregates. An example of this trend is DSBQ vs. DSBQ(OH)2 (Fig. 2 and 9). The exceptions to this trend are DiPSQ(OH)2 and DiPSQ (Fig. 4 and 11). The common features of these molecules are that they are both branched and both pentyl.

Another trend among all the data is the thermodynamic spectra tend to be red shifted from the kinetic spectra, meaning thermodynamic aggregates absorb longer wavelengths of light. This effect is clearly shown in most spectra. However, there are two exceptions, DPSQ(OH) and DiBSQ(OH)2. This feature is less noticeable in the DiBSQ(OH)2 because both spectra are similar but the effect is significant in DPSQ(OH). DPSQ(OH) is different from the other squaraines in that it only has one OH group. However it is difficult to draw trends with only one of this type of squaraine.

In general, all monomer spectra, regardless of what type of squaraine they are from, are almost identical. However a trend that contrasts the hydroxy-squaraines with the deshydroxy-

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**Fig. 15.** The absorbance spectra for DHSQ(OH)2. The black line is the monomer, the blue line is the aggregate in 0% DMSO and the red line is the aggregate in 80% DMSO.

**Fig. 16.** Different squaraines and their states at different solvent qualities.

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The squaraines is that the shoulders of the monomer peaks tend to be more pronounced in the squaraines with OH groups (Figures 8-15). This appears to be the only difference shown in monomer peaks among any groups.

The spectra of the deshydroxy-squaraines tend to show more differences in spectra between the kinetic and thermodynamic forms. For a few squaraines, namely DESQ(OH)2 with OH groups it’s unclear whether two different forms even exist (Figure 10).

The exception to this is DiPSQ(OH)2 (Figure 14). Even though it has OH groups it shows remarkable differences in spectra between the kinetic and thermodynamic forms. The difference between the wavelength where the maximum absorbance occurs in the thermodynamic and kinetic forms was ~300nm. The deshydroxy squaraines show varied types of spectra whereas the hydroxy tend to show characteristic double hump features (examples in Figures 10-12 and 15). This double hump spectrum is associated with intermolecular charge transfer (ICT) indicating that squaraines with OH groups exhibit ICT more than ones without (4). The exceptions are DiBSQ(OH)2 and DiPSQ(OH)2. The common link between these are they are both branched. However, not all branched squaraines exhibit this so it doesn’t appear to be a trend among branched squaraines. Although there weren’t clear trends among the branched squaraines, there were some among the dihydroxy squaraines.

It was expected that squaraines with OH groups would be more soluble in water because the OH groups form hydrogen bonds that were expected to interact favorably with water. Surprisingly, squaraines with OH groups tended to be less soluble (Figure 16).

Another trend among the OH squaraines was their thermodynamic and kinetic spectra were fairly similar however the second peak in the thermodynamic spectra were higher intensity (Figures 8-15). In the double hump spectrum, the second peak is associated with ICT so the thermodynamic form likely exhibits more ICT than the kinetic form.

In summary, there was a large range of different spectra observed. There was a greater difference between spectra within the deshydroxy squaraines than the dihydroxy squaraines. Squaraines with OH groups were less soluble and exhibited double hump spectra. The main difference between kinetic and thermodynamic spectra in the hydroxy squaraines was intensity rather than shape.

**Discussion**

This paper will focus mainly on the comparison of squaraines with OH groups to ones without. For that reason, the paper will not deal with comparisons between branched and unbranched squaraines nor will it discuss isobutyl or isopentyl squaraines because they are exceptions to almost every rule and discussing why is outside the scope of this paper.

For each squaraine, the monomer spectrum was basically identical to every other squaraine (Figures 4-15). However, the squaraines all exhibited vastly different spectra when they formed aggregates. This indicates that changes or differences in spectra can be attributed to the packing structure which is influenced by molecular structure rather than the differences in spectra being attributed to the molecules directly.

All molecules tended to become less soluble in water as the side chain length increased (Figure 16). This is likely a combination of two effects. The first is when the molecule has bigger side groups, it becomes heavier and there will be more London dispersion forces between squaraine molecules. Therefore, there will be a stronger intermolecular bond between them and it will take more energy to break them up. Additionally, the side groups are hydrophobic so the squaraines will have a tendency to pack in a way so as to minimize their contact with water. As the side chains get larger, more surface area is exposed to water if they are monomers so they will tend to come together as aggregates.

When OH groups are present, the squaraines are less soluble in water, contrary to expectation (Figure 16). This is likely because instead of forming hydrogen bonds (H bonds) with water, they form intramolecular H bonds. These H bonds make the backbone of the molecule more rigid, decreasing the orientations it can take. Due to fewer degrees of freedom, the molecule has lower entropy and it is not as thermodynamically stable for it to dissolve in water.

Intramolecular H bonding is also a possible explanation for why hydroxy squaraines show fewer differences between thermodynamic and kinetic forms (Figures 8-15). Because they have a rigid backbone, the only degree of freedom is the slip stacking angle. So there are fewer aggregates that can be formed and the spectra will look similar among squaraines with OH groups.

Since only hydroxy squaraines show double hump spectra and double hump spectra are associated with ICT, this indicates that the OH group is important for facilitating ICT. A potential explanation is that since the OH groups make the squaraine more rigid, the molecules in aggregates can get closer together, thus the charge transfer happens more easily.

Another implication is that in deshydroxy squaraines steric hindrance plays a larger role in absorbance and electric properties.

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**Fig. 17.** (A) The squaraines pack so that the positive and negative charges are aligned. This is a potential thermodynamic aggregate. (B) The squaraines pack so that the benzene rings stack on top of one another. This is a potential kinetic aggregate.
Since the molecules have more degrees of freedom than ones with OH groups, they can become bulkier and not pack as closely, which would lead to decreased charge mobility. However, because there are more possible orientations for the molecule to take, the aggregate structures are more varied, which improves absorbance.

For deshydroxy squaraines, the side groups play a larger role in packing. As stated before, they are more affected by steric hindrance so it would be expected that changing the side groups would change the spectrum more for squaraines without OH groups than changing side groups would for those with OH groups.

For dihydroxy squaraines, the fewer degrees of freedom means that pi stacking and coulombic interactions become more important in determining packing structure. Without the bulky side groups in the way, the molecules will likely pack in a way that is more favorable in terms of charge interactions and/or stacking of benzene rings instead of a way that is favorable in terms of dispersion forces or steric hindrance.

Since we expect that the molecules with OH groups stack in a way that is favorable in terms of coulombic interactions, we would also expect to see more ICT since the charges line up. This is supported by the double hump spectra seen for molecules with OH groups.

The only major difference between the thermodynamically stable and kinetically stable spectra for the OH groups is the second hump is lower in the kinetic form. It's possible that this occurs because the slip stacking angle in the thermodynamic form is such that the positive and negative charges line up which facilitates ICT (Figure 17a). The kinetic aggregates may line up so that the benzene rings are on top of one another so that it's more unstable in terms of the charge alignment and charge can not transfer as easily (Figure 17b).

Conclusion

Based on the spectra obtained from all the squaraines, it's evident that packing structure has a great effect on the absorbance and electric properties of the molecule. Using the information obtained, we can design and select the molecules that are best suited for OPVs. Future work in this area may be explaining the exceptions to certain trends and verifying the predicted aggregate structures.

References


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The Effects of Food Cues on Students’ Overall Performance and Attentiveness on Exams

Luke Nicosia

Abstract
The experiment featured 23 freshman and sophomore students who underwent a series of six academic tests in order to determine the effects of potato chips and carrots on their scores and times of completion. With one control, two exams featuring potato chips distributed at t=0 minutes and t=3 minutes, and two exams featuring carrots distributed at t=0 minutes and t=3 minutes, it was hypothesized that students would show the highest time of completion for the potato chip exams, and the lowest for the control. Additionally, it was hypothesized that the control would exhibit the highest overall score. The data provided show that students ate four times as many chips as carrots on average, which was expected. The control exhibited both the highest time of completion as well as the highest overall score, the former of which was not expected. These results may be explained by the high variety in Yale Food Addition Survey scores, odd testing circumstances, and a small sample size. It is thus concluded that further testing is needed to definitively evaluate the hypothesis.

Introduction
With the growing concern over health detriments caused by unhealthy foods, namely junk food, fast food, and candy, there is a need to study the effects of the consumption of such foods. As students today are growing with readily available and easily accessible unhealthy food options, as well as a society that has seen obesity, bulimia, and other food related disorder cases increase in occurrence, it is significant to study the possible problems that may arise from these factors in an academic setting (Smeets, Roefs, van Furth, & Jansen, 2008).

While a majority of research has been conducted on the long-term effects of the consumption of candy and fast food, there has been very little research done on how unhealthy and addictive foods affect students in the classroom during an exam. As the concern for the mental effects of unhealthy foods has escalated due to published studies that have showcased the adverse effects of their consumption, there have been psychological papers documenting that the brain, when presented with more palatable unhealthy food, acts with a level of craving similar to drug addiction through a positive biofeedback mechanism (Gearhardt, Corbin, & Brownell, 2009). Additionally, the presence of elevated amounts of monosodium glutamate (MSG), a chemical that has been utilized as a flavor enhancer, has been shown to increase the palatability of many foods, including unhealthy ones (Yamaguchi & Kimizuka, 1979). The presence of MSG, therefore, may be a possible explanation for the addictive behavior exhibited by consumers of certain unhealthy food products. The function of the brain under both food and drug cues have been shown to release elevated levels of dopamine and activate reward stimuli (Gearhardt, Yokum, Orr; Stice, Corbin, & Brownell, 2011). The main difference in the responses between the two cues, however, is that the average brain enjoys the consumption of unhealthy foods, and thus engages in a form of positive feedback (Pelchat, 2009). According to a study conducted in the late 1990’s by M. Pelchat, there is a correlated psychological association with junk food, meaning that the brain would have a preference to promoting the consumption of such food, if given the opportunity (Federoff, Polivy, & Herman, 1997). The data in this experiment show that energy depletion in an individual inevitably leads to an inclined drive to consume food with a greater energy content. There is also a relationship shown in the study as to how the presence of visual and/or oral cues may influence some to crave a specific food, and thus increase self-assessed ratings of hunger (Meule, Skirde, Freund, Vögele, & Kübler, 2012). Exposure to these food cues, and the later prompt to consume them, may stem from an internal memory bias, or a higher chance of the recollection of a specific memory, as research from a Chicago-based laboratory has shown (Teras, 2005).

There have also been correlations showing an increased intake of food when attention is diverted to another task, such as watching television (Ogden et al., 2013). In adverse, addiction to specific foods has also shown to serve as being a distraction from a specific task. For example, the specific addiction to chocolate has been shown to have implications of distraction (Smeets et al., 2008). Individuals addicted to chocolate (i.e. “chocoholics”) have been shown to have an increased distraction from memory-related tasks when they crave it (Smeets, Roefs, & Jansen, 2009). The study, however, has found to not just be limited to chocolate addiction. Visual cues from fast food have also been shown to decrease the time for responses in cognitive memory tests (Meule et al., 2012). Further studies have shown the significance
for children to establish a proper eating routine as well. Improper meal routines in lieu of the consumption of junk food have been found to worsen academic achievement more than those who have a balanced dietary pattern, negatively impacting academic performance (Bellisle & Halix, 2001; Feinstein et al., 2008). Recently, researchers have created a scale in order to judge how predisposed to craving a junk food certain individuals are, known as the Yale Food Addiction Scale (YFAS). Researchers at the aforementioned university have attempted to assign a numerical value to the level of addiction individuals feel to a certain food (Gearhardt et al., 2011). This exam was developed for a general audience so as food psychologists may have a standardized way to diagnose individuals with food-related disorders.

In the classroom, it is important to comprehend the effects that unhealthy food may have on children. Several studies have concluded that there have been evident non-positive effects from the habitual consumption of fast food; a study of over 11,000 middle-school children showed that regularly consuming fast food outside of school correlated with a decrease in the rate of their mean academic growth (Tobin, 2013). Researchers have reasoned that this trend is due to an iron deficiency in fast foods, which is an essential mineral for cognitive development (Purtell & Gershoff, 2014).

The concern of the effects of the habitual consumption of unhealthy foods in the classroom has led to the need to further study the academic effects of unhealthy foods. As a majority of tests on the subjects have focused on chocolate and fast foods, not many have focused on store-brand junk foods, namely potato chips. To study the effects of junk food on the overall attention span of students during an exam consisting of different academic disciplines, a test will be conducted as to how performance time, level of distraction, and overall scores change with respect to the presence of food cues. The objective of this study is to see if the presence of a high-carbohydrate, high energy, junk food—potato chips—during a moderately challenging test would affect the level of attention given to the exam; to also test the opposite case, the experiment will also feature the administration of a healthier food substitute—baby carrots—in order to observe how the presence of a food cue of any kind affects exam scores. This experiment would be significant, as it may show the connection of poorer academic achievement at a specific instant and the presence of junk food and not in that of healthier foods. Also, in this research it is also important to take into account how the presence of junk food during an exam may potentially lead to substantial distraction from the task at hand. This experiment will attempt to show the correlation as to how the presence of the potato chips distracts the students at a different level than the vegetable, thus ruling out the students’ distraction by these foods, possibly correlating to similar foods as well.

An important aspect of this experiment is to show how the presence of food cues can promote a positive psychological feedback loop, prompting an increased eating of the chips. The presence of the potato chips, coupled with the possibility of active contemplation and addiction of eating the chips as evidenced by the YFAS scores, may possibly hinder a student’s attention to an exam, resulting in a longer completion time, and possibly lower test scores. Supporting the aforementioned correlation could be rather difficult, as the presence of confounding variables and the relative similarity of the test scores has not definitively proven that there would be a correlation of test scores and common fast food consumption (Bellisle & Halix, 2001). It is thus hypothesized that if specific students consumed a higher amount of junk food during the exam, they would have a longer time of completion, possibly from an increased level of distraction from the exam, and possibly lower exam scores.

**Methods**

A mixture of freshmen and sophomore students in the biology classes (n=23) from Allendale Columbia School in Pittsford, New York were given the option to participate in the experiment. Each student and either a parent or legal guardian signed an informed consent waiver in order to be eligible to participate.

The students were divided into two classes, both of which met on the same day. The foods and bowls for the experiment were purchased two days prior to the administration of the first exam. The students were administered the tests on both January 10th and January 20th, 2017, with one class meeting at 8:20 AM on both days, while the other at 1:25 PM. Both classes were administered the exams at the beginning of the class.

In order to ensure that no class was given a benefit in the explanation, a script was read before the beginning of each test. A timer was placed in front of the class in order to pace students; the students were responsible for recording the amount of time left on the timer when they completed the exam, the number serving as the student’s time of completion. During the administration of each non-control exams, the number of times that a student either consumed a chip or carrot during the testing period was recorded.

The experiment itself (not including the later administered YFAS) was a series of five short multiple-choice tests; the exams contained anywhere from ten to twelve total questions. Each exam contained paragraph-based grammar, non-calculator mathematics, and graphing questions (either adapted from ACT.com or improvised to approximately the same degree of difficulty); the exams were divided into subsections of the aforementioned topics ranging from two to six questions each. The tests were varied based on the ordering of these subsections. Due to time constraints, students were given a limit of nine minutes to complete the exams before they were collected.

Three of the five main exams were administered on the first day of testing (January 10th). The first exam served as a control for the participants. This exam was utilized to give a baseline for the group’s level of comprehension for the exam material. The second test featured a small bowl of potato chips at the start of the exam; the students were given specific instructions to not eat or touch the chips prior to the beginning of the exam. Students were given nine minutes to complete the test with the option to eat the potato chips throughout the testing period, after which the bowls were collected. Third, a small bowl of carrots was used instead of potato chips, but the bowls were placed on each student’s desk at three minutes into the start of the exam; students were not informed that they would receive the carrots three minutes into the exam. Each of these exams were distributed in succession, the same order being done for both classes. However, only three exams were distributed during each day of testing.

On the second day of testing, students were administered the
remaining two exams, one of which featured carrots at the start of the exam while the other featured potato chips three minutes into the exam. After these tests were conducted, the YFAS was administered to each student; the YFAS consisted of 25 questions concerning the eating habits of the students, the purpose was to aid in correlating the changes in time of completion and score with the YFAS scores. Each student’s subcategory scores, overall scores, times of completion, YFAS scores, and number of times a student had consumed a chip or carrot were calculated. The overall time of completion was additionally correlated with the scores from the YFAS in a bar graph, ensuring student results were separated into groupings based on their respective YFAS scores.

Results

The data for the time of completion, overall scores, and number of times students ate the offered food were organized into graphs. Additionally, the p-values of each collected data cluster was also calculated using a two sample t-test, in order to determine the statistical significance of the data. The YFAS scores produced an average of 15 out of 100, indicating that the population did not exhibit a predisposition to an addictive food such as the potato chips. However, students ate close to four times as many chips as they did carrots (Figure 1). The overall trend of the scores are shown in Figure two; the average score in the figure showed that the control exam exhibited the highest overall score, while the scores were lowest, yet were relatively similar, for the two exams involving chips. Figure three shows the actual average time spent on completing the exam. As a result of the unusual trend presented in Figure three, it was hypothesized that the trend came as a result of each exam not having the same amount of questions. Figure four was constructed with the times of completion under the assumption that every test contained twelve questions that were answered at the same speed; this change was done because as some exams featured only ten questions, less error would be involved in the figure. As a result, the trend in times of completion became different than the unaltered times of completion. The data in the figure show that, if each test were to have twelve equally difficult questions, the control would still have the highest time of completion, and the exam involving chips at three minutes would have the lowest.

Discussion and Conclusion

While certain aspects of the data did appear to coincide with the hypothesis, many of the trends produced did not. Certain trends, additionally, had statistically significant p-values, while others did not exhibit such trends. The variety of p values does give considerable doubt on the replication of the experiment, as well as overall validity to the hypothesis. However, there are several issues with the experiment itself, namely limitations in participation and controlling for confounding variables and factors. With being forced to conduct an experiment with such a small sample size, it may not necessarily mean that the experiment itself is flawed. Thus, it may be necessary to increase the sample size of the original experiment in a future instance.

It is quite significant to note that the trend presented in Figure one coincided with the hypothesis. The figure quite clearly shows the discrepancy between chips and carrots eaten. This data was expected, as it is shown that students easily consumed higher amounts of chips than carrots despite the low YFAS scores. As the YFAS tests for addiction, and not necessarily for preference, it can be inferred that students did exhibit a preference to chips over carrots. The p-values for this experiment does validate this data as statistically significant. What is of important note, however, is the size of the error bars for the exams involving chips. Many
more students chose not to eat during the chip exams than the carrot ones, and therefore the standard deviations were quite high for the former. Additionally, the scores for all the exams were extremely close to one another, differing by less than five percent in some cases. While this figure seems to corroborate certain aspects of the hypothesis, Figure 2 did not contain any p-values that suggested statistical significance. As some p-values were as high as 0.98, some—such as the p values comparing the population’s times that a food cue was consumed—were less than 0.01.

Other data, however, were unexpected. The overall trend that was shown in Figure 3 portrayed the opposite of the expected trend. It was expected that, due to food distraction, the exams involving potato chips would have a higher time of completion than the control and carrot exams. The data thus shows that a student was more likely to finish an exam quicker if food cues

Fig. 2. This graph shows the overall scores per exam. The graph has a 95 percent confidence interval. There were no statistical differences found for the overall scores.

Fig. 3. This graph shows the unaltered times of completion. The graph here shows that the control test showed the highest time of completion. The graph has a 95 percent confidence interval. As done with Figure one, the data were compared using a t test. It was found that there was a statistical difference of the control test to the carrots at 0 minutes, with a p value of .03. The control exam versus the chips at 0 minutes, using the same test, was found to be nearly statistically different, with a p value of .06.
were brought out later. As the figure shows that the shortest time of completion was one of the chip tests, and that the control test had the highest time of completion, the trend does not coincide with the hypothesis. However, a possible error for this trend may be due to the lack of consistency with the length of the tests. While it was initially assumed that each test was equally difficult, tests ranged from ten to twelve questions. This discrepancy possibly meant that times required to complete certain exams were shorter than others, resulting in the bizarre time trend. Thus, with the adjustment of times, as shown in Figure 4, the times were shown to be more similar to one another, but did not perfectly reflect the expected trends. The control, as well as the exams involving chips starting at the start, and carrots starting at 3 minutes, displayed similar times of completion. Yet, the exam involving chips at three minutes still showed the smallest time of completion. In addition, the average time of completion between the two carrot tests was higher than the average between the two chip tests, definitely refuting the hypothesis. The trend of times of completion in Figure 1 may have been due to some students purposefully rushing through the potato chip exams in order to eat the chips without worrying about the exam. Such actions could account for the unusual times of completion. As the figure is an estimation of the times, as well as the trend being possible within the error bars, there is not necessarily a rejection of the hypothesis with this data.

After analysis, several problems were found that might account for the production of the trends. On the first day of testing, one of the classes may have consumed chips before the start of their exam due to chips being served for lunch unexpectedly. This event would have affected twelve of the test scores for the control tests, as well as the exams featuring chips at the start, as students may have already been satisfied with their consumption of chips prior to taking the test. Another problem with the data is the population size. The population was limited to 23 students due to time constraints and the failure of some students to turn in required forms, and thus the sample size may not have been sufficient to show statistically significant trends. The experiment itself had several flaws that could also be improved, namely the brevity and inconsistency of the exams. As the exams were only nine minutes, and the exams were not necessarily the same length, there is reason to believe that these flaws accounted for a significant portion of the error.

The trends shown by the data coincide with the hypothesis in several ways, but the unexpected results from the time of completion did not completely support the hypothesis. The possible reason for this result may be due to several factors that were not controlled for during the exam. It is thus concluded that, based off of the data collected, the experiment proved inconclusive. However, there is sufficient evidence to suggest that future administration of the exam, with a larger sample size, a longer exam, and limited outside biases, may yield more statistically significant results, and possibly support the original hypothesis.

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The Effects of Food Cues on Students’ Overall Performance and Attentiveness on Exams


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Kissing Spine Syndrome and Weight Capacity: An Evaluation of the 20% Rule
Alivia Martin

Abstract
Spinal deformities in the equine population are unknowingly prevalent. Although many owners come across these issues several times throughout their equestrian career, few acknowledge the consistency and severity of the problems that arise. To begin to address this, I began at the very base of our interaction with horses. Riding is the automatic activity that all people think about when the word “Horse” is spoken. A survey was sent out worldwide regarding riders and their animals, asking questions about their habits and horse’s response to saddling. With 92 submitted pieces of data, a conclusion was made to suggest a new way of approaching the sport using equations to help out our equine friends in determining how we should be safely riding them.

Introduction
A commonly held belief among the equine population is the average horse, approximately 60 inches tall, average build with healthy muscles, has a carrying capacity of 20% of its body mass, give or take the dependent variables of health and age (Erichsen, 2003). However, upon further investigation of why such a rule is suggested by veterinarians and is held as ‘common knowledge’, research to adequately support this rule does not exist. Although all breeds vary in bone structure, the similarity of mammalian spinal structure allows for a wide range of research subjects, which as a result allows one to approach this question with a wide option of which breed to use.

Kissing Spine Syndrome (KSS), otherwise known as Dorsal Spinal Process (DSP) impingement (Coomer, McKane, Smith, & Vandeweerd 2012), occurs when the vertebrae in the spine are horizontally flexed to the point of contact, either touching or nearly touching, leading to minor or severe dips of the back. Severe cases cause atrophy along the vertebrae that can be detected by radiography as depicted in Figure 1 (Erichsen, 2003). Occurrence of this bend takes place primarily in the section of the T13 to T18 vertebrae, the thoracic section of the spine where a rider rests when mounted. Previous research from a pool of 173 horses found that the alteration in the bones appears often in the breeds involving sport — suggesting that the weight combined with physical exertion places stress, mostly transient, on the spine of the equine (Erichsen, 2003). It is this syndrome that I am analyzing in the context of weight that the average sport horse can carry.

When an average person of 72 kg is riding the horse, the flexion of the spine in response to weight-bearing at various gaits results in no temporary discomfort. However, should this rider be more complacent in form than that of an advanced rider, where weight is distributed evenly and moves with the horse, it is possible that discomfort will occur along the lumbar portion of the spine, I see as a possible oversight in another study performed addressing the potential problems of riding (de Cocq, van Weeren, & Back, 2004). In Cocq et al. (2004), incorrectly studying the locomotion of an equine under a solid, unmoving weight allowed the chance of error to rise due to the lack of motion occurring on the spine. With a mobile rider, being ridden would be less uncomfortable for the horse, and the results would differ.

The importance of this research is primarily focused towards those who care for their animal’s health, which is limiting because horseback riding is such an old sport with entrenched beliefs. There seems to be a lack of urgency in addressing possible problems in regards to the results of weight on the spine. An estimated 40% of horses within a given population, a number suggested by Dr. Tracey Turner who has researched this subject for a new treatment, are diagnosed with KSS; many of those cases more often than not lead to misbehavior under saddle because of the discomfort felt. Left untreated, the syndrome will either continue to pester the equine and/or progress to a worst state should the animals continue to be used improperly. The latter would also occur should the horse not be diagnosed properly. KSS and its effects on the horse’s behavior often results in a selling, auction, or in the sporting business, euthanization.

Treatments for this syndrome vary widely from acupuncture, cutting ligaments, and bone removal. However, even with today’s technological advances, the most beneficial surgery, which requires only a small lesion in the skin to extract sections of bone, often results in only temporary relief, where KSS is still at a high risk to return.

There is a major dearth of research performed in attempting to observe the spinal fluctuations in the relationship to the rider on the horse, so most to all information gathered is self-collected. Past research has analyzed the effects of 75 kg of
weight on different gaits of the Warmblood horse (de Cocq et al., 2004). Based on a survey of riders and their riding habits, it is hypothesized that a correlation between horses with KSS and their past weight-bearing experiences will be detected. The expectation is to estimate, approximately based on these results, what an appropriate weight would be before KSS begins to appear as a long-term effect. Further, the research performed with the actual riding of the horse is expected to express the discomfort temporarily caused while bearing under weight; this is expected to guide the estimations of the 20% rule either to become accepted enough for further research or to be refuted. The hypothesis is that there is a correlation between KSS and the weight of the rider and that the 20% capacity rule will remain significant to analyzing how much a horse should carry.

**Methods**

A survey was sent to an audience of horse enthusiasts who own or lease the animal, asking for the critical information needed to find specific trends in the appearance of back pain (See Appendix A). The statement of breed was required due to the varying bone structure that appears between the different breeds to ensure a more understandable reading of the data collected. The addition of the question also allows for potential new inquiries to arise about correspondence between breed and behavior under saddle. Age and height of the horse were recorded for the validity of the data. Horses above the age of 20 years old were not included in the analysis due to the deterioration of muscle that occurs with aging. The height allowed for a more assured confirmation that the horse was of the breed specified instead of a distant cross. Weight was surveyed, coming in at various readings, and was converted to kilograms to allow consistency in the determination of trends. The rider’s weight was also submitted as the second needed aspect to perform calculations of the 20% capacity rule. Once found, graphs were created to suggest and express any trend in the rider’s weight with the appearance of a spinal problem.

**Results**

Once the survey was closed, a total of 59 responses were vetted to support or refute the proposed hypothesis. Within the individual responses, there were several with more than one horse included in the data, thus—87 horses were vetted in total. Calculations were made of what weight best fit each horse’s 20% capacity suggestion (the capacity) and then the rider’s weight percentage of that capacity was found using their weight divided by the capacity. Of the 27 horses expressing discomfort under saddle, 6 of which were diagnosed with KSS but remained asymptomatic, 88.8% of the rider’s weights were over 50% of the capacity for each horse. All subjects expressing problems, undiagnosed or otherwise, participated in some form of showing. Surprisingly, 85% of these animals had been participating in the specific sport of Jumping (Hunter or eventing).

The duration of the horse’s rides per week was analyzed in regards to the appearance or suggestion of discomfort, elucidating a trend beyond 4 hours per week. The amount of time per ride was multiplied by how many days a week the animal was ridden, giving the hours/week result on the graph (See Figure 1). The majority of horses who exhibited back discomfort, specifically 19 of 26 cases, were ridden 4 hours and 30 minutes per week or more. Specific weight percentage of the capacity does not appear to have significant correlation with this observation due to the spread out appearance of the x’s beyond the 4.5 x-axis line. However, a curve was created to express the clear observation that as the amount of hours ridden increased, the capacity of the horse decreased (See Figure 1). Below the line, there is approximately a 12.5% chance that the horse will exhibit or acquire a back problem, and
Similarly, there is a developed equation in regards to finding a horse’s weight using its measurements should the rider not have a weight tape. The goal is to create something similar to this to ensure the safety of the rider as well as the lessening in appearances of back deformities.

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**Appendix A.** [https://goo.gl/forms/OsIEmdau9OTKdsoT2](https://goo.gl/forms/OsIEmdau9OTKdsoT2)

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![Horse's rider's weight v. hours/week](image)

Fig. 2. Rider's weight (in percent) in relation to the amount of hours ridden per week. The rider's weight is expressed as a percentage of their horse's carrying capacity (20% of total horse body weight). This means that a rider's weight value of 100 is equal to 20% of the horse's weight. Horses with no apparent back problems are denoted by black dots (・) while those with potential or diagnosed problems are denoted by a red x (x). Graph by Nathan Morse and Jeremy Abbott.

above the line, there is approximately a 66% chance of symptoms. Based off of this curve, two equations were formed, inverses of each other, to assist equestrians in deciding how much they should be riding. The 90 and 2.5 are constants seen with the points on the graph.

**Weight % = 90(hours/week)-0.4**

**Hours/Week = (90/weight %)2.5**

**Discussion**

Using the graphed data, the second equation above is the suggested ideal all riders should follow. If a rider abides by their suggested time, in an ideal scenario, their horse as a result would have no spinal difficulties throughout its life. All horses and riders data inserted into the equation will fall beneath the curve placed. It is important to draw attention to the original prevalence of back problems in the first population of the survey. No riders used in this study fell above the 20% capacity rule in relation to their horse's weight. Because field work has not yet been performed regarding the long term effects of different weights in relation to the amount time their ridden, the future holds such work. As Dr. Turner studied the temporary results of weight surrounding 15 to 30% of a horse's weight, similar research should be performed addressing the long terms effects; estimate duration of the project to be around 10 to 20 years.

**Conclusion**

Because the 20% capacity rule is a widely known suggestion, it is proposed with this research and further studies to instead turn to the relationship of weight and total time ridden. Similarly, there is a developed equation in regards to finding a horse’s weight using its measurements should the rider not have a weight tape. The goal is to create something similar to this to ensure the safety of the rider as well as the lessening in appearances of back deformities.
Observations of Traumas Made from Medieval Bladed Weapons

Nadia Linton

Abstract

The observation of two individuals from a Medieval Christian cemetery in the Czech Republic help us to understand the weaponry and warfare used in late 10th Century Bohemia. These individuals are suspected to be victims of interpersonal violence, meaning that these people were intentionally harmed and their wounds are not accidental. This study focuses on discovering the weapon of infliction and whether these two individuals were victims of interpersonal violence.

Burial 169 was a middle-aged male who has major perimortem trauma to his craniofacial region. Burial 264 was a young female with evidence of sharp force trauma to the frontal and parietal bones, along with trauma to the ribs and tibia. She has a parry fracture (defensive wound) on her left ulna, which was demonstrated through criteria established by M.A. Judd. This parry fracture is one of the four criteria used in an article by M. Slaus to demonstrate whether a person was a victim of interpersonal violence. Using Slaus’ criteria, I was able to show that Burial 264 and Burial 169 were victims of interpersonal violence. Most of the wounds on both victims were consistent with those caused by swords. However, after using a 3D articulated skeletal model for Burial 264’s wounds, the sharp force trauma to her ribs showed to be multiple stab wounds as opposed to the hypothesized single slice down her back, suggesting that a smaller blade was also used. My conclusion of the additional use of a sword was demonstrated through examining pictures of the wounds on the skeleton and looking at the actual swords found in graves at the site. I then determined that a long heavy bladed weapon was needed to create such detrimental head trauma to both these victims.

Introduction

In this particular case, the observation of skeletal remains from two individuals excavated from a Medieval Christian burial site in 10th-century Bohemia will be used to facilitate the understanding of medieval war practices and weaponry. The two individuals in this study are from the city of Libce in the Czech Republic. The history of countries like Poland, the Czech Republic, and Slovakia during the Middle Ages have many unfilled gaps. Far less is known about these Central European countries in general, especially on topics like violence and war practices. These gaps in history are due to the Nazi and Soviet regimes entering these countries and confiscating and destroying artifacts and texts during World War II.

The marks left on excavated bones can provide clues about the deceased’s social class, occupation, how much labor they engaged in, and if he and she were associated with interpersonal violence, all of which help broaden our current understanding of life in the past (Novak, 2000). Being able to identify wound patterning on bones is important with regard to determining if the cause of death was accidental or intentional. The two individuals I will be discussing show major perimortem skeletal trauma, which leads me to believe that they were victims of interpersonal violence, meaning someone was intentionally trying to hurt them. Examining these remains and demonstrating that their wounds were not accidental will provide information about weaponry and warfare during the Middle Ages.

History of the individuals

In the 10th century, numerous Slavic-speaking tribes resided in Bohemia, part of what is now known as the Czech Republic in Central Europe (Figure 1). The Přemyslids and the Slavníks were two of the most powerful Christian dynasties in Bohemia during the Middle Ages, but unfortunately, their relationship was not cordial (Cosmas, 2009). Most of what was recorded during the 10th century can be found in the Chronica Boemorum, a text written by the Czech chronicler Cosmas of Prague (Cosmas, 2009). This book is filled with political and military activities of the Přemyslids and the Slavníks.

On a certain feast day, they secretly broke into the burg of Libice, where the brothers of Saint Adalbert and all the burg’s warriors stood, like innocent sheep, celebrating the feast with the holy solemnities of the Mass. Like savage wolves, the comites broke through the walls of the burg, killing everyone to a man, male and female. (Cosmas, 2009)
The city of Libice is located 60 km east of Prague (Figure 1) and was under Slavnik control during the time of the massacre (Hosek, 2014). To historians, this event is important because it marks the beginning of a unified administration under the Přemyslid dynasty (Hosek, 2014). During a mass excavation of the city in the 1950s, archaeologist Rudolf Turek found that there was no mass grave at this site, meaning that there was no archeological evidence that the massacre ever happened (Hosek, 2014). Turek, however, uncovered weapons, like arrowheads and swords, along with currency from both dynasties buried in graves which suggest that the site (Figure 2) was involved in rivalry or military action between the two powers (Hosek, 2014). The remains of an earthen rampart also implies that the city was prepared for defensive warfare (Figure 2). The amount of archaeological evidence found at Libice relating to warfare was limited. Turek also excavated one of the two cemeteries located in Libce: the Akropole cemetery. The two individuals in this study are from this cemetery, which was located inside a walled off palace area. The people buried here would likely be wealthy, upper class individuals, like noblemen and military generals, as opposed to those in the Kanin cemetery, where commoners and artisans would be buried. Any skeletal trauma on those individuals from the Akropole cemetery has a higher chance of being non-accidental due to injuries from war or attempted assassination. Skeletal trauma found on those from the Kanin cemetery would be more likely accidental due to the labor-intensive lifestyle that the lower class lived.

Therefore, examining skeletal remains will provide insight into the weaponry and warfare of the Middle Ages. Due to the high occurrence of perimortem trauma to their bones, this project will be providing evidence that these two people were victims of interpersonal violence. The objective is to learn about medieval warfare and weaponry in 10th century Europe. The hypothesis of this study is that both individuals are victims of interpersonal violence and that the main instrument used in the attack was from a sword.

**Methods and Materials**

**The Skeletal remains**

**Burial 169**

This burial contained a middle-aged male from the 10th century. Buried in the Akropole cemetery within the palace walls, the skeleton has major perimortem craniofacial fractures. His skull was found broken into many pieces. Most of them are postmortem breaks caused by erosion and excavation. Close...
examination of the cranial bones show that there are smooth indentations and lines on the surface of the shards, indicating that some of the breaks were due to injury in this area, labeling it as perimortem trauma. The postcranial skeleton also has tiny cut marks, especially concentrated on his larger limbs and around the pelvic area. (Figure 3.1)

**Burial 264**

A young female was buried in the Akropole cemetery in the same time period. She has major perimortem trauma to the frontal and parietal bones. Her skeleton also shows sharp force trauma to the ribs and tibia. She has multiple parry-fractures on her left forearm and one of her vertebrae is sliced in half. (Figure 3.2)

**Research and Reconstruction**

Methods were done in three different parts, consisting of archeological and historical research, and the reconstruction and sequencing of wounds using plastic skeletal models.

**Historical**

Since these individuals are from the past, studying sources from the Middle Ages enables a better understanding of life and war in that era. In order to find out what weapons were used against these two victims, I researched medieval weaponry and trauma descriptions in historical sources. The Chronica Boemorum, by Cosmas, provided details of the fighting style in 900 A.D. (Cosmas, 2009). This was also the text that mentioned the massacre in Libice. I scanned the book for keywords like those relating to weaponry: sword, blade, axe, knife, etc. pinpointing passages that mentioned battle or altercation. Cosmas describes the scenes with poetic detail, allowing the imagery of the disputes to facilitate the understanding of fight tactics and practices used against adversaries. Going through this book would give me an idea of what weapons might have been used in this era based on what Cosmas was observing and describing.

**Archeological**

Rudolph Turek, the Czech archaeologist working on the Libce site, cataloged all the burials and the artifacts found at the Akropole Cemetery in the Inner Bailey at Libice (Turek, 1980). His book contains descriptions of all the artifacts found in each of the graves. Scanning through the book, I searched for weapons, or traces of what may have been weapons, within the burials. This gave me literal evidence of what weapons/tools were used in Libice at that time. A basic list of Czech vocab was learned to properly analyze and read through the pages to pinpoint specific graves that were listed to be buried with weapons or fragments of weapons.

**Reconstruction/Sequencing**

Pictures taken of the bone trauma of Burials 169 and 264 were brought back from the Czech Republic for further research. But, due to the limitations of a 2D model, it was necessary to

![Fig. 3. Skeletal diagrams of (A) Burial 169 and (B) Burial 264. Red circles highlight the location of the trauma on the individuals.](image-url)
Forensic Anthropology

The wounds on a victim’s skeleton are categorized into time periods based upon when they occur: identified as antemortem, perimortem, and postmortem. Antemortem wounds are those that are nonlethal and have occurred before death and can be recognized from evidence of healing (Novak, 2000). Perimortem wounds occur around time of death, being before or shortly after, and show no signs of healing (Novak, 2000). Postmortem fractures are damages made to the bone after death, usually from factors such as ground pressure, excavation damage, plant roots, and other organisms such as small rodents (Novak, 2000). Telling the difference between peri- and postmortem breaks is crucial when examining remains because false identification can lead to a misunderstanding of what actually happened. Postmortem fractures are recognized by the differences in color from the surrounding unharmed bone as well as the rougher, irregular edges to the lesion or break (Lockau, 2013). The morphology of perimortem wound patterns includes feathering or peeling, flaking, radiating fractures, and presence of bone shards within the cut marks (Lewis, 2008).

Blunt, projectile, and sharp force trauma are three categories that are used to classify skeletal wounds based on the type of weapon involved in the assault (Novak, 2000). Blunt force traumas involve fractures made by blunt instruments, e.g., hammers, maces, the top spike of a poleaxe (Giuffra, 2015), or a pommel of a sword, and can also include injuries from a blow of the fist or hard contact with the ground (Novak, 2000). Injuries in this category leave radiating fractures with an internal bevel (Giuffra, 2015).
sharp edges that have “flat, smooth, and polished cut surfaces” (Hosek, 2014). Stab wounds are puncture wounds and are deeper than they are wide (Novak, 2000). Cuts are wider than they are deep (Novak, 2000) and usually have a V or U-shaped profile (Lockau, 2013). The lowest depth of the cut mark is identified as the ‘kerf,’ or the ‘floor’ (Lewis, 2008). Striations from the blade are left within the cut’s kerf and walls and allow us to deduce the direction. The direction of the striations show the angle of entry of the weapon. The presence of radiating fractures is key when sequencing wounds that are found in proximity to one another. The intersection of the lines can determine which blow happened first (Hart, 2015). For example, linear fractures radiating from the left temporal bone terminate at fractures coming from the right temporal bone, indicate that the blow on the right side of the head happened first (Hart, 2015).

Summary of methods

Taking all the information gathered, I used it to demonstrate that these individuals were victims of deliberate interpersonal violence. The historical and archeological research was used to learn about warfare and the type of weaponry fought with in Bohemia in the early 10th century. The model helped me three-dimensionally visualize all the wounds inflicted on the individual. I used the models of Burial 169’s skull and left radius and ulna and left set of ribs of Burial 264 to show that specific wounds are related, and to figure out the order and angle that these injuries happened at. I used Mario Šlaus’s (2012) criteria for distinguishing whether the wounds were deliberate or accidental (Judd, 2008). He lists four credentials that provide evidence on if the attack was interpersonal violence: evidence of perimortem trauma, sharp-force trauma, craniofacial trauma, and parry fractures (Šlaus, 2012). To demonstrate that specific wounds on Burial 264 are

Projectile injuries are made from high-velocity weapons such as arrows and bullets and usually have distinct entry and exit wounds (Novak, 2000).

In this case study, I will be focusing on sharp force trauma due to the high incidence of occurrence on the two individuals and the suspicion of the injuries being caused by bladed weapons. Sharp force traumas are made from instruments such as swords, knives, daggers, axes, and poleaxes (Giuffra, 2015). These blades produce linear lesions from stabbing or cutting and have defined

Fig. 5. (A) Left radius and ulna of Burial 264. (B) Drawn replica of left radius and ulna. Numbers mark the trauma to the bone, grayed out areas signify what is missing. (Courtesy of Lauren Hosek)

Fig. 6. Lay out of all tools used in recreation and sequencing: plastic model of human skull (rest of skeleton not shown), wooden cutting board, metal ruler, Exacto knife, pencil, painter’s tape, masking tape.
parry fractures, I used Margaret Judd’s criteria for distinguishing parry fractures from accidental: absence of radial involvment, transverse fracture line, location of fracture is below midshaft, misalignment and healing (Judd, 2008).

**Results and Discussion**

**Historical**

I scanned through the book of Cosmas searching for passages containing the following words: sword, axe, blade, knife, spear, weapon, blood, battle, cut, kill (Cosmas, 2009). Using this technique I was able to pinpoint passages that mentioned the use of these weapons: sword, axe, ‘hunting’ spear, small knife, arrow, javelin. The use of horses for warfare appeared a few times, along with the mention of helmets and shields in some cases. Within these passages, Cosmas described how these weapons were used against victims. There were mentions of beheadings, stabs/slicing of the midriff, hanging, and throats being slit. Forms of violence for humiliation purposes were found to be common in this era. An example of this type of violence, as demonstrated in the passage from the Chronica Boemorum, would be cutting off hands and feet, ears, noses, and genital mutilation and dismemberment. (Cosmas, 2009)

“And just like someone cutting tender poppies in a garden with iron, so he cut off the heads of the opposing enemy with his sword until, covered in spears like a hedgehog, he fell in the midst of the carnage upon a great pile of the slain.” (Cosmas, 2009)

Taking this information I deduced that the tiny cut marks to Burial 169’s upper femur and pelvic area might have been attempt at genital mutilation (Figure 7). Additionally, one of the injuries to his skull, wound number 7, slices down his left temporal, severing his zygomatic process (Figure 8). This area is right where the ear would be located if the skull had a flesh layer. The practice of cutting off an ear in 10th century Bohemia is shown in the Book of Cosmas and can be used to show that the injuries to the pelvis and femur on Burial 169 may have been from genital mutilation and that wound number 7 on Burial 169 could be the result of the removal of his ear.

**Archaeological**

Rudolph Turek’s survey of the excavation of the Akropole Cemetery was written in Czech, so I had to learn basic vocab relating to those the words I used in the historical research. Out of the 288 burials excavated from the Akropole Cemetery, 34 of them were found to be buried with a weapon. The most common weapon proved to be a type of iron knife, quite small and probably utilitarian (Table 1). One large sword was found in Burial 227-A, along with spur fragments and a partial iron knife (Figure 9). Of the two individuals analyzed, Burial 169 was found with knife fragments under the right palm, suggesting that it was placed in his hand when buried. In contrast, Burial 264 was buried with silver earrings and pieces of pottery, but no weapons. (Turek, 1980). Figure 11 gives a good representation of what a 10th-century sword would look like. The partial knife located next to his left femur is very small and inferior compared to the size the sword. I can infer that the knives were probably more for everyday use, like cooking and crafting, as opposed to for use in warfare. This assumption is further supported by the large amount of the knife fragments found in child and woman burials.

**Osteological**

**Burial 169**
I used Slaus’ four criteria for demonstrating interpersonal violence: perimortem trauma, sharp force trauma, craniofacial injuries, parry fractures (Šlaus, 2012). The trauma was labeled as perimortem in the initial analysis as well as distinguishing sharp force trauma to the skull. Sharp force trauma was also confirmed with the model. There are craniofacial wounds to the skull from initial analysis. There is a possible parry fracture to the left ulna on the distal half, however, it is hard to determine if the break was perimortem or postmortem. The break of the ulna is very jagged but shows no discoloration, which would lead us to label it as postmortem. Therefore, it is inconclusive on whether Burial 169 has a parry fracture, however, I believe there is other evidence to support that he was a victim of interpersonal violence.

For Burial 169, the main goal was to figure out which wounds were related to each other and find the type of weapon used. Since his skull was found mostly in pieces, it is hard to tell if any of these separate cut marks are continuations of each other. The use of the 3D model came into play and helped me distinguish which wounds were related or continuations of each other (Figure 10). In the initial analysis, it was estimated that Burial 169 had 12 separate head wounds out of the pieces that were found. Using the model, I was able to discover that there are actually 9 separate wounds. I did this by looking at the model and taking a straight edge and lining up the cuts with each other. In Figure 11, the drawing suggests that wound 12 is a continuation of wound 1. However, the model suggests otherwise (Figure 11).

Figure 11 shows a facial view of Burial 169’s skull. The model highly suggests that wound 4 is a continuation of wound 1. The angle that wound 1 comes down across the frontal bone and into the eye socket would more likely connect to wound 4 than wound 12. Wound 12 has a completely different angle as it slices down the zygomatic bone. This wound will now be referred to as wound 1-4.

Referring to Figure 11, it is clear that wound 2 and wound 3 are not related to any other cut on his skull. It was previously hypothesized that wound 5 was related to wound 4 through a curved wound across the face (Figure 10). However the model shows how wound 5 is more likely related to wound 6 (Figure 12). When a person is alive and breathing, their jaw rests slightly open with their teeth unclenched. Taking this into account, wound...
5 almost perfectly aligns with wound 6. The model suggests that a heavy bladed weapon came in and sliced across the maxilla bone and continued into the left mandible, creating wound 5-6. Based on the model, wound 7 is not related to any other wound. It does however suggest that Burial 169's left ear was sliced off during the attack.

Wound 8 is located on the left greater wing of the sphenoid bone on the bottom of the cranium (Figure 13). Wound 10 is a tooth wound to the left molar (Figure 14). The whole left side of the mandible is missing, however the right side of his mandible is fractured into multiple pieces (Figure 10). The radiating fractures were likely caused by a blunt or sharp force object hitting the left side of his mandible, resulting in the fracture of the right. However, based the presence of wound 10 being a sliced tooth wound with similar angles to that of wound 8, I can infer that the object that created the radiating fractures to his right mandible was from a heavy bladed weapon. The model suggests that an inferior blow to the left mandible resulted in the shattering of the right side of the mandible, in addition to the shearing damage to the left molar wound 10. The wound possibly continues under the crania and into the left greater wing of the sphenoid, creating wound 8. This wound is now known as wound 8-10. Wound 9, located on the occipital bone and wound 11, a wound to left parietal bone, are located on the back of the skull and are not related to any other wound (Figure 15.1). However, wound 11 was essential in the sequencing of the attack. The radiating fracture that wound 11 creates begins at the superior terminus that intersects with the sagittal suture and continues down the frontal bone until it intersects and ceases with wound 1. This means wound 1 was created before wound 11, indicating that Burial 169's facial injuries happened before the wounds to the back of his skull (Figure 15.2). Based on the locations of Burial 169's cranial wounds, I can determine the likely positions that he was in during the attack. Wound I came from a superior angle, suggesting that the attack was from above, such as on a horse or the victim was on his knees. Since wounds 9 and 11 are located on the back, wound 9 on the lower half of his skull, we can assume he was attacked while prone. The sequencing of wound 11 and wound 1 demonstrates...
this individual, but it is likely that the fracture was caused by a heavy bladed weapon with enough force to fracture both lower arm bones. There are pieces of bone missing from the fracture, so there is no evidence that a bladed weapon caused the fracture, but the remaining sharp force lesions on the rest of the ulna support that a bladed weapon was used during the attack. It is hypothesized that wound 6 happened first, creating the fracture, but was then strong enough to break through the bone and slice into the radius, resulting in Wound 8 (Figure 17 (B)). The parry fractures that Judd mentions in her article are caused by blunt force objects, which would only affect the ulna in those cases (Judd, 2008). Therefore Wound 6 goes against one of Judd’s criteria, however, it is probably because of the use of a heavy bladed instrument.

Burial 264
I used Slaus’ criteria for this individual (Šlaus, 2012), as well as M. A. Judd’s for determining a parry-fracture (Judd, 2008). Burial 264 has perimortem trauma, which is known from the initial analysis of the bones and from photographs. She has many sharp force lesions to the head, ribs, left arm, right leg, and clavicle (Figure 16). Her craniofacial wounds were observed to be sharp force from the initial analysis. She has a suspected parry fracture on the left ulna, Wound 6, which I evaluated using Judd’s criteria for a parry fracture.

I hypothesized that wound 6 on Burial 264’s left ulna is a parry fracture (Figure 17 (A)). I used the 3D model of the left ulna to provide evidence that wound 6 is a defensive wound. It is noted that there is radial involvement (i.e., a fracture to the radius) for A

Fig. 15. (A) The posterior and superior view of Burial 169’s skull. Figure 15.1 shows location of wound 9 and wound 11. (B) shows the radiating fracture created from wound 11. Green arrows represent the direction of the fracture as it traveled to the front of the skull. (Courtesy of Lauren Hosek)

Fig. 16. (A) Full skeletal diagram of Burial 264. Red circles indicate trauma to the skeleton. (B) Picture shows the sharp force trauma to her skull. (Courtesy of Lauren Hosek)

this individual, but it is likely that the fracture was caused by a heavy bladed weapon with enough force to fracture both lower arm bones. There are pieces of bone missing from the fracture, so there is no evidence that a bladed weapon caused the fracture, but the remaining sharp force lesions on the rest of the ulna support that a bladed weapon was used during the attack. It is hypothesized that wound 6 happened first, creating the fracture, but was then strong enough to break through the bone and slice into the radius, resulting in Wound 8 (Figure 17 (B)). The parry fractures that Judd mentions in her article are caused by blunt force objects, which would only affect the ulna in those cases (Judd, 2008). Therefore Wound 6 goes against one of Judd’s criteria, however, it is probably because of the use of a heavy bladed instrument.

The fracture line on the ulna is observed to be possibly less than 45°, indicating that it is an oblique fracture line. This was caused by the use of a bladed weapon. Blunt force objects create transverse fracture lines (Judd, 2008). There is the possibility that the fracture was transverse, but since there are pieces of bone missing, the angle of entry cannot be determined.

Fig. 17. (A) Burial 264’s left radius (LR) and ulna (LU). Wound 6 is highlighted with a red circle, showing fracture to the ulna. Figure (B) Plastic model of Burial 264’s left radius and ulna. Blue tape represents cut marks to the bone, or sharp force trauma. Grayed tape represents fractures, including radiating. (Courtesy of Lauren Hosek)
The 3D model demonstrates that wound 6 is below the midshaft (Figure 17 (B)). This was determined from measurements taken from the initial analysis that were then translated onto the model. The model also shows that the majority of the wounds to the left ulna are located below the midshaft.

Judd’s fourth criteria for a parry fracture is minor misalignment and healing (Judd, 2008). This criteria does not apply to our individual because her wounds are perimortem. Judd mentions misalignment and healing because she is indicating that the victim is surviving the attacks and are usually under the circumstances of acts of domestic violence (Judd, 2008). Wound 6 on Burial 264 fits into most of Judd’s criteria and we can accept the hypothesis that this was a suspected parry/defensive wound. This is a final indicator of interpersonal violence according to Slaus and this also demonstrates that the victim was alive during part of the attack (10).

Burial 264 has observable sharp force trauma to the left ribs 2-7 (Figure 18 (A)). I used an articulated model and a disarticulated model to display the wounds. It was previously proposed that these sharp force lesions were from a single continuous blow from a heavy bladed weapon down the back of the individual. The model demonstrated that these were multiple stab wounds from a smaller, thinner blade, due to the location, length and depth of the wounds (Figure 18 (B)). The articulated model allowed me to see how these wounds did not line up, demonstrating that there are up to 8 separate shallow stab wounds down her back. Most of the rib wounds would have been covered by the scapula, mostly wound 3, wound 4, and wound 5. The scapula would have been involved, more precisely the blade of the scapula, however, looking at photos of her bones, I can see the scapula was present but the blade was missing. The absence of the blade is not unusual because it is a very thin bone and easily shatters. These rib wounds suggest the breakage of the scapula into multiple pieces that were probably lost prior to excavation. The model shows that these are multiple stab wounds down her back. To have created these wounds, a smaller thinner blade was used in the attack. Also, the v-shaped striations and superficiality (i.e., shallowness) of these wounds suggest a smaller blade, as opposed to a sword.

Knowing that there were multiple weapons used in the attack, it could be possible that there were multiple attackers, or that the assault happened in multiple phases, i.e. the aggressor moved from a sword to a knife. The locations of the rib wounds demonstrate the different positions she was in during the attack. The superior posterior angle of the wounds show how she was stabbed in the back from behind, which adds another dimension to her attack as a whole. We can tell from her parry fracture and the wounds on her back that she was struck in the front and then possibly in the back while she was prone, resulting in the stab wounds and some of the injuries to her skull.

**Conclusion**

Using Mario Slaus’ guidelines I was able to determine that Burial 169 and Burial 264 are both victims of interpersonal violence. For Burial 169, the model changed the initial number of twelve separate wounds, to nine. The model also demonstrated the three different angles of attack: face to face, prone, and supine. I was able to determine that Burial 169 acquired his craniofacial injuries before obtaining wounds 9 and 11. I can also conclude that a sword was most likely used in this attack due to the severity, length, and depth of wound 1-4, wound 5-6, and wound 8-10 as evidenced by the model. Overall my hypothesis is supported for Burial 169.

For Burial 264, the hypothesis is partially supported. The articulated skeletal model showed that the injuries to her back were from a smaller bladed weapon. However, the use of a sword in the attack is still supported based on the severity of her cranial trauma and her beheading, but in addition to the use of a knife from her rib injuries. Using the knowledge from the models, I was able to determine that she was attacked from front on and also from behind based on the locations of trauma. We can affirm that Burial 264 is a victim of interpersonal violence, but cannot say that all her wounds were from a sword.

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Does the Mind In the Eyes Test Work as a Predictor for Autism Spectrum Disorders?

Dylan Dailor

Abstract

I use a redesigned version of a classic test for Autistic symptoms along with a redesigned test for the ability to recognize emotional states to test the ability of neurotypical subjects to recognize emotional states. This experiment questions assumptions made in research beginning in the early 2000s by challenging the idea that neurotypicals can correctly identify the emotions presented to them. Even though previous research predicted that they would correctly identify emotional states 71% of the time, this study showed that they only correctly identified emotions in 48% of instances.

Introduction

Autism is a neurodevelopmental disorder that affects an estimated 1 in 68 children and an unknown number of the adult population (Christensen, 2016). Severity of symptoms can vary and tend to include impairments in behavior, cognitive, development, and a variety of psychological maladies (Baron-Cohen et al., 2001), with the main symptom being an impairment in verbal and nonverbal communication. Those who place on the autism spectrum find their environments to be overwhelming, but these symptoms may not emerge until social demands exceed the limited capacity of the individual. Those people also tend to struggle with the ability to read facial cues, a stark difference when compared to their neurotypical counterpart.

Intelligence in Autistic children has been thoroughly researched with findings tending to show that subjects display higher than standard deviation IQs with a lower speed of processing (Scheuffgen, Happéé, Anderson, & Frith, 2000). Selective impairment on several parts of the Wechsler Intelligence Scale for Children (WISC) test has also been discovered (Asarnow, Tanguay, Bott, & Freeman, 1987). Verbal-performance discrepancies have not been able to explain the lack of an average bell curve in Autistic IQ (Scheuffgen et al., 2000). Other challenges to the theories of general intelligence presented by Autism Spectrum Disorders include those with savant-like abilities; where individuals show areas of surprising ability such as mathematics with a lower IQ (Hermelin & O'Connor, 1983).

Dr. Simon Baron-Cohen conducted the first major research project into the subject of autism and the Theory of Mind (Baron-Cohen, Leslie, & Frith, 1985). Baron-Cohen found that the autistic group had an average score of 82 on the IQ test with only one subject scoring less than 70 (often considered mentally deficient.) This research then continued on to find that all autistic individuals passed basic questions involving the identification of the two people in the cartoon, but could not pass the belief questions on the Sally-Anne Test where they had to explain where a person would look for an imaginary item after it had been moved (Baron-Cohen et al., 1985). Intelligence proved to have no correlative factor in the research and therefore continues to be excluded from other works. This study has since been criticized for its method in gathering the answers to the questionnaire from the control group of neurotypical subjects with the assumption that neurotypicals would give the correct answer. The belief is that the assumption has greatly influenced other works and there has been no true test done to see if neurotypicals could correctly identify emotional responses.

Eighty percent of psychologists have coalesced around the idea that there are a universal set of emotional signals. Of that sample, no less than 76% believed that happiness, sadness, fear, disgust, and anger all were universal (Ekman, 2016). Charles Darwin was the originator of the five emotion theory after publishing The Expression of the Emotions in Man and Animals, where he made the first recorded argument that all humans and genetically related animals shared facial responses to emotions (Darwin, Ekman, & Proderger, 1998). His results were disputed by a close friend, Guillaume-Benjamin-Amand Duchenne, who argued for the inclusion of 60 separate emotions but was partially disproved by a simplistic double-blind study run by Darwin (George, 1994).

Later work was done by Paul Ekman who continues to further the work of Darwin. One of his seminal pieces involved an advanced version of Darwin’s study, which confirmed the original work (Ekman & Friesen, 1971). Nine years later Ekman traveled to Oceania to photograph the indigenous people who lived in an isolated culture. He wished to obtain photographs that would further aid in his research at the time. Their isolated status ensured that they had not learned from viewing any form of mass media, which could have taught them what the expressions were. The subjects were given facial expressions to show based off of a set of scenarios given to them so that they could simulate the responses (Ekman, 1980).

By showing that neurotypical facial reading abilities hover closer to those of their autistic counterparts, this research is attempting to corroborate the finding that the facial reading...
abilities of neurotypicals have been overestimated in the previously referenced work. This might also invalidate the findings on the natural mentalizing abilities of autistic subjects, which would affect the tests done to determine a proper diagnosis. Research into this area can help to allow clinicians to better understand the disorder and in turn develop diagnostic tools that support areas that are truly deficient. Further research is also beneficial because it could change the diagnostic criteria that are assessed by pragmatic language tests, which determine social skill levels.

Methods
A random sample of people was administered the three parts of the test as a whole through an online HIPAA-compliant program. The first test was a short demographic test including questions on age and gender. These questions were needed because all of these factors can affect the way that emotions were interpreted to some degree. The second test was a modified Autism Quotient Test (Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001) with ten of the questions that, in the original test, were meant to determine social ability. The Autism Quotient test ensured that the sample is not influenced by those displaying more Autistic traits and they can possibly be sorted into another group that can give a complete set of results. The next test given was the modified “Reading the Mind in the Eyes” test, which contains 23 photographs of emotional reaction displayed by the eyes, which vary in difficulty. The pictures used in this research were different from the original research because photos of actors were used instead of real expressions.

In the new set of photographs, the pictures being used have emotions that were verified by Dr. Ekman or another researcher. Photos were also still in black and white to ensure that there is no distraction due to the skin tone of the subjects. Answers and questions were randomized by the computer to ensure that there is no bias in the order. The compiled results (the number of questions correctly answered divided by the total number of questions) were quantified in a spreadsheet and had a binomial test applied. The results of this study were finally compared to the results of the original study to see if there is a significant statistical difference.

Results
When the survey was closed there were 65 responses, but that number was cut to 43 due to the fact that some tests had unanswered questions or had repetitive answers. The first test, Modified Autistic Quotient Test, showed that no participant reported any significant autistic traits that would disqualify them from being counted in the study. For that reason, the results of that test were eliminated from consideration in the study and will not be reported. The second test, Modified Reading the Mind in the Eyes, gave varied results with the range of correct answers fluctuating between three and 42 out of the 43 responses. There was an average of 22.65 correct answers across all emotions (anger, happiness, sadness, surprise, disgust, shame, contempt, and fear). The surprise was correctly recognized 68% of the time with the primary foil being contempt. Fear was correctly recognized 51% of the time with the primary foil being surprise. Happiness was correctly recognized 92% of the time with the primary foil being contempt. Sadness was correctly recognized 45% of the time with the primary foil being contempt. Anger was correctly recognized 68% of the time with the primary foil being happiness. Shame was correctly recognized 41% of the time with the primary foil being disgust. Contempt was correctly recognized 52% of the time with the primary foils being shame and fear. Disgust was correctly recognized 27% of the time with the primary foil being happiness.

Discussion
Results of the survey suggested that the original study may have had several inaccuracies in relation to the original study (Baron-Cohen, Wheelwright, Hill, Raste, & Plumb, 2001) and subsequent trials (Golan, Baron-Cohen, Hill, & Rutherford, 2007). Many of the results showed that participants were less likely to identify the emotions shown. Happiness was the only emotion correctly identified at a rate of 70% with all other emotions falling below 68%. This is comparable with other research placing the correct identification of happiness at around 92-94% (Golan et al., 2007). Results that challenged contemporary theories were fear and anger, which had rates of correctness 58 and 68%. These results do not follow with current evolutionary psychological theories that suggest fear and anger continue to be important emotions recognizable by most humans due to the need for protection from predators. The fact that neurotypical subjects could not be directly challenging those theories and will be important to study in the future. Disgust tested the lowest of any emotional response with only 27% correct response. This invalidated the response
that the emotions of disgust and contempt would test with similar numbers, suggesting that the emotions were too similar to be tested. In fact, disgust is considered to be a universal emotion by many researchers, but like many of the other "universal emotions," neurotypical subjects struggled to make a positive identification. This research is not calling into question the work done by Dr. Paul Ekman and suggesting that there are no universal emotions, but it is instead suggesting that emotional recognition is harder than represented in previous studies. The information gathered by this research should call into question some of the previous results of studies based on this format. Baron-Cohen's original research made the assumption that if the majority of neurotypicals agreed on an emotion for a picture, that was the correct emotion. However, this new data suggests that they would have been unable to identify most of the emotions at a rate over 50% and even less over the average of 71%. At this point, it is difficult to consider alternate explanations for this research considering the wide variation between this study and previous studies with neurotypical control groups. Nonetheless, there should be some modifications made in the next iteration of the research to ensure maximum effectiveness. First, more questions could have been posed to participants about each emotion state chosen for the research. Due to time constraints and a lack of a motivating force such as a form of payment, my study was purposely brief. Second, a greater number of participants should be gathered. The first set of testing could have a larger pool if run at an institution with more students such as a college. Both of these suggestions should be adopted by any future research projects into the same topic.

References


Using an Evolutionary Program to Model Organic Population Evolution

Mason Grimes

Abstract
Evolutionary computing is a field of computing that is modeled after organic evolution. A program that utilizes evolutionary computing can be used to ‘evolve’ given objects. A general evolutionary program was written in order to evolve objects modeled after organisms in a population. Variables within the program were adjusted to match various theoretical and observed organic populations. Comparison of computer-generated population data with observed population data allows for various conclusions about the organic population, such as evolutionary pressures, phenotypic change rates, and percentage of selected progenitors.

Introduction
In the field of programming, implementations of certain programs are carefully planned by programmers, relying only on computers for running the implementation. In the specialty field of evolutionary programming, the system of evolution as proposed by Charles Darwin is used to ‘evolve’ an object (Darwin, 1963). By facilitating a version of ‘natural selection’ of randomly generated objects, a computer can effectively take advantage of its ability to perform quick, repetitive functions to refine said object. As Darwin proposed, organisms best suited to survive in an environment are “selected” by nature to spread their genotypes. Similarly, in evolutionary programming, objects best suited to a specific set of parameters (e.g. an object that represents a peppered moth may be in an environment where its color is the primary means of camouflage, and therefore survival and procreation) are selected to spread aspects of their implementation (Darwin, 1963; Eiben & Schoenauer, 2005; Fogel, 1997). In this way, evolutionary programming can be viewed as a system of generalized optimization, starting from completely unoptimized objects, to better suited—or in some cases optimal—objects (Eiben & Schoenauer, 2005). Such evolutionary programs follow a specific path (Eiben & Schoenauer, 2005; Fogel, 1997):

1. A population of random objects is generated.
2. The ‘fitness’ of each of these objects (to a set of defined parameters) is determined.
3. LOOP START~
   3. Genitors—or parents—are selected from the population proportionally to their fitness.
   4. A system of variation is applied to the parent objects to create offspring objects.
   5. The fitness of these new offspring objects are calculated.
   6. Some of the best fit offspring replace some of the worst fit in the population.
   7. LOOP END~ (Go back to step 3) (Stop repeating after a set amount of time or generations)

Evolutionary programs (EPs) are a way to use a computer’s ability to perform quick repetitive operations to create an optimized object. When human applied ingenuity serves to be too little to create an object, an EP may be employed. For example, when a team of engineers was unable to construct an ideal antenna for a space mission, they instead relied on an EP to generate the ideal antenna (Lohn et al., 2003). Not only have antennas been created by evolutionary programming, objects such as software robots to play a virtual game of soccer have been designed using evolutionary programing as well (Luke, 1998). The author, S. Luke, instead of relying on human coders to create these virtual soccer players, relied entirely on an EP. Starting with robots who jumped randomly around the field, Luke ended up with a team of bots able to win against two human designed teams—winning the RoboCup97 Scientific Challenge Award (4).

Since the power of computer systems is approximately doubling every two years, evolutionary programming may become a more useful tool in the future (Thompson, S.E. & Parthasarathy, S. (2006)). The objective of this study is to demonstrate how evolutionary programming can be applied in a simple and intuitive matter. Evolutionary programming can be used to model the evolution of a generation of organisms pertaining to a certain environment with certain evolutionary pressures. An EP that evolves objects representing organisms would serve as evidence that evolutionary computing is viable for studying population evolution.

Methods
Creation of the evolutionary program followed a method derived from Eiben and Schoenauer (2005) and Fogel (1997). The entirety of the evolutionary program was written on a personal computer within BlueJ, a Java development environment.

The evolutionary program was facilitated within an outer
skeleton function that was written and called evolution. Within this function was a number of steps contained within a loop. The first step was to randomly generate a list of organism representative objects. These objects were initialized to have random characteristics/parameters, such as height, weight, bone density, pigmentation, or any other physical characteristic that can be represented as an integer value. In addition, each object included an integer value that tracked their respective fitness. This list of objects was the first generation.

Once the fitness of each algorithm was determined, either 10% or 90% of the generation was selected from the generation proportionally to their fitness value. These parents were variated using a Gaussian variation equation in order to create a second generation of size 300 that was derived from the parents, where each object varies from the next. In this way, the next generation consists of the best-fit from the previous generation, where changes were made to each object’s characteristics by chance. This allows new traits of implementations to arise in the generation, just as mutations randomly arise within organic generations (Darwin, 1963).

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The average fitness value of each generation was recorded, and a graph of average fitness against generation number was generated. This allowed for direct comparisons to evolution speed in biological populations. This program was modeled after a set of data that was measured from a biological population, and it was determined if the program was a good model for an evolving population.

The evolutionary algorithm was modeled to fit data from Peter R. Grant and B. Rosemary Grant’s observational study of Geospiza fortis finches on Daphne Major Island in the Galapagos, which is seen in figure 1 (Grant & Grant, 2013). The phenotypic change rate between generations, ideal fitness, reproduction selection rate, starting generational composition, and organism parameters—like beak length and depth—were derived from the data and inputted into the evolutionary model. The evolutionary program then modeled the 20 generations since the first generation observed in 1973 from the Grants’ study (Grant & Grant, 2013). The outputted median beak length was compared by generation to the data from the Grants’ study—at both 10% and 90% selection rate—to generate figures 2 and 3. This model was then run again for 100 generations, with the 10% selection, and a graph of median and maximum fitness was created—in order to analyze how the fitness shifts between generations.

Results

From the observed data in figure 1, it is very important to notice the dip at 3-4 years and subsequent rise at from 3-8 years; this is a trend seen often in organic populations, most likely due to a changing evolutionary pressure. The changing pressure in this case was a drought that affected the Daphne Major area—

![Graph of Measured Organic Population of Finches](image-url)
Fig. 2. Plot of average beak length against year generated by the evolutionary model with 10% selection rate.

Fig. 3. Plot of average beak length against year generated by the evolutionary model with 90% selection rate.
changing the diet of the finches and therefore changing the evolutionary pressure on beak lengths (Grant & Grant, 2013). Also, the stagnation in change in beak length after year 15 in figure 1 shows that the population has reached a mostly optimal fitness for beak length—around 10.93 mm. Figure 2—the modeled population with 10% selection rate—is important to notice due to its sharp rise from the starting average to the most fit average, a much faster approach to maximum fitness than figure 3. Figure 3 is more akin to figure 1 with its less harsh selection rate of 90%—which more closely matches the selection rate of the finches on Daphne Major during the period indicated in figure 1 (Grant & Grant, 2013).

Conclusion

The objective of this study—to accurately mirror an organic population using this evolutionary model—has not been accomplished. The data seen in figure 1 is not accurately modeled by the data in figures 2 and 3. The most prevalent reason for this disparity in models is due to the model’s usage of a static evolutionary pressure—meaning that the ideal fitness is static between generation. This does not allow for the initial dip seen in year 3 and the eventual spike at year 8 in the Grants’ data. However, the model is able to effectively model the end behavior of the Grants’ data with an element of random variation inherent to recombinant reproduction. For example, after 15 years, the average beak length remains stagnant, creating an end behavior similar to the end behaviors of figures 2 and 3.

A version of this model could be used by breeders of different domesticated species to determine the amount of time that for a selected trait to arise. For example, a breeder of Canis lupus familiaris—the domestic dog—could apply a static non-changing evolutionary pressure by selectively breeding their dogs to have larger ears or smaller size, for instance. This dog population could then be modeled using a version of this evolutionary program—determining the amount of generations needed for the population to reach the ideal fitness of that specific trait.

More accurate modeling of any given population could be achieved with a variable evolutionary pressure, as well as a more in depth representation of an organism—such as genetic representation instead of phenotypical. Different methods to model the population could be found by using a genetic algorithm or an particle swarm optimization program instead of a simple evolutionary program. A genetic algorithm, such as the type seen in S. Luke (1998), could be used in order to model the population on a genotypic level, instead of the current phenotypic level. By doing this, there could be a representation of dominant and recessive alleles within the population, allowing for analyses such as determining Hardy-Weinberg equilibrium after the population has reached ideal fitness. A particle swarm optimization program would allow for the population to reach fitness at a faster rate—and might be a more applicable model for organisms with higher mutation rates and fast evolutionary changes, such as bacteria.

References

Frequency Conversion Crystal Designs for Improved Ultraviolet Power Balance on the 60-Beam OMEGA Laser

Nathan Morse

Abstract

A Monte-Carlo-based method was developed and used to characterize the predicted performance of several different frequency conversion crystal designs for the 60-beam OMEGA laser located at the University of Rochester's Laboratory for Laser Energetics (LLE). The OMEGA laser is used to conduct implosion experiments and basic physics experiments in support of the National Inertial Confinement Fusion (ICF) program. A key element to achieving LLE's 100-Gbar implosion goal is improving the ultraviolet power balance of the OMEGA laser's 60 beams. The frequency conversion crystals (FCCs) on OMEGA convert an infrared laser pulse to an ultraviolet laser pulse using three crystals (a single doubler and two triplers), and were originally designed for higher laser input intensities and larger spectral bandwidth than are currently required. Less sensitivity of the ultraviolet laser power balance to beam-to-beam variations in the infrared energy and FCC angular alignment might be possible by using a different FCC design. A Monte-Carlo-based merit function was developed and used to characterize two different categories of FCC designs: 1) A reconfiguration of the current FCCs, and 2) FCC designs with alternative crystal lengths. Using an ultraviolet pulse designed for an 80-Gbar implosion campaign, improved power balance was achieved by eliminating OMEGA's second tripler. Additional improvement to power balance was obtained in a single-tripler design by changing OMEGA's crystal lengths.

Introduction

At the University of Rochester's Laboratory for Laser Energetics (LLE), scientists are attempting to create fusion in the laboratory using the 60-beam OMEGA laser. The method chosen, direct drive inertial confinement fusion, is performed by impacting a small spherical deuterium/tritium (DT) target with high-power ultraviolet lasers, compressing it with extreme acceleration. When the lasers hit the target, the outer shell explodes outwards. Newton's Third Law (every action must have an equal and opposite reaction) dictates that the rest of the target accelerates inwards and implodes. The radius of the target decreases by approximately a factor of 30, and the resulting high density and temperature within the target cause the DT fuel to fuse. The main goal of this research is to achieve ignition, at which point the energy output from the fusion process is greater than the energy of the impacting lasers (Craxton, McCrory, & Soures, 1986). The current goal of LLE is to achieve 100 Gbar of pressure on the target in a direct-drive implosion, a value that is required for ignition at National Ignition Facility (NIF) scale energies.

There are many challenges to direct-drive inertial

Fig. 1. A diagram of the OMEGA frequency conversion system. The input IR beam has an electric field polarization that is at 35 degrees to the o (ordinary) axis of the doubler crystal and an angular frequency of ω. The frequency of the green beam is 2ω, and the frequency of the ultraviolet beam is 3ω. The polarization angle determines how the photons will be distributed to the e (extraordinary) and o axes of the doubler crystal. In the nonlinear frequency conversion process, each crystal produces an output beam of light with electric field along its e axis whose angular frequency is the sum of the frequencies of the crystal's inputs. Conversion efficiency is maximized by tilting each crystal to an appropriate angle about its o axis.
confinement fusion. One of the main difficulties is achieving implosion uniformity. Small beam-to-beam variations in on-target irradiance can produce hotter and colder spots on the target's surface, causing the target to deform from an exact spherical shape as it implodes, inhibiting fusion (Skupsky & Craxton, 1999). Several possible sources of irradiation nonuniformity are being investigated at LLE, including the frequency conversion crystals (FCCs) that convert each of OMEGA's 60 beams from infrared (IR) to ultraviolet (UV) laser energy.

Each of the frequency conversion systems on OMEGA originally consisted of a doubler crystal and a single tripler crystal (Craxton, 1981). The doubler crystal converts some of the incoming IR light into green light, and the tripler crystal converts the green and residual IR light to UV light. A technique called Smoothing by Spectral Dispersion (SSD) is implemented in OMEGA to increase implosion uniformity on the target by phase modulating the IR light to increase its spectral bandwidth, and then angularly dispersing this bandwidth on the fusion target using diffraction gratings (Skupsky et al., 1989). In order to efficiently convert all IR wavelengths within the bandwidth to the UV, a second tripler had been added to the frequency conversion system (Babushkin et al., 1998; Auerbach, Barker, Eimerl, Milam, & Milonni, 1997; Eimerl, Auerbach, Barker, Milam, & Milonni, 1997) as shown in Figure 1. However, the current high-pressure implosion goal requires smaller bandwidth and lower IR intensities into the FCC than required for previous experiments.

In order to achieve a precise pressure on all points of a spherical target, all 60 of OMEGA's beams must be approximately equal in power, or power balanced, throughout the temporal width of the laser pulse (typical pulse width is 1 – 3 nanoseconds). Preliminary simulations by LLE scientists suggested that improved beam-to-beam power balance might be possible while maintaining sufficient IR-to-UV conversion efficiency under current FCC-input beam requirements by removing the second tripler. In the work reported here, the frequency conversion process was simulated using the smaller IR bandwidth and lower IR intensity conditions, and a Monte-Carlo-based model was developed and used to calculate the expected temporally dependent UV power nonuniformity across all 60 of OMEGA's beams for several different FCC designs. This approach allowed the different designs to be compared based upon the sensitivity of each design to variations in IR input and FCC configuration (e.g., IR input intensity and polarization angle, angular alignment of the FCCs and differential tripler angle, and width of the air gap between the two tripling crystals) and an optimized design to be chosen. Two categories of FCC designs were optimized: 1) A reconfiguration of the current FCCs, and 2) FCC designs with alternative crystal lengths.

In Section II, we describe the relationships between the parameters of the frequency conversion process and the ultraviolet pulse. In Section III, we discuss the Monte-Carlo method used to predict errors in UV power. In Section IV, we compare the best designs for OMEGA that were found using the Monte-Carlo method. In Section V, we show the process behind optimizing for crystal length, and observe the strengths and weaknesses of an FCC design with alternate length crystals. In Section VI, we conclude with a brief discussion of the impact of this study and future work.

**Frequency Conversion Process**

Figures 2 and 3 show how the efficiency of converting IR light entering the FCCs to UV light depends on the tilt angle of the doubler and tripler, respectively, for several different

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**Fig. 2.** Graphs of IR to UV conversion efficiency v. doubler detuning for different IR intensities entering a 15-mm single tripler design. In this design, the second tripler was removed, and FCCs of 15 mm were used instead of the current 12.2-mm FCCs in OMEGA. A single IR intensity was used for each curve shown, with IR intensities ranging between 0.5 GW/cm² and 1.0 GW/cm² (inclusive), and an increment of 0.1 GW/cm² between curves. For this set of IR intensities, greater IR intensity corresponds to greater conversion efficiencies at 0° doubler detuning. As the doubler is detuned, conversion efficiency decreases nonlinearly, and differently for each IR intensity.

**Fig. 3.** Graphs of IR to UV conversion efficiency v. tripler detuning for different IR intensities entering a 15-mm single tripler design. This is for the same FCC design and IR intensities used in Figure 2, where higher IR intensities also correspond to higher conversion efficiencies at 0° tripler detuning. Tripler detuning decreases conversion efficiency at a much greater rate than doubler detuning, as shown by the sharper efficiency peaks at 0° detuning in Figure 3 than in Figure 2. This implies that tripler detuning will be a larger source of error than doubler detuning.
A desired UV pulse shape for the 80-Gbar shot campaign was used, as shown in Figure 4 with its corresponding IR pulse in the absence of any crystal detuning. Generation of an IR pulse that would, presuming no errors, convert to the desired UV pulse is necessary because the effects of frequency conversion parameters are dependent upon IR intensity. Among the FCC errors investigated, differential tripler detuning, IR polarization angle, and air gap distance were found to have less of an effect on the UV pulse than errors in IR energy, doubler detuning, and tripler detuning.

Monte-Carlo Method

Measurements on OMEGA in the past have shown that beam-to-beam variations in crystal detuning and IR energy can be approximately described by Gaussian random distributions. In the Monte-Carlo method, the errors in IR energy and crystal detuning for each of 60 beams were randomly drawn from normal distributions whose standard deviations were taken from experimental data, as shown in Figure 5. Error in IR energy was described as a constant for each beamline, and was multiplied by the IR power at each temporal point throughout the IR pulse. The Monte-Carlo method assumes that each source of error independently contributes to the error in the UV pulse. For a given realization of 60 input IR pulses and FCC detunings, the look-up tables described in Section II were used to generate a set of 60 UV pulses. For each of the 60 UV pulses, the three error contributions were added together to obtain the total error at each temporal point in the pulse. This process allowed the calculation of the average UV pulse power and its standard deviation at each temporal point across 60 OMEGA beams. This standard deviation is expressed as a percent of the UV power (RMS). The eventual goal of OMEGA is to achieve <1% RMS UV power imbalance.

Configuration of Current FCCs

There were two main candidates for the optimized configuration of OMEGA's current FCCs: the single-tripler
design, and the dual-tripler design. The single-tripler design was found to achieve better UV power balance overall, and roughly equivalent at the picket, as shown in Figure 6. At low UV power, such as at the step portion of the pulse, the dual-tripler design has slightly lower RMS power imbalance than the single-tripler design. However, at greater UV power, such as at the drive portion of the pulse, the dual-tripler RMS power imbalance is much greater than that of the single tripler. Since UV RMS error decreases with higher IR energies owing to saturation of frequency conversion, we can deduce that the major source of error for the dual-tripler design in this region of the pulse is from crystal detuning. The dual-tripler design thus requires tighter control of crystal alignment than the single-tripler design.

Fig. 6. Predicted RMS power imbalance (left vertical axis) throughout the 80-Gbar pulse for dual-tripler (blue) and single-tripler (green) designs with current 12.2-mm FCCs on OMEGA. The right vertical axis plots the desired UV power in TW, shown dashed in green.

Fig. 7. UV power v. IR intensity for single-tripler designs with different FCC lengths. Reconversion, in which UV converts back to IR and green light, happens at lower IR intensities for longer FCC single-tripler designs. This lowers the limit on achievable UV power. A single-tripler FCC design with 15-mm length crystals can achieve the 450 GW peak UV power in the 80-Gbar pulse, but cannot generate more than 500 GW of UV power.

Crystal Length Optimization

Since the current FCCs were designed for higher IR input intensities than required for the 80-Gbar pulse, it was suspected that they would be of suboptimal length for the single-tripler design modeled in Figure 6. Figure 7 shows that lengthening the FCCs in the single-tripler design decreases sensitivity to changes in IR energy. However, in the nonlinear frequency conversion process, the reconversion of UV light back to IR and green light limits the achievable UV power in long-crystal, single-tripler designs, as shown in Figure 8. The longest crystal length that was able to achieve the peak power in the 80-Gbar pulse was 15 mm. Therefore, the optimal FCC design for the 80-Gbar pulse used in this study is a single-tripler design with 15-mm crystals. This design achieves lower RMS UV pulse error than both dual- and single-tripler designs that use the current 12.2-mm length FCCs, provide less UV error, and thus greater power balance, for to reach LLE’s eventual goal of <1% RMS UV power imbalance, so the single-tripler design is favored. As shown in Figure 6, the dual-tripler design was unable to achieve <1% RMS UV power imbalance for an IR energy error of only 0.5% RMS. Therefore, despite generating slightly greater power balance at the picket, the dual-tripler design is less suitable for use on OMEGA under current conditions.

Conclusion

Using a Monte-Carlo-based approach, the statistical performance of different FCC designs was compared and two optimized designs for LLE’s 60-beam OMEGA laser were found. We anticipate that these designs will provide enhanced UV power balance over the current FCC configuration for LLE’s 100-Gbar implosion goal. The single-tripler design with the current FCC crystal thickness of 12.2 mm is being implemented on OMEGA by removing the second tripler. An improved single-tripler design for OMEGA consists of a 15-mm doubler crystal and a 15-mm
tripler crystal, although this design would make OMEGA incapable of generating more than 500 GW of UV power. With the Monte-Carlo merit function, LLE can now predict approximately how much error there will be in the UV pulse for given errors in the IR energy, doubler tuning, and tripler tuning, thus providing a tool to perform an error budget analysis, and to compare and optimize different FCC configurations. Future work may include enhancing the Monte-Carlo method by adding other sources of UV pulse error, such as beam-to-beam differences in IR wavefront and beam-to-beam variations in crystal temperature.

References


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Pilot Study on EEG Analysis of Focus and Creativity Markers Within the Brain

Leeore Intrator

Abstract

The brain and its states of activity have yet to be fully discovered and understood, hence this project takes on the task of understanding focus and creativity in the brain. To do this Neurosteer EEG headsets and analysis algorithms were used in conjunction with specific smartphone games that would induce either a state of focus or creativity in the subjects. The subject would play each of these games while their EEG signals were being recorded and then similarities in the data across subjects while in either focused or creative states were noted to find possible indicators in the data of these brain states. The resulting statistical tests found specific clusters from Neurosteer’s analysis that were statistically more active in one state of mind over the others tested for. Using this study an application to help distinguish between focused and/or creative brain states for an individual could also help in education, work, and many other aspects of life.

Introduction

Analyzing and understanding brain activity is very difficult and has not yet been perfected. One way to analyze and monitor the brain is to use Electroencephalography (EEG), which monitors the electric signals and frequencies (beta, gamma, alpha, theta, and delta) emitted by neuronal activity in the brain. The most seminal work in EEG was conducted by Hans Berger in the early 1920s and his methods have been replicated throughout the 20th century to find correlations between different brain states and these frequencies. For example, high theta levels have been correlated to positive mood, and the state between sleep and consciousness (Gevins, Smith, McEvoy, Leong, & Le, 1999; Gruzelier, 2009). Various brain disorders, such as Post Traumatic Stress Disorder (PTSD) and Attention Deficit Disorder (ADD), can also be treated based on neural feedback and activity levels of these frequencies.

In addition to EEG, there are a few other methods of spatio-temporal mapping of brain activity, such as Functional Magnetic Resonance Imaging (fMRI), which shows oxygenated blood-flow to the entire brain, allowing neuroscientists to see the exact areas of the brain that are active (Intrator, 2016; Khushaba et al., 2013). This can only be used when a person is in an fMRI machine though, which is not mobile, while EEG sensors on the other hand allow the brain to be analyzed while a patient conducts other tasks, and not while lying in the fMRI machine (Dietrich & Kanso, 2010; Castellani, Intrator & Remondini, 2014; Miniussi, Thut, & Combing, 2010), as seen in Figure 1. This is what makes EEG sensing more useful as a minimal and mobile brain monitor for novel analysis of brain functionality in real-time.

Hans Berger’s methods have dominated the field of EEG analysis since its creation nearly 90 years ago, but with the many advances in digital signal processing in recent years, other types of analysis have been made possible. One such method, created by Nathan Intrator and his company Neurosteer, decomposes the EEG data as a whole using a mathematical method called harmonic analysis, creating functional neural networks (Intrator, 2016). There are other scientists who conduct separate analyses with their own algorithms and these vary based on the individual scientist or company, and their equipment. The subjects being recorded usually conduct a specific task, or think in a specific way, so that correlations can be made between the recorded data and that specific brain function or thought process, such as decision-making (personal communication with Nathan Intrator) or creativity (Khushaba et al., 2013; Kinreich, Podlipsky, Intrator, & Hendler, 2012; Srinivasan, 2017).

Although there are many areas of neuroscience that have
been studied and understood by scientists, many brain states have not yet been fully understood. These brain states can be viewed using EEG analysis of the brain to see which areas of the brain, as well as which EEG characteristic features are active during those thought processes or states of mind (Dietrich & Kanso, 2010; Gevins et al, 2009; Hasson-Meir, Zhdanov, Hendler, & Intrator, 2011; Intrator, 2016; Keynan et al., 2017; Khushaba et al., 2013). Of the many brain states we know, focus and creativity, are not yet completely characterized or understood. Therefore, this project focuses on understanding the brain states of focus and creativity -- and their markers or indicators -- further, as well as providing a method to eventually enhance both brain states using personal neural-feedback.

Using Neurosteer’s equipment and novel algorithms for analyzing brain activity, this project was conducted to determine if focus and creativity are specific and different brain functions that also have particular and similar characteristics among different people. Multiple subjects’ brain activity were recorded using this technology while being induced into a state of either focus or creativity at any given time. These states of mind were induced by the subjects playing specific smartphone games that facilitate these types of thinking. A pattern and/or correlation of electrical brain waves that are consistent to focus and creativity was found in the data set that included all recordings from all subjects to determine a pattern could be found as a general case across all subjects. This pattern could be used to create a general model to determine whether or not a person was focused or creative at any point in time using an application monitoring neural activity and giving neural feedback (Dietrich & Kanso, 2010; Hasson-Meir et al., 2011; Khushaba et al., 2013; Kinreich et al., 2012). The application would also hopefully be used to enhance focus and/or creativity in an individual using an individual’s specific stimuli that induce and/or enhance focus and/or creativity, whether that be for the betterment of the individual on their own, or the betterment of a student in the classroom.

Methods

Subjects and Sampling Description

There were a total of seven subjects, each aged 17-18, who were high school students at the Allendale Columbia School. Three subjects were males and four females. All subjects were given a consent and assent form that their parents, themselves, and myself (Leeore Intrator) had to sign before they were allowed to begin trials as subjects. A total of 20 EEG recording sessions were conducted between all seven subjects.

All of these students shared some common free periods with myself, which gave them availability to be subjects for the project, which is partially why they participated. The sample of these subjects was a random sample as I could not control which people had the same free periods as myself.

Data Collection

A lightweight headband and Neurosteer’s proprietary EEG data processing programs were used. The headband has three EEG sensors embedded into the forehead section of the headband, as seen in Figure 2. This headband detects electrical waves from the neocortex, which has been correlated to higher brain functions (such as focus and creativity).

The EEG headband sensor was placed on the subject’s forehead at approximately one centimeter above the eyebrows (as seen in Figure 1). The placement of the sensor was not extremely important and would not cause error unless one or more of the sensors embedded in the headband were not touching the subject’s skin (Intrator, 2016). The subject was then given a smartphone with the games Brain It On! and Piano Tiles 2 loaded onto it (both of which have millions of downloads across multiple platforms). The subject played each game, inducing a state of focus during Piano Tiles 2 or a state of creativity during Brain It On!.

A control distribution (denoted as “procrastination”) was also recorded. This distribution was created while a subject was recorded procrastinating on their own cell phones or by taking part in small talk. This distribution acted as a control to simulate “normal” brain activity, or at least brain activity of a subject who is neither creative nor focused on any specific topic. This distribution was collected to determine whether focus and/or creativity was different from normal (control) brain activity.

Description of Phone Games Played

“Piano Tiles 2”: This game was used to induce focus because it is a game that has a menial task. The task is to touch rectangles on the screen in the order in which they appear. The rectangles are in four separate columns and come in different orders based on the “song” being played (the same “song” was used for all subjects). The objective of the game is to get a large number of rectangles sequentially pressed correctly during a single game; this number is the score for that specific game. The way one ends, or loses, the game is by touching the wrong rectangle in the sequence, or missing the rectangle on the screen altogether. The score for each individual game was unimportant, as long as the subject was playing and in an induced sense of focus the data were valid.

“Brain It On!”: This game was used to induce creativity in the brain. There were a multitude of tasks in the game that sequentially become more difficult as subjects achieved higher levels. Ultimately, the goal was to draw any shape that comes to mind to complete the task presented on each level. These tasks included challenges such as drawing a shape to move an object already on the screen from one edge of the screen to the other.
avoiding obstacles in the way. Another example is to put some drawn shape into a pre-formed object, where there is an area of the screen that cannot be drawn on. Shapes must be created around that area to successfully move a shape across the screen. The score was based on how long it took the player to complete the task, how many shapes they drew, and whether or not they completed the task at all. Each of these accomplishments resulted in either a star received or not. The maximum was three stars for all three of these objectives accomplished. Similar to Piano Tiles 2, the score of each individual level was unimportant, as long as the subject was in an induced state of creativity which was used to solve each level, the data were valid.

**EEG Data Analysis**

The headband used in this project (shown in Figures 1 and 2) detected electrical waves from the neocortex, which is the most recently evolved part of the human brain, and conducts higher brain functions, such as creativity. The EEG data were then analyzed using the processing algorithm created by Neurosteer, which decomposes the EEG data into multiple channels of brain waves based on the mathematical method of harmonic analysis (Intrator, 2016). These channels have been correlated to different functional brain activities, such as decision-making (Castellani, Intrator & Remondini, 2014), or brain states such as stress (personal communication with Nathan Intrator). This data analysis relies on harmonic signal processing of the EEG data in real time. The EEG data were separated and decomposed by Neurosteer’s algorithms into different networks that relate to specific functional neural networks, which are known as the channels described earlier (depicted in the top graph in Figure 3). The amount of activity for each functional neural network correlates to a color scale in the graphs of the data, at any point in time in the recordings, where red is the most active and blue is the least (as seen in the top of Figure 3; Intrator, 2016). Although these channels are not necessarily from specific areas of the brain or neocortex, they instead represent functional neural networks of multiple areas of the neocortex and their corresponding EEG data working in unison for a specific task. Some of the areas in the brain contributing to these channels may be close in proximity to each other, but they are not always necessarily neighboring areas of the neocortex (Intrator, 2016). The actual area of the brain was not important to this study, though what was important was the neural network, or channel, active at specific points in time during the tasks presented in the project.

Neurosteer has two depictions of its EEG data (as seen in Figure 3), though, the first depiction being the channel data (top of

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**Fig. 2.** The two depictions of the same EEG data – each created by Neurosteer. The top being the activity levels of all the channels at once on a red to blue scale, where red is more active and blue is less. The cluster depiction (on bottom) shows clusters based on the correlation of the ratios of activity levels in relation to all channels at the same time. Both graphs are plotted against time (independent variable) while the top graph has channel number as the dependent variable (with channel activity depicted each second by its color) and the bottom graph has cluster number (the specific cluster active) as the dependent variable.
Figure 3) of a subject’s brain at every second. The other depiction (bottom of Figure 3) was a one-dimensional representation of the same channel data. This one dimensional graph shows clusters, which are created by finding the correlations between concurrently active channels’ common activity ratios using a specific clustering algorithm on the channel data – also created by Neurosteer.

It is important to note that the numbering of these channels and clusters was merely a way to distinguish them, and that each cluster and channel was discrete, meaning it was not necessarily similar to the other clusters or channels in close proximity to it on the number scale.

If there was a straight, ongoing, horizontal line in the cluster graph, it meant that the same function within the brain is occurring for the period of time that the line stays horizontal. This horizontal line shows that the same channels correlated with that cluster are acting together for that function as well (personal communication with Prof. Nathan Intrator). This type of consistency of a single cluster being active for a long time is the type of correlation that was searched for in the data acquired for this project. This data was then correlated to focus or creativity respectively of where specific cluster occurred and how statistically significant the occurrences of each cluster to that type of data or distribution was.

Statistical Analysis

Statistical analysis of the EEG data recorded was only performed on the one-dimensional cluster data – as seen in Figure 3 – of the EEG data created by Neurosteer. This was because the cluster data relies on, and is correlated to, the channel data, which allows any significant findings to be related back to the original channel data. It was also much easier to run a statistical analysis on the one-dimensional data that covers 80 discrete clusters, where the possibilities for the 80 clusters were binomial: that cluster either occurs or does not at any point in time in the recording.

The first part of the analysis was to find the frequency of occurrences for that cluster across an entire data set. Highly active and statistically significant clusters were then correlated to focus, creativity, or procrastination by conducting binomial distribution significance tests. The number of occurrences of these clusters was recorded across two different distributions three separate times: procrastination vs. focus (Figure 4), procrastination vs. creativity (Figure 5), and focus vs. creativity (Figure 6). Once the number of occurrences for these clusters was recorded among the two distributions, a binomial test was conducted to determine if each cluster occurred more often, statistically, in one distribution over the other. For the binomial test, a success was if the cluster was active in one distribution, while a failure was if that cluster was active in the distribution it was being tested against at any point in time. The test was conducted with the number of positive occurrences (number of occurrences for one distribution and not the other) divided by the total number of occurrences,

Fig. 4. Results of the procrastination (procrastination is denoted as “Proc” in the header) against focus binomial test. In (A) the number of observations of each of the 80 discrete clusters is presented in the red bars as a proportion multiplied by 318 total observations. The blue bars are the proportion that each of the 80 discrete clusters were active in the procrastination distribution and not focus. (B) shows the statistical significance of each individual cluster from the binomial test in standard deviations above or below the mean as depicted by the blue line. The red lines indicate the cut-off point of four standard deviations above or below the mean, which indicates statistical significance for that cluster in this project. The clusters on the x-axis were sorted by statistical significance, causing them to be out of order for a number scale. The blue line does go above and below the window provided for (B), meaning that each cluster for which this occurred was more than eight standard deviations away from the mean, indicating an even higher statistical significance.
which gave a proportion. Then this proportion was tested to find its statistical significance from a null hypothesis proportion of $p = 0.5$, or 50%, which would indicate that the cluster occurred approximately the same number of times in each distribution. If the difference between frequencies of occurrences for a specific cluster was statistically significant by the binomial test, then that cluster could be correlated to that distribution. This was then done with all 80 clusters to see which of them would correlate to which distributions.

Statistical significance for this project was set to be four standard deviations above or below the mean (mean of $p=0.5$ as stated earlier). The $p$-values resulting from this statistical significance was $p$-value $\leq 3.1686\times10^{-5}$. This level of statistical significance was used to compensate for the smaller sample size of subjects and recordings. Such a high level of statistical significance would allow inferences to be made even with very little chance of false-positive occurrences. This analysis was conducted using all the data collected, after recordings were segmented so each cluster was a part of the focus distribution, the creativity distribution, or the procrastination distribution respectively.

After these binomial tests were conducted, clusters indicative of focus, procrastination, and creativity by their statistical significance in each test were recorded. Then the overlapping clusters, or clusters that were statistically significant for each brain state in both tests that brain state was a part of, were recorded as well. These overlapping clusters (found in Table 1) are used to show that a brain state is active against both of the other brain states, and so these overlapping clusters can indicate a specific brain state against all others tested against. The overlapping clusters act as indicators of that specific brain state, where if those clusters are active then it can be deduced that a person is in the same brain state correlated with the cluster active at that time.

**Results**

Figures 4-6 show the results of the binomial test described in the Methods section and the statistical significance of each cluster to each distribution (focus, creativity, and procrastination). The proportion in blue in (A) for all these figures indicates the proportion that a specific cluster would occur in the first distribution in the name of each test, and not the other distribution in the test. The closer the proportion is to one, the more that cluster occurs in the first distribution in the test, while the closer this proportion is to zero, the more that specific cluster will occur in the other distribution of the same test. The red bars in (A) show the number of observations of each cluster as a proportion of the number listed in each figure. In part (B) of these figures the blue line indicated statistical significance in standard deviations away from the proportion mean of $p = 0.5$, or 50%. The red lines in (B) indicate four standard deviations away from the mean, which is the cut-off point in this experiment for statistical significance, and gave a $p$-value $\leq 3.1686\times10^{-5}$.

Figure 4 is the test of procrastination (denoted as “Proc”)
are two separate brain states.

The most important part of the results section was Table 1, as it depicted the overlapping clusters for each distribution. These overlapping clusters were found when tested against both other distributions, meaning that these clusters were found to be active for an individual over a significant period of time while the subject was in that brain state, allowing the correlation to be made between that brain state and cluster. These clusters could be used as indicators for the specific brain states (which is why they were named as such) they were correlated to in the data. These indicative clusters can then also be used in the application as explained in the Introduction. This phone application would allow a person to correlate stimuli to being focused or creative, and that is why finding the correlations of focus and creativity to neural activity data was essential first, which was the point of this project.

There was an interesting trend in finding the clusters that were indicators for creativity, as there were only two overlapping indicators for the creativity, as opposed to the 19 for procrastination and 17 for focus. The reason for this may be that creativity is more spontaneous than focus or procrastination, so fewer clusters may correlate to creativity. This trend may also be explained by the error in observations that occurred during this

Discussion

The data supports the hypothesis that focus and creativity are both different from each other and from control (procrastination) data as well. Because there are clusters that can be more statistically significant to each distribution when tested against another, it can be deduced that there is a difference between each distribution, which would indicate different and specific brain states. Because focus was found to be different from procrastination, as well as creativity to be different from procrastination, we can assume that they are not normal brain states but in fact their own brain functions. Because there were differences in the clusters being statistically significant for one brain state or the other between focus and creativity it can also be deduced that focus and creativity

Fig. 6. Results of the focus against creativity binomial test. In (A) the number of observations of each of the 80 discrete clusters is presented in the red bars as a proportion multiplied by 559 total observations. The blue bars are the proportion that each of the 80 discrete clusters were active in the procrastination distribution and not focus, which means that the closer this proportion was to 1 the more that cluster occurred in focus, while the closer the proportion was to 0 the more it occurred in creativity. (B) shows the statistical significance of each individual cluster from the binomial test in standard deviations above or below the mean as depicted by the blue line. The red lines indicate the cut-off point of four standard deviations above or below the mean, which was the cut off for statistical significance for that cluster in this project. The clusters on the x-axis were sorted by statistical significance, and this is why they are out of order for a number scale. The blue line does go above and below the window provided for the bottom of the figure, meaning that each cluster for which this occurred was more than eight standard deviations away from the mean, indicating an even higher statistical significance.
The clusters that were the most statistically significant towards each brain state that were also overlapping in significance across both binomial tests that each brain state was tested against as described in the Methods section.

<table>
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<tr>
<th>Cluster Number</th>
<th>Procrastination Indicators</th>
<th>Focus Indicators</th>
<th>Creativity Indicators</th>
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</table>

The data tables for Figure 4, Figure 5, and Figure 6 can be found in the appendix.

In the future, a more controlled amount of time for each specific distribution should be collected when recording EEG data, as well as a larger and more diverse selection of subjects to reduce bias in the experiment. Less error would then be involved in the experiment as a result, which could help to find the most correct indicative clusters for each individual brain state. Another big step in further tests and analysis would be to find out if focus, creativity, and/or procrastination are transient or continuous brain states. A transient brain state would be that the subject goes in and out of the brain state constantly while they are technically in that functional brain state, so there would be much more diversity in the cluster activity for the brain state, and those cluster correlated to the brain state would happen sporadically. For a continuous brain state the same few clusters would be active for a longer amount of time. This could help to create the application described earlier and even make it more accurate, as well as finding the clusters correlated to focus and creativity more accurately. The application would be used to hopefully enhance focus and/or creativity on an individual basis, as seen fit by the subject or user of such an application. The methods of this study, if proven effective with more studies, could also possibly be used to find and understand other brain states.

References


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