The Best of The Journal of Young Investigators 2019
Cover photo entitled “Neuron” by NICHD NIH is licensed with CC BY 2.0. To view a copy of this license, visit https://creativecommons.org/licenses/by/2.0/.
The Journal of Young Investigators

Who are we and what do we do?

The Journal of Young Investigators (JYI) is a non-profit (501c3), independent, peer-reviewed journal that is run by undergraduates from around the world. As the only international journal of its kind, JYI aims to provide all undergraduates with training in scientific writing and publication opportunities.

We are a community of future scientists, writers, physicians, among many other things. We believe in providing a hands-on approach to provide all students, regardless of their background, with the resources for a successful career in science communication. To do this, we involve undergraduates in every step of the writing, editing, and peer-review process. Recently, we have spearheaded an initiative to provide undergraduates with resources for professional development, such as our webinar series. Furthermore, we run an online blog to allow undergraduates, as well as our advisory board, to more informally describe personal experiences and advice for a career in the sciences. Our advisory board is made up of graduated ex-JYI members who advise current members throughout the scientific writing and editing process.

JYI’s mission is to enhance science education for all students, regardless of location or background. As such, JYI focuses on the latter part of the research process: research communication, reviewing and being reviewed by peers, and publishing.

Most importantly, we believe that science communication should be a global effort built on collaboration and cooperation.

“

I joined JYI when I was in the second year of my undergraduate degree as a Science Journalist. I have since been a News and Careers Editor, Managing Editor and Editor in Chief. I have gained invaluable skills throughout my time with the journal and have made friends for life. I am now the editor of a UK veterinary magazine and would not have the job I have now if it weren’t for the skills I gained throughout my time at JYI. I would wholeheartedly recommend JYI to any undergraduate looking to gain experiences outside of university.

-Amelia Powell | Editor-in-Chief

We also believe in a rich experience which brings with it meaningful relationships.

“As a Layout Designer, I remember how rewarding it was to see the papers that I worked on being released every month. Even now, years later, I make sure I read every paper, article, and blog JYI publishes. Seeing the hard work from the talented JYI staff makes my day every time.

I also remember meeting with the Executive Board (back when I was CTO) in Washington, DC. After a day of working together on different projects, presentations, and meetings, we went out}

Best of JYI | 2019
to see the city. Our then SRE was super excited to see the National Mall. At the Smithsonian, I remember searching for the Narwhal, which our then ME wanted to see. And I remember taking a million photos at each in-person Executive Board meeting I was a part of (much to the chagrin of the others).

I made some of my closest friends while a part of JYI. These are just a few of the moments from our meetings and phone calls that stick with me. And every month I get to see JYI becoming even better.

"-Adam Sychla | Board of Directors

We pride ourselves in the opportunities that come with JYI involvement.

I would say that personally JYI is the single best thing that I have done as an undergraduate in terms of promoting not only my understanding of academic writing and editing but also the scientific process as a whole. My role as an Associate Editor has opened the door to many amazing opportunities both inside and outside of JYI. For example, becoming a Research Assistant on an international expedition and taking up a Research Project with the British Geological Survey.

I accompanied a lecturer (who is actually my advisor for JYI) from my university department on a research expedition to Maliau Basin in Borneo, Malaysia. For this I successfully applied for my own research grant funding to become an undergraduate Research Assistant. We teamed up with a colleague from Germany as well as a Research Assistant from the University of Malaysia, Sabah to undertake a Paleolimnological study of a very remote lake site (Lake Linumunsut) within Maliau Basin Protected Area. Paleolimnology uses the law of superposition (that older sediment will be the deepest) to reconstruct climate, pollution, vegetation and other environmental records from inland water bodies. Our aim at Linumunsut was to reconstruct a local climate record for the previous 100 years (instrumental records only go back to 1990), to test whether long-range atmospheric pollution was impacting this remote protected area and to try to reconstruct the formation of this lake site, a unique landform in the area (being the only lake in the reserve). This involved much preparation and a challenging five day trek through a largely untouched rainforest with all of our equipment (including a sediment coring device and weights) just to reach the site. Whilst in Malaysia, I also helped out at a Paleolimnological Summer School at the University of Malaysia Sabah with the aim to inspire a new generation of Paleolimnologists. At the summer school I actually presented a short talk about what we do at the Journal of Young Investigators and how students can get involved.

"-Brittany Pugh | Associate Editor

JYI publishes research and review articles in the biological and biomedical sciences, physical sciences and mathematics, engineering and applied sciences, and psychology and social sciences. To find out more, and for opportunities to join JYI, visit our website at www.jyi.org.
Dear reader,

Welcome to the annual print edition of Best of JYI, featuring our best research published in 2019. Our team work year-round to publish undergraduate research and we couldn’t be prouder of the incredible research we were honoured to publish in 2019. With papers on a wide array of topics, from studies on Mycobacterium tuberculosis to the role of synaptic plasticity in the pathophysiology of cocaine addiction, and convergence in mixed effects logistic regression models, we had a range of great contenders for this issue. Our Executive Board and Board of Directors have voted for the best papers in three categories: biology, physical sciences, and social sciences.

As well as publishing research, JYI also has its own team of undergraduate journalists who work hard all year to provide information about science in the news, and also interview renowned scientists and write articles on different careers in science. This year, we are featuring two of such articles, again as voted for by our board members.

2019 was a big year for JYI, with a lot of change and new and exciting things. We welcomed many new staff members and were able to host our first in person staff meet up for staff members in London, UK, fostering a stronger sense of community among the staff of JYI, an entirely online organisation. We also hosted our first ever webinar, published our first press release and moved to a new submissions portal to manage the research department’s workload.

I have been a part of JYI for three years now, and I’m forever impressed by the hard work and dedication of all of our members of staff to keep this journal running. I have had the opportunity to meet lots of new people in-person at our executive board meetings and the staff meet-up in London, and have made some of my closest friends across the globe through my time here. We always have new projects in the works and I can’t wait for them to come to fruition and to share even more of our work with you, but for now I hope you enjoy this compilation of our best research and news articles from 2019.

All the best,

Amelia Powell

Editor-in-Chief

eic@jyi.org | Journal of Young Investigators
Table of Contents

Who We Are and What We Do

Letter from the Editor

Smartphones as a Non-Invasive Surveying Tool to Monitor Bats
Amanda-Jean Blackburn and Shem Unger

A Review of Quantum Games
Gaon Kim and Eung-won Nho

Varying Amount of Social Information in an Image Affects Facial Processing Strategies of Participants with an Autism-related Phenotype
Nidhila Masha, Jeff J. MacInnes, and Elizabeth N. Johnson

Scientists at Temple Health Find Potential Cure for HIV
Tanvee Sinha

Understanding a Physicist’s Work to Explore the Stars and His Community: An Interview with Dr. Jorge Lopez from the University of Texas at El Paso
Andrew Lowrance

Acknowledgments
Bats are important keystone species which provide ecosystem services by consuming a variety of insects and agricultural pests. Many native bat species are currently threatened with either habitat loss or emerging infectious diseases, including White Nose Syndrome. Therefore, there is a need to develop survey approaches which increase accessibility to citizen scientists and researchers alike to monitor populations, such as with emerging, affordable smartphone enabled technologies. We assessed the efficacy of a smartphone enabled hand-held bat detector (Wildlife Acoustics Echo Meter Touch 2) to record and identify echolocation calls of common bat species on a semi-natural area of Wingate Campus, a small university in the Charlotte metropolitan area, North Carolina. We further utilized smartphone technology to record seasonal internal temperature and luminosity fluctuations within deployed bat boxes using HOBO thermo-loggers. Lastly, we used a smartphone enabled WIFI endoscope inspection camera to periodically check occupancy of bat boxes. We identified five species of bats, from 55 recordings during Spring and Fall of 2018 (4/2/2018 to 10/28/2018), including the big brown bat (Eptesicus fuscus), hoary bat (Lasiurus cinereus), Mexican free-tailed bat (Tadarida brasiliensis), silver haired bat (Lasionycteris noctivagans), and northern yellow bat (Lasiurus intermedius) at our study site. Temperature and luminosity of bat boxes varied depending on location (full or partial sun), while the endoscope allowed for non-invasive monitoring of bat boxes, of which none were found to be occupied. The purpose of this study is to use smartphone enabled technology as a non-invasive surveying tool for identification and monitoring of bats.

INTRODUCTION

Bats play critical roles in many ecosystems by consuming insects potentially harmful to agriculture, dispersing seeds, pollinating, and as bioindicators of environmental change (Jones et al., 2009; 2010; Boyles et al., 2011). Across North America, bats can typically be observed feeding on insects immediately following sundown, as they emerge from their roosts to forage in both urban and forested environments. North Carolina is home to 17 species of bats, four of which are federally listed as endangered or threatened (Caldwell et al., 2017). Occupancy of these bat boxes can be affected depending on location (full or partial sun), while the endoscope allowed for non-invasive monitoring of bat boxes, of which none were found to be occupied. The purpose of this study is to use smartphone enabled technology as a non-invasive surveying tool for identification and monitoring of bats.
and adequate solar exposure (White, 2004, Rueegger et al., 2018). Moreover, not all species are likely to use bat boxes at equal frequencies (Griffiths et al., 2017). However, little attention has been given to more recent methods for either more affordable bat species identification or monitoring of deployed bat boxes using non-invasive smartphone technology. These technologies can help increase the amount of available data on bat species presence and habitat use in urban environments. Smartphones have become increasingly utilized for data collection in environmental sciences by both citizen scientists and researchers (Gutowsky et al., 2013, Frigerio et al., 2018, Stitt et al., 2019), for the identification of flora and fauna incorporating geographic location and pattern recognition applications such as iNaturalist (Nugent, 2018). Several smartphone-based research devices have recently become available to researchers and citizen scientists. For example, the Echo Meter Touch bat detector (Wildlife Acoustic) has previously been used by researchers to record bat echolocation calls (Willie et al., 2018), however few studies have reported on its use and application as an affordable, non-invasive monitoring technique in exploratory studies. Endoscopes are an additional wildlife survey technology for assessing occupancy of habitat, i.e. burrows (Parsunath et al., 2017), and now have smartphone compatible models available. These affordable, smartphone-enabled emerging technologies may in time prove to be either an alternative or additional method for monitoring bats and other organisms.

The goal of this study was to survey and monitor bat populations around Wingate University using new smartphone compatible technology. Specifically, we assessed the use of smartphone devices to (1) identify common bat species using the Echo Meter Touch 2 (Wildlife Acoustics), (2) monitor temperature and light in bat boxes placed in either direct or indirect sun using a HOBO® Pendant® MX2202 data logger, and (3) check for bat box occupancy using a smartphone enabled endoscope. We hypothesize that these various smartphone-enabled devices will allow us to accurately monitor bat populations and habitats. These non-invasive survey tools may provide conservation managers and educators an affordable method for effectively monitoring and researching bats and an avenue for incorporating these techniques into outreach citizen science education programs.

**METHODS**

**Study Site**

Wingate University is a small liberal arts college located in close proximity to the Charlotte metropolitan area of North Carolina, USA. A section of Wingate campus includes a semi-natural area that consists of mixed hardwood forest (including Quercus spp. (oak), Juniperus spp. (cedar), and Loblolly pine trees, Pinus spp.), in addition to several open mowed fields and trails with a small 55,000 m² man-made university lake (Figure 1). This area, was selected as an ideal location to monitor bats and deploy bat boxes, based on previous visual observation of bat activity at the site, including emerging and foraging bats.

**Bat Box Deployment and Monitoring**

We monitored bats on Wingate Campus from April to October of 2018. On April 5, 2018 two bat boxes (one single chambered and one triple chambered, Bat Conservation International; BB1 & BB2) were deployed around Wingate University Campus Lake (Figure 1), at a height of 6 meters attached to a tree to allow bats to drop down an adequate distance when emerging to forage (Tuttle, 2013). Bat boxes were painted prior to deployment with brown, non-gloss outdoor paint to increase heat absorbance. The locations were
selected based on proximity to a water source (within 300 meters) and range of ideal sunlight the location received daily (Tuttle, 2013). For example, we deployed a triple chamber Bat box 1 (BB1), in full direct sun within 300 m a small pond and bat box 2 (BB2), a single chamber box placed in only partial sun near the lake for comparison (Figure 1). Each bat box was fitted with a HOBO® Pendant® MX2202 logger to simultaneously record both temperature and light luminosity hourly (24 data points per day; Figure 2). Data loggers were calibrated to record data at the same time, to allow for comparisons between light and temperature for BB1 and BB2. We downloaded temperature and light luminosity data on October 25, 2018 using the Bluetooth HOBOmobile application. This data is exported as an excel, CSV, TEXT, or HOBO file formats. The data was downloaded to the author’s smartphone within 5-10 seconds as the smartphone was within a ~6 meters radius. In addition, on February 9, 2018, we deployed four bat boxes on two 1.2 m by 1.2 m poles, each with one single chamber and one triple chamber from Bat Conservation International (BB3, BB4), at a height of 6 meters in full sun surrounding the lake. These bat boxes were used primarily to examine occupancy (if bats were present) in addition to other bat boxes with temperature loggers. Finally, we used a smartphone enabled endoscope camera (a YPC110 Leadnov® wireless endoscope inspection camera equipped with an 8mm waterproof LED lens, semi-rigid cable, and WIFI) monthly to determine whether bat boxes were occupied and if so by how many bats.

Bat Species Identification
A Wildlife Acoustics Echo Meter Touch 2 and related smartphone application was used to listen, record, and identify bats while in flight at our study site on Wingate University (Figure 3). This ultrasonic module and application transforms the sound data into audio that humans can hear in real time and allows the user to identify various bat species by their call without handling individuals. Bat calls enter the module through the acoustical horn, designed to reduce unwanted echoes. The horn directs the sound into the module’s microphone, capturing frequencies up to 192k Hz. The Wildlife Acoustics application allows recording and automatic identification of echolocation calls, using the Auto ID Selection tab, North American database with 16 possible species found in North Carolina. All recorded calls were analyzed for total call length in seconds, pulse ratio (percentage of individual calls or pulses positively used to identify species), time, GPS location, and date of echolocation recordings. To ensure quality control, all recorded calls were manually examined to ensure recording peaks were consistent with bat echolocation calls, and minimal peaks from ambient noise were not present which could result in a false identification. In addition, we excluded any echolocation recordings with low pulse ratios (below ~50%), to increase likelihood of echolocation call identification, as low pulse ratios indicate low numbers of calls were used for species identification, indicating either potentially low quality recordings or high distance of bat to observer. We also excluded any potentially spurious species identification, species observed less than three separate sampling occasions. Bats were surveyed twice a week, from April-May and September-October by walking a 15 minute loop in an open clearing near deployed bat boxes (BB1 & BB2 areas, Figure 1). All acoustic surveys occurred 30 minutes before and after sunset, when individual bats were visibly seen by authors active in flight. Lastly, to inform bat call recordings, we obtained wind (mph) and ambient temperature data (°F) collected from the AccuWeather website (AccuWeather) for each day that bat calls were recorded. We ran a Pearson Correlation Coefficient between the number of bats identified and temperature, as well as the number of bats identified and wind speed. To compare bat box temperature and luminosity, we ran a t test for BB1 and BB2 for both fall and spring temperatures (Fall: 9/1/18 to 10/25/18; Spring: 4/6/18 to 5/31/18).

RESULTS
We noted fluctuations in temperature between the spring and fall data for BB1 and BB2 (Figure 4). We noted a variation of ~0.5 to ~5°F in daily temperature values during certain times of the day, however mean temperatures for spring and fall BB1 were 68.1 and 73.6°F, while spring and fall BB2 temperature was 67.7 and 72.9°F, respectively. We did not find significant differences between BB1 and BB2 for either spring or fall temperatures, $t(499) = -0.973, p = 0.165$, and $t(499) = -0.612, p = 0.268$, respectively. Temperatures recorded during both spring and fall seasons followed seasonal fluctuations representing ambient temperature, with spring temperature increasing over time and fall temperatures decreasing over time. Temperature fluctuations remained consistent in the fall until the second week of October and in the spring until the third week of May 2018. Luminosity values (amount of light penetrating bat boxes measured in lux (1 lumen per

Figure 3. Echo Meter Touch 2 (Wildlife Acoustics) workspace screenshot. Bat echolocation calls are shown with peaks below 60 KHz (left) and identification and pulse ratio shown with bat species identification (right).
Figure 4. Temperatures of Bat Box 1 (top) and Bat Box 2 (bottom) for Fall and Spring. Temperatures were recorded and downloaded from HOBO® Pendant MX2202 temperature and luminosity loggers.

Figure 5. Luminosity values for Spring (A) and Fall Seasons (B) for Bat Box 1 and Bat Box 2. Luminosity values are shown from HOBO® Pendant MX2202 temperature and luminosity loggers. Bat box 1 represented by BB1 and bat box 2 represented by BB2.
square meter) for the spring were higher than the luminosity values for the fall (Figure 5). Mean lux for BB1 and BB2 in the spring were 11 and 1 respectively, while mean lux for BB1 and BB2 for the fall were 5 and 1 respectively. As expected, we found significant differences between BB1 and BB2 for both spring and fall luminosity, \( t = 11.767, p < 0.0001 \), and \( t = 9.12, p < 0.0001 \), respectively. This showed that the luminosity was significantly higher in BB1 deployed in full sun, compared to BB2, deployed in partial shade. While we detected several bat species in close proximity to our deployed bat boxes using the bat detector, using the smartphone endoscope we found no individual bats occupying any bat box during our study.

Acoustic Surveys using the Wildlife Acoustics Echo Meter Touch 2 positively identified 5 species of bats from a total of 55 detections occupying Wingate University Campus Lake. These were observed at different relative abundances (Figure 6). These include the big brown bat, Eptesicus fuscus, hoary bat, Lasiurus cinereus, Mexican free-tailed bat, Tadarida brasiliensis, silver-haired bat, Lasionycteris noctivagans, and northern yellow bat, Lasiurus intermedius (Table 1). All identified bats echolocation frequencies were found to be within expected ranges, i.e., Eptesicus fuscus (25-51 kHz), Lasiurus cinereus (21-32 kHz), Tadarida brasiliensis (24-48 kHz), Lasionycteris noctivagans (26-38 kHz), and Lasiurus intermedius (29-41 kHz; Williams et al., 2002). The pulse ratio average (percentage of calls identified to species) and the average call length in seconds (s) varied across species (Table 1). Most echolocation call peaks were below 60 KHz. Average wind speed during acoustic surveys was 8.7 mpg, and average temperature was 71.5°F. We did not find a significant correlation between the total number of species identified during surveys and temperature (Pearson correlation coefficient = 0.329, \( p = 0.387 \)) or the total number of species identified during surveys and wind speed (Pearson correlation coefficient = -0.115, \( p = 0.769 \)).

**DISCUSSION**

In this study, we investigated and successfully utilized several non-invasive, affordable smartphone enabled applications and devices to study bats. While no bat individuals occupied deployed bat boxes during the course of our research study, our hypothesis was supported as we successfully detected 5 species of bats using the Wildlife Acoustics Echo Meter Touch 2. We expect bat boxes require longer monitoring periods than 2 seasons (April to October 2018), as often it may take several years for bats to occupy any individual bat box (Tuttle et al., 2013). Moreover, two additional non-invasive methods were successfully utilized supporting our hypothesis; a WIFI smartphone endoscope to check for bat occupancy, and WIFI smartphone enabled temperature and light data loggers to record internal bat box temperature and luminosity. We found the bat box deployed in full sun showed significantly higher amounts of natural light, indicating the placement of this bat box may more closely mimic ideal natural roosts (Tuttle et al., 2013). While we noted some slight variation, mean temperature of bat boxes was similar in both partial and full sun bat boxes (BB1 and BB2), as average temperature was likely influenced by ambient temperatures. Potential source of error for the data logger could include ideal location inside the bat box, as we attached data loggers to the bottom entrance. Future studies could vary placement of data loggers further inside the bat box to test variation in temperature within each bat box chamber. In addition, if bat boxes are occupied, the internal temperature may be affected by the number of bats generating heat. Subsequently, if bat boxes are occupied researchers should exercise caution.

Table 1. Bat Species identified using the Echo Meter Touch 2 application (Wildlife Acoustics) on Wingate Campus. Included are species code, species, common name, number of detections, average call length, and pulse ratio percentages. All species were sampled during surveys of Wingate Campus area.

<table>
<thead>
<tr>
<th>Common Name</th>
<th>Species ID</th>
<th>Total Detections (#)</th>
<th>Cell Length Average (s)</th>
<th>Pulse Ratio Average (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Big Brown Bat</td>
<td>EPTFUS</td>
<td>30</td>
<td>12.9</td>
<td>71.1</td>
</tr>
<tr>
<td>Hoary Bat</td>
<td>LASCIN</td>
<td>10</td>
<td>8.1</td>
<td>82.4</td>
</tr>
<tr>
<td>Mexican Free-tailed Bat</td>
<td>TADBRA</td>
<td>6</td>
<td>13.0</td>
<td>55.4</td>
</tr>
<tr>
<td>Silver-haired Bat</td>
<td>LASNOC</td>
<td>6</td>
<td>13.5</td>
<td>69.4</td>
</tr>
<tr>
<td>Northern Yellow Bat</td>
<td>LASINT</td>
<td>3</td>
<td>11.0</td>
<td>61.1</td>
</tr>
</tbody>
</table>
when inserting the endoscope into the bat box as to not disturb bats. Additional research of occupied bat boxes could document emergence time of individual bats exiting the boxes for feeding using the Echo Meter Touch 2.

The most frequently detected bat species in our study, the big brown bat, is capable of detecting insects as far away as five meters (Kick and Simmons, 1984), and is resistant to white nose syndrome (Frank et al., 2014). This may indicate the most common species inhabiting semi-urban and semi-natural areas is either naturally common in population size or is successfully outcompeting other native North Carolina Piedmont bat species possibly due to disease resistance. Alternatively, E. fuscus is a species which is able to thrive in urban areas (Geggie and Fenton, 1985), similar to our study area and more likely forms maternal roost in buildings over bat boxes (Agosta, 2002). The Mexican free-tailed bat has more recently expanded its geographic range into North Carolina and is now established in year-round colonies, often inhabiting buildings and bat boxes (McCracken et al., 2018). Other species we detected, the hoary bat, has been observed in similar habitats, even showing interspecific aggression behavior towards the Silver-haired bat which was another species detected (Brokaw et al., 2016). Lastly, the Northern yellow bat is among the largest of North Carolina Piedmont area bats commonly documented foraging in golf courses and edges of lakes and forests, but can be negatively affected by increases in agriculture of development (Barbour and Davis, 1969; Neece et al., 2018).

While our study focused on non-invasive monitoring methods for bats, future work on our study site should focus on confirmation of bat identification by monitoring both man-made structures and natural roost sites used at our study area and possibly capturing individual bats. However, this type of research requires following both state and federal permits, and obtaining rabies vaccination by local health centers for handling of any individual bats, so both citizen scientists and researchers should follow appropriate guidelines for animal care and use involving research on bats. Possible sources of error in this study include issues pertaining to misidentification of species based on the accuracy, echolocation call parameters, quality of calls (ambient noise or increased distance of observer recording to bat in flight), and assumptions of the automated identifier used (Wildlife Acoustics Echo Meter Touch 2 application). We recommend the use of additional software to analyze in more detail echolocation call parameters and confirm species identification. In addition, we only recorded calls 30 minutes before and after sunset, indicating that possibly other species may be present at different times or that some species of bats may alter their emergence and foraging times based on season, temperature, and other factors (Thomas and Jacobs, 2013).

Clearly, smartphone technology has a great deal of potential for collecting a greater volume of baseline data, not just in bat species observations, but also for collecting other environmental data. For example, non-invasively checking natural cavities for insects, or assessing occupancy of bird nesting boxes, as well as many other applications for acoustic surveying and determining species presence. Citizen scientists and undergraduate researchers at universities should incorporate the smartphone technologies we assessed in our study into their own research or even for outreach science programs, for which we have used the Echo Meter Touch 2 on several occasions as a teaching tool for undergraduate biology majors and for the local community at large. Moreover, continued development of smartphone technology for monitoring species can allow citizen science communities to function much as their own research institutions collecting important baseline data which they can share with local state conservation agencies (August et al., 2015). Therefore, we propose further research using affordable smartphone enabled technologies which can be incorporated into testing many future scientific hypotheses in wildlife biology.

ACKNOWLEDGMENTS

The authors would like to acknowledge the Wingate Wildlife Club, Mark Rollins, and Brandon Wilson for helping with bat box deployment and painting. Wingate Biology Department provided funding for this undergraduate directed research project. As no animals were handled in this study, authors received approval from the Wingate Research Review Board.

REFERENCES


ABOUT THE AUTHOR
Amanda-Jean Blackburn is a biologist with primary interests in conservation biology, ecology/evolution, citizen science, and biogeography. She received her Bachelor of Science in biology from Wingate University (2019), and is currently studying for her Master’s Degree at Western Carolina University. Her current research focuses on soil seed banks and vegetation present on high-elevation rock outcrop communities in the southern Appalachian Mountains. She plans to pursue a PhD in ecology following her graduation from WCU, and would like to continue research on insularization of rare/endangered terrestrial habitats.
A Review of Quantum Games

Gaon Kim* and Eung-won Nho²

Over the past two decades, the quantum mechanical concepts of superposition and entanglement have been applied in game theory to produce novel and interesting results. Quantization offers significant improvements to classical games that cannot be realized using purely classical strategy spaces. Because quantum game theory is a recent development with both merits and limitations, this review attempts to critically evaluate existing research as well as gaps in the literature requiring further research. The literature is classified into four categories of games based on differences in quantization schemes and results: quantum simultaneous non-zero-sum games, quantum simultaneous zero-sum games, quantum coalitional games and quantum sequential games. The first two categories exhibit the results of Pareto efficiency and improved payoffs, but the literature reviewed does not sufficiently analyze the role of strategic coordination in bringing about such improvements. Quantum coalitional games also have improvements over their classical counterparts, often leading to cores that yield higher payoffs to a greater number of players, given a quantization scheme that encompasses all players’ strategy spaces. However, the mechanism through which these improvements are realized is generally unclear. Finally, quantum sequential games exhibit cooperative behavior among players that is absent in the corresponding classical games. This review concludes that quantum games have significant advantages over their classical counterparts and suggests the role of strategic coordination in quantum games as a fruitful direction for future research.

INTRODUCTION

It is perhaps not a coincidence that the mathematician John von Neumann was a significant contributor in both economic game theory and quantum mechanics (von Neumann, 1953; von Neumann, 1955). Although classified as two discrete subjects of modern science, game theory and quantum mechanics exhibit deep, interesting connections (Meyer, 1999). At a glance, the two topics seem completely unrelated indeed: game theory is an analytical tool used to model and study the decision-making process of rational economic entities, whereas quantum mechanics is a branch of physics describing the nature of motion at the smallest scales of physical quantities. However, over the past two decades, numerous surprising connections have been found linking the fields after two key concepts from quantum mechanics – superposition and entanglement – were applied in classical game theory. Superposition refers to the property that a physical state can be a sum of multiple distinct states, each of which has a probability of being observed; entanglement is a phenomenon in which multiple particles are related, such that each of their quantum states is dependent on each other, regardless of physical distance (Nielsen and Chuang, 2000). A classical game is quantized when (i) the outcomes of the game are entangled and superposed, (ii) players’ strategy sets are expanded to include unitary operators (termed “quantum strategies”), or (iii) both of the above occur. These quantum mechanical applications in games produce various novel and interesting results. In this review, the term “novel” refers to a result in quantum game theory that is favorable and could not be realized in classical game theory. Quantum game theory literature focuses on a number of such results to establish the topic’s significance.

Pareto efficiency refers to an outcome in a game such that there are no other possible outcomes that give higher payoffs to a non-zero number of players without decreasing any player’s payoff. Conversely, Pareto inefficiency is observed when the Nash equilibrium of the game – an outcome where all players of a game do not have an incentive to change their strategies – does not exhibit Pareto efficiency (Nash, 1951). Games that are Pareto inefficient under the classical paradigm can be made efficient through the use of quantization, which is a novel result beneficial to the players (Eisert, Wilkens, and Lewenstein, 1999). Another key result is higher payoffs for players in the game, which directly indicates that they have benefitted from quantization (Meyer, 1999). Quantization can also lead to new coalitions among
number of players (Chen, Hogg, and Beausoleil, 2002). These results, obtained uniquely in quantum games, are significant as they expose a deep and rich econophysical connection wherein quantization is conducive to strategic coordination. Although the current lack of quantum technology imposes significant limitations on immediate practical applications of the theory, the accuracy of a few simple quantum games has been supported with experimental evidence through computer science, suggesting the potential relevance of the theory once necessary technological advances are made (Du et al., 2002; Prevedel et al., 2007; Schmid et al., 2010).

Research conducted on quantum game theory may be classified into four categories: quantum simultaneous non-zero-sum games, quantum simultaneous zero-sum games, quantum coalitional games, and quantum sequential games. These games are fundamentally different, as simultaneous games have players choose their strategies independently, whereas players compete as groups in coalitional games and players take turns choosing their strategies in sequential games (with at least some information on others’ strategies in previous turns). This review attempts to examine research from the four major categories described and discuss the significances of their results, as well as gaps and limitations in the current theory. Based on comparisons between classical and quantum games, this review asserts that quantization is significant in allowing for strategic coordination between players that improve payoffs, leading to novel results favorable for the game’s players.

**QUANTIZATION SCHEME FOR SIMULTANEOUS NON-ZERO-SUM STRATEGIC GAMES**

The quantization scheme used prevalently in simultaneous non-zero-sum strategic games was proposed by Eisert et al. (1999). It is widely researched using the Quantum Prisoner’s Dilemma (QPD) as well as the Quantum Battle of Sexes (QBos). Eisert et al.’s presentation of the quantization scheme through the QPD is outlined below and shows a remarkable example of quantum game theory – namely, the emergence of a Pareto efficient Nash equilibrium benefiting both players. However, further research is needed to investigate the role of strategic coordination in the emergence of this favorable outcome.

Classical Prisoner’s Dilemma (PD) is a standard game that reveals how two rational players, Alice (player \(i = 1\)) and Bob (player \(i = 2\)), may choose strategies that lead to an outcome that is not in their best interest – a Pareto inefficient outcome. In the PD, Alice and Bob are accused of a crime, and both players can adopt one of two possible strategies – confessing to the crime or defecting from doing so. Each possible pair of strategies chosen by Alice and Bob lead to a particular payoff for each player, enlisted in the matrix of Table 1. It is clear from this payoff matrix that “defect” is the dominant strategy for both players, hence the Nash equilibrium (\(\hat{D}, \hat{D}\)). However, because both players can improve their respective payoffs by shifting to “confess” in \((\hat{C}, \hat{C})\), the equilibrium is a Pareto inefficient outcome. Thus, the players are placed in a “dilemma”.

The QPD builds on the classical PD by using quantization to produce an efficient outcome. Firstly, the strategy space for both players is expanded so that it is quantized:

\[
A(\theta, \varphi) = \begin{pmatrix}
\cos \theta \cos \varphi & -\cos \theta \sin \varphi \\
\sin \theta \cos \varphi & \sin \theta \sin \varphi
\end{pmatrix}
\]

where \(\theta \in [0, \pi]\) and \(\varphi \in [0, \pi/2]\) (Eisert et al., 1999). This unitary strategy space encompasses classical strategies: “confess” is represented by the operator \(\hat{C} = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}\) and “defect” by \(\hat{D} = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}\).

Another feature is introduced in the QPD: the final state of the game determines the payoff. The initial state is defined as:

\[
|\psi_i\rangle = \hat{J} |CC\rangle
\]

and the final state of the game, determined according to the two players’ strategies \(A_{i=1}\) and \(A_{i=2}\), is

\[
|\psi_f\rangle = \hat{J} \langle A_{i=1} \otimes A_{i=2} \hat{J} |CC\rangle
\]

where \(|C\rangle = \begin{pmatrix} 1 \\ 0 \end{pmatrix}\) and \(|D\rangle = \begin{pmatrix} 0 \\ 1 \end{pmatrix}\); the unitary operator \(\hat{J}\) determines the extent of entanglement present in the state before Alice and Bob apply their strategies. Mathematically, an entanglement of two states “0” and “1”, represented by vectors \(|0\rangle\) and \(|1\rangle\), is denoted by \(|01\rangle\), which is the tensor product \(|0\rangle \otimes |1\rangle\), indicating that the two states are observed together. In the case of maximal entanglement that is examined, \(|\psi_i\rangle = \frac{1}{\sqrt{2}} (|CC\rangle + i|DD\rangle)\). Since the strategy space is unitary, the final state has the magnitude of 1 as \(|\psi_i\rangle\) and is a superposition of the entangled orthonormal basis \(|CC\rangle\), \(|DC\rangle\), \(|CD\rangle\), and \(|DD\rangle\), each of which represents one of the classical outcomes of the game (i.e. \(|\psi_i\rangle = \frac{1}{\sqrt{2}} (|CC\rangle + |CD\rangle)\).

This QPD is a superposition of \(1/2\left(|CC\rangle + |CD\rangle\right)\) gives payoff \(\frac{1}{2}(3,3) + \frac{1}{2}(0,5) = (1.5,4)\) as it represents the case where Alice confesses and Bob confesses with probability \(\frac{1}{2}\), while Alice confesses and Bob defects with probability \(\frac{1}{2}\). Note that \(|C\rangle\) and \(|D\rangle\) represent “confess” and “defect” within the context of the final state, but are not actual strategies open to players – these vectors have been
introduced simply as a way of determining players’ payoffs using the outcomes of the classical PD.

The case of maximal entanglement caused by the operator $\hat{J}$ is significant due to its unique property of containing a Pareto efficient Nash equilibrium when both players choose the strategy $\hat{Q} = A(\theta, \pi/2) = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$ (Eisert et al., 1999). In other words, the “dilemma” present in PD of an inefficient equilibrium has been solved as $\hat{Q}$ gives rise to an efficient equilibrium (Eisert et al., 1999). As shown in the matrix of Table 2, the equilibrium $(\hat{Q}, \hat{Q})$ gives payoffs of $(3, 3)$ equivalent to that of $(\hat{C}, \hat{C})$ in the classical game, which was previously seen to be Pareto efficient but not an equilibrium in PD. Thus, the creation of an efficient equilibrium following quantization is a novel result. Note that Table 2 does not contain the entire set of strategies and payoffs, which are continuous and would result in a multidimensional graph rather than the simple and discrete matrix presented; this method of presentation is motivated by Grabbe (2005).

The question then arises: how has the quantization of the PD resulted in this efficiency? Considering the final state interpretation of the game, it is clear that quantization of the game has allowed for coordination between Alice and Bob’s classical strategies of $|C\rangle$ and $|D\rangle$, as they were entangled. In fact, it is because of this strategic coordination in the final state that Alice and Bob attain an efficient equilibrium equivalent to that of $(\hat{C}, \hat{C})$ in the classical game, which was previously seen to be Pareto efficient but not an equilibrium in PD. Thus, the creation of an efficient equilibrium following quantization is a novel result. Note that Table 2 does not contain the entire set of strategies and payoffs, which are continuous and would result in a multidimensional graph rather than the simple and discrete matrix presented; this method of presentation is motivated by Grabbe (2005).

Another aspect of the QPD that could benefit from further research is the role of the operator $\hat{J}$ in the quantization scheme outlined above. It seems that $\hat{J}$ is inconsistent with the original context of the PD, which involves two players suspected of a crime strategically trying to benefit themselves (Enk and Pike, 2002). In the QPD, $\hat{J}$ is helpful to the players, who are prisoners, as it creates entanglement, leading to an efficient equilibrium. However, considering the context of the original game, it is unclear what entity could play the role of $\hat{J}$, allowing for the prisoners’ strategic coordination through entanglement. A possibility might be the prisoners’ interrogator or attorney, but such a scenario is unrealistic because neither have any incentive to help the prisoners (Enk and Pike, 2002). Enk and Pike’s article suggests that it is necessary to carefully define the entity playing the role of $\hat{J}$ in a way consistent with the original context and that further research is required.

One may follow Enk and Pike’s line of reasoning and question the significance of the strategy space given in Equation 1, given its arbitrary appearance. It is hard to find a meaningful interpretation to defining the strategy space in this particular way (Benjamin and Hayden, 2001). On the other hand, a more physically “natural” way of defining the strategy space would include all possible unitary operators that do not affect entanglement, reflecting an interpretation in which the players can adopt anything that is possible within quantum mechanics (Benjamin and Hayden, 2001). In fact, Benjamin and Hayden (2001) found that no equilibrium of pure strategies exists using this strategy space for the QPD. However, despite this limitation, Eisert et al.’s restriction in strategy space as given in Equation 1 is significant and necessary precisely because it can produce an efficient equilibrium in all two-player simultaneous games, not just for the QPD (Du et al., 2000). Thus, although Benjamin and Hayden (2001) correctly point out that Eisert et al.’s quantization scheme restricts the strategy space without a realistic physical interpretation, this restriction is necessary in order to obtain the desired result of an efficient equilibrium in any two-player simultaneous game (Du et al., 2000).

<table>
<thead>
<tr>
<th>Alice</th>
<th>$\hat{C}$</th>
<th>$\hat{D}$</th>
<th>$\hat{Q}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\hat{C}$</td>
<td>3, 3</td>
<td>0, 5</td>
<td>1, 1</td>
</tr>
<tr>
<td>$\hat{D}$</td>
<td>5, 0</td>
<td>0, 0</td>
<td>0, 5</td>
</tr>
<tr>
<td>$\hat{Q}$</td>
<td>1, 1</td>
<td>5, 0</td>
<td>3, 3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bob</th>
<th>$\hat{Q}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\hat{C}$</td>
<td>3, 3</td>
</tr>
<tr>
<td>$\hat{D}$</td>
<td>0, 5</td>
</tr>
<tr>
<td>$\hat{Q}$</td>
<td>1, 1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Alice</th>
<th>$\hat{D}$</th>
<th>$\hat{T}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\hat{D}$</td>
<td>5, 0</td>
<td>0, 0</td>
</tr>
<tr>
<td>$\hat{T}$</td>
<td>$\alpha &lt; \beta &lt; \gamma$</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bob</th>
<th>$\hat{D}$</th>
<th>$\hat{T}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\hat{D}$</td>
<td>5, 0</td>
<td>0, 0</td>
</tr>
<tr>
<td>$\hat{T}$</td>
<td>$\alpha &lt; \beta &lt; \gamma$</td>
<td></td>
</tr>
</tbody>
</table>
Another example of a quantum non-zero-sum simultaneous strategic game is the QBoS, first proposed and studied by Marinatto and Weber (2000). The payoff matrix for the Classical Battle of Sexes (BoS) is shown in Table 3. The game is played between Alice (player \(i = 1\)) and Bob (player \(i = 2\)), who both have two strategies \(\hat{O}\) – going to the opera – and \(\hat{T}\) – watching television. Both \((\hat{O}, \hat{O})\) and \((\hat{T}, \hat{O})\) are Nash equilibria in this game and give payoffs of \(\alpha\) to one player and \(\beta\) to another. However, if they fail to choose the same strategy – that is, if they choose either \((\hat{O}, \hat{T})\) or \((\hat{T}, \hat{O})\) – the players will receive the worst possible payoff of \((\gamma, \gamma)\). Thus, the classical BoS is a game of coordination for the players to choose the same strategy. The QBoS is also played by Alice (player \(i = 1\)) and Bob (player \(i = 2\)), and the same quantization scheme developed by Eisert et al. is used (Benjamin, 2000; Marinatto and Weber, 2000), but the strategy space is extended to the set of all two-by-two unitary matrices. The classical strategies in the strategy set are represented by the operators (i) \(\hat{O} = \begin{pmatrix} 1 & 0 \\ 0 & 0 \end{pmatrix}\) and (ii) \(\hat{T} = \begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix}\). The final state is therefore a superposition of the orthonormal basis \(|OO\rangle\), \(|OT\rangle\), \(|TO\rangle\), \(|TT\rangle\) such that \(|O\rangle = \begin{pmatrix} 1 \\ 0 \end{pmatrix}\) and \(|T\rangle = \begin{pmatrix} 0 \\ 1 \end{pmatrix}\). Marinatto and Weber (2000) proved through algebraic reasoning that there exists a certain pairing of mixed quantum strategies between Alice and Bob such that \(|\psi_I\rangle = \frac{1}{\sqrt{2}} (|OO\rangle + |TT\rangle)\). Consequently, the expected payoff to both players is \((\alpha + \beta)/2\), which can be interpreted as the average payoff of the two Nash equilibria \((\hat{O}, \hat{O})\) and \((\hat{T}, \hat{T})\) (Marinatto and Weber, 2000). This is observed to be an improvement over the classical BoS (Marinatto and Weber, 2000). Similar to the QPD, this improvement seems to be the result of strategic coordination between Alice and Bob due to quantization. Because the two players’ strategies are entangled, they can readily be coordinated to obtain the desirable outcomes of either \(|OO\rangle\) and \(|TT\rangle\), where the players choose the same strategies.

As noted by Benjamin (2000), one limitation of the QBoS is that the game requires mixed quantum strategies to obtain the desired equilibrium, yielding another uncertainty in strategies. Mixed strategies, whether quantum or classical, are probabilistically determined, so both desirable and undesirable outcomes can arise – the expected payoff simply gives the average of the different possible outcomes weighted according to their probabilities. In fact, a similar result of an equilibrium can be obtained even in the classical version if mixed classical strategies are used (Grabe, 2005). When using mixed classical strategies in the BoS, the players can decide on a probability distribution between the two strategies \(\hat{O}\) and \(\hat{T}\) that will maximize their respective expected payoffs. Defining \(p^*\) as the probability of Alice choosing \(\hat{O}\) and \(q^*\) as the probability of Bob choosing \(\hat{O}\), the expected payoffs for Alice and Bob can be optimized using calculus. This computation yields an expected payoff of \(\pi = \frac{a\beta + \gamma}{a + \beta - 2\gamma}\) to both players, which is lower than the expected payoff of \(\frac{a + \beta}{2}\) for the QBoS (Marinatto and Weber, 2000). Thus, although the QBoS does result in higher expected payoffs than the BoS due to coordination through quantization, since the QBoS requires mixed strategies to obtain its equilibrium, which is possible even in the classical version, the advantage of the QBoS over the BoS does seem to be under-mined.

**QUANTIZATION SCHEME FOR ZERO-SUM SIMULTANEOUS STRATEGIC GAMES**

Because Eisert et al.’s quantization scheme uses both quantum strategies and entanglement to quantize a game, considering the effects of using only quantum strategies without entanglement may offer insight into their unique advantages (Du et al., 2000). Meyer’s scheme, which does not use the operator \(\hat{J}\), exposes the advantages of quantum strategies by comparing them with classical strategies without entanglement (Meyer, 1999; Du et al., 2000). Despite the absence of entanglement in Meyer’s scheme, the results of the zero-sum quantum game are highly analogous to those of Eisert et al.’s scheme in which payoffs are improved through quantization. Meyer’s scheme is outlined below. Meyer’s quantum game is equivalent to the classical “Matching Pennies” game in all respects other than its strategy set, which has been expanded into the entire set of unitary two-by-two operators. A penny is placed head up initially. Then, without looking at the penny each time, player \(i = 1\), player \(i = 2\), and player \(i = 1\) (once again) apply strategies of their choice to the penny in the order listed. If the penny appears as “head” in the end, player \(i = 1\) and \(i = 2\) receive payoffs of +1 and -1 respectively, and vice versa in the case of “tail”. Thus, the game is classified as zero-sum. Though the game is played in sequence, it is still a simultaneous game because neither players receives any information about his opponent’s strategy nor the state of the penny throughout the game. In the classical game, both players are restricted to the strategy set of “flip” and “not flip,” represented by \(\hat{F} = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}\) and \(\hat{N} = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}\) respectively, which may be mixed probabilistically. However, in Meyer’s quantum game, player \(i = 1\) alone has access to quantum strategies in the form of the unitary operator \(A(a, b) = \begin{pmatrix} a & b \\ b & -a \end{pmatrix}\). The state of the game, which is a superposition of “head” and “tail,” is represented by a linear combination of \(|H\rangle = \begin{pmatrix} 1 \\ 0 \end{pmatrix}\) and \(|T\rangle = \begin{pmatrix} 0 \\ 1 \end{pmatrix}\). Quantum strategies induce the final state of the game to be in the form \(|\psi_I\rangle = a|H\rangle + b|T\rangle\), which is superposed, but not entangled. In general, the initial state of the game is \(|H\rangle\), and ultimately:

\[|\psi_I\rangle = A_2 \left\{ pF + (1-p)N \right\} A_1 |H\rangle\]

where \(A_1\) and \(A_2\) are player \(i = 1\)’s strategies in chronological order, and \(p\) is the probability at which player \(i = 2\) will choose “flip” as his strategy. Meyer (1999) computed the fi
nal state density matrix – a matrix showing the respective probability amplitudes of each of the possible states a superposed state may be in – to assert that if $A_i = A_2^i = A_2^{\frac{1}{\sqrt{2}}, \frac{1}{\sqrt{2}}}$, the final state will be “head”, independent of player $i = 2$’s choice of $p$. The Nash equilibrium thus gives payoffs of +1 to the quantum player and -1 to the classical player. This contrasts with the classical equilibrium of the Matching Pennies game, which gives an expected payoff of zero to both players (Meyer, 1999). This analysis of Matching Pennies game therefore suggests that a simultaneous zero-sum game between a quantum player and a classical player will be advantageous for the former. Meyer (1999) generalized this observation to prove that (i) all simultaneous zero-sum games do have a Nash equilibrium when played between a quantum player and classical player, and (ii) the expected payoff for the quantum player in this equilibrium is at least as great as the expected payoff when he plays mixed classical strategies like the other player (Meyer, 1999). In other words, the observation that the quantum player has an advantage over the classical player holds in general for simultaneous zero-sum games. Using quantization in this way is another novel result that can be utilized to improve players’ payoffs.

The observation above has been verified through other games as well. The quantized “Card Game” presented by Du et al. (2000) is an interesting example: the initial zero-sum game is between a quantum player and a classical player using mixed strategies, each with zero expected payoff. However, consistent with the theorem above, when the quantum player is reverted into a classical player by restricting his initially quantum strategy space to simply mixed classical strategies, he actually receives less payoff than his opponent. It is evident from the quantized Card Game that the quantum player did possess an advantage when allowed to use quantum strategies.

This result of Meyer’s quantization scheme implies that quantum strategies have properties absent in classical ones that can make the quantization of a classical game an advantageous choice. The invariance of the final state suggests that quantum strategies create strategic links between the players. When player $i = 2$ chooses to flip the penny, his opponent also ends up flipping the penny. However, when he chooses not to flip, his opponent also ends up not flipping the penny. This dependency between strategies from the perspective of the final state is a consequence of the extension of the strategy space to the quantum domain. The player capable of playing with the quantum strategies is at an advantage because he can manipulate the strategic link to benefit himself. Consequently, quantum strategies without entanglement can create strategic links in accordance with the final state between players in ways analogous to the QPD. This is a significant observation regarding the impact quantization of strategies has on a classical game without entanglement.

**QUANTUM COALITIONAL GAMES**

The effects of quantization observed in various simultaneous games can be readily applied in coalitional games. Some methods illustrated in this section that are used to quantize coalitional games include sharing entangled states, using quantum strategies, and entangling players’ states with others. The appropriate quantization of coalitional games yields novel, significant results of effective cooperation between players resulting from strategic coordination, often leading to win-win situations, as explored in games such as the Public Goods Game and the Minority Game. A wider variety of quantum coalitional games must nonetheless be researched using a greater number of methods to determine the general mechanism through which quantization leads to these improved outcomes.

An illuminating example, motivated by the idea of multiplayer entanglement, is Mermin’s Multiplayer Pseudo-Telepathy Game between $n$ players (Brassard et al., 2004; Mermin, 1990). A review of pseudo-telepathy games in general is provided by Brassard, Broadbent, and Tapp (2005). In the formulation of Mermin’s Multiplayer Pseudo-Telepathy Game by Brassard et al. (2004), a single state $x$ is given to each player who is then allowed to apply a transformation $T_i$ to get $T_i \cdot x \rightarrow y_i$. Given that $\sum x_i$ is even, all players receive a total payoff of +1 if and only if the following condition is satisfied:

$$\frac{1}{2} \sum x_i = \sum y_i$$

(5)

In all other cases, all players receive a payoff of -1. The key aspect of this coalitional game is strategic coordination and cooperation among players, which is unachievable in the classical context as each player does not have perfect information about the strategies of all other players, preventing coordination. However, Brassard et al. (2004) present a proof for the existence of a set of transformations that results in the group certainly receiving a payoff of +1. The desired set of transformations involves the sharing of an $n$-qubit, which is an entanglement of $n$ states of either $|0\rangle$, $|1\rangle$, or both (i.e. $|0^n\rangle = |0\rangle \otimes |0\rangle \otimes |0\rangle$ is an example of a 3-qubit). The players first agree to share an entangled $n$-qubit state $\frac{1}{\sqrt{2}} (|0^n\rangle + |1^n\rangle)$ and to apply different operators on their parts of the shared $n$-qubit in accordance with the parity of their own given state $x_i$. This gives rise to a transformation that makes $y$, a superposition of only odd or only even states that satisfies Equation 5. In other words, quantization is used in these transformations to (i) create coordination between players’ strategies through a shared entangled state and (ii) exploit quantum strategies to create a superposition of states with the same parity. In effect, superposition and the sharing of the $n$-qubit has led to the novel result of a win-win cooperation between the players, which was previously impossible in the classical context. Grabbe (2005) commented that the remarkable feature of this coalitional game is that,
as a consequence of quantization, the core is achieved only when full cooperation occurs in the form of a grand coalition involving all players. Mermin’s “Multiplayer Pseudo-Telepathy Game” suggests that the appropriate application of quantum mechanical concepts in coalitional games can result in the emergence of a core that is beneficial to a greater number of players by creating cooperation between players.

The “Public Goods Game” is a well-established game in standard economic theory and is also amenable to quantization. Chen et al. (2002) investigated a variation of the “Public Goods Game” in which there are \( n \) players each indexed as \( k = 1, \ldots, n \). Player \( k \) has an initial personal endowment of \( y_k \) and contributes the amount \( c_k \) to the public good. It is assumed that \( y_k = 1 \forall k \). Then, according to the production function \( g(C) = aC/n \), where \( C = \sum c_k \), the amount of public goods produced \( x \) is determined. The utility of player \( k \) is then determined through the function \( Q(x,y) = x + y \), where \( y = y_k - c_k \) is the amount of private wealth remaining after contributing to the public good. In this classical version, players will contribute nothing when \( a < 1 \) and everything when \( n < a \), which are both Pareto efficient equilibria (Chen et al., 2002). However, when \( 1 < a < n \), the equilibrium is for players to contribute nothing, which is an inefficient outcome; a coalition between all players to contribute everything would be Pareto efficient, but players have an incentive to cheat and contribute nothing for personal gains (Chen et al., 2002).

The quantum version, also proposed by Chen et al. (2002), assigns the vector \[ |0\rangle = \begin{pmatrix} 1 \\ 0 \end{pmatrix} \] to “cooperation” (\( c_k = y_k = 1 \)) and \[ |1\rangle = \begin{pmatrix} 0 \\ 1 \end{pmatrix} \] to “defection” (\( c_k = 0 \)). Each player may choose a superposition of these vectors as their strategy. Chen et al. (2002) investigated three cases of entangling the players’ strategies: (i) full entanglement between all players, (ii) entanglement between all possible pairs of players, and (iii) entanglement between neighboring pairs of players. All three cases are shown to have an equilibrium in which all players contribute between 0 and 1 in the equilibrium under \( 1 < a < n \), which is not yet Pareto efficient, but still an improvement over the classical version (Chen et al., 2002). Once again, quantization of a classical game has created strategic coordination, which for the “Public Goods Game” resulted in a set of payoffs beneficial for all players. The “Quantum Public Goods Game” further demonstrates that coalitional games can exhibit cooperative behavior in the interest of all players through appropriate quantization. Furthermore, the quantization scheme presented seems to produce a valid version of the classical game that retains its coalitional nature – in both versions, players have a choice between cooperating with and defecting the coalition, with quantization as an effective reinforcement of the coalition.

More quantum coalitional games need to be quantized, as there is yet a limited number of quantized versions of such games, hindering the advancement of more accurate and general observations on these games. Various patterns and schemes of quantization are observed throughout the literature on this topic; in fact, the Public Goods Game has three different quantization schemes that each produces a different result (Chen et al., 2002). Additionally, some classical games such as the “Minority Game” produce unexpected results under quantization: while the classical Minority Game (players choose between two options, and those in the minority win) is primarily studied using an odd number of players to avoid balance of players, the quantum version can be designed to avoid the balance as much as possible, resulting in the same set of payoffs as the classical game for an odd number of players and higher payoffs for an even number of players (Benjamin and Hayden, 2001). The roles quantization and strategic coordination have in such a result is interesting but also bizarre. As with the “Public Goods Game,” there are multiple ways to quantize the “Minority Game,” but another bizarre result is that entanglement between pairs does not improve the payoffs in the Minority Game, which is inconsistent with the “Quantum Public Goods Game” (Flitney and Hollenberg, 2008). More coalitional games must be quantized with various schemes and methodologies in order to further investigate the precise rules and mechanisms through which strategic coordination occurs and novel results are produced.

**QUANTUM SEQUENTIAL GAMES**

Sequential games also seem similarly affected by quantization. One such example is the quantum version of the quantity leadership model of a duopoly, also known as the Stackelberg model (Iqbal and Toor, 2002). The Stackelberg duopoly is a classical sequential game that attributes more profit to the leader firm, but profits are shared more equally in the form of a Cournot equilibrium – where no firm is the leader – when the game is quantized appropriately (Iqbal and Toor, 2002). Iqbal and Toor (2002) transformed the classical game into a quantum one by (i) using the quantization scheme equivalent to the QBoS, but with a sequential structure and (ii) defining a function (Equation 6) that assigns each choice of quantity \( q \) in the classical model to a unique value \( x \) in the range \((0, -1]\) that describes the probabilistic distribution of the player’s mixed quantum strategy. Iqbal and Toor (2002) then proved that their quantization scheme for the Stackelberg model leads to an outcome equivalent to that of a Cournot equilibrium, such that the leader firm has lost its dominance through quantization.

\[
x = \frac{1}{1 + q}
\]

Although Iqbal and Toor (2002) concluded that the result is “counter-intuitive,” the results seem reasonable and consistent with the effects of quantization observed throughout this review. In the classical version, the strategic link between the two firms works to the advantage of the leader firm, which has more market power over the other firm, whose strategy is in turn limited to “following” the leader. Quantization, on
the other hand, strengthens the mutual strategic link between the two firms and allows the follower firm to have a greater and more direct impact on its competitor. Because the classical Cournot equilibrium does not contain a leader firm, the quantized Stackelberg equilibrium obtains an equivalent outcome as a result of this mutual and hence “fair” strategic link between the firms. This “fair” distribution of the firms’ profits in the quantum Stackelberg equilibrium has not been observed in the classical version of the game, and is hence another example of a novel outcome induced through quantization.

As additional evidence, Li et al. (2002) followed Iqbal and Toor’s investigation and found that the quantum version of the Cournot equilibrium – which is not a sequential game, but still an illustrative example – also exhibits more cooperative behavior than the classical version, in which firms act selfishly for their respective profits. The firms of the quantum Cournot duopoly exhibit a greater degree of cooperation than those in the classical Cournot duopoly in the sense that they choose strategies that effectively maximize their combined profits rather than their individual profits (Li et al., 2002). This behavior was observed to be increasingly strong for higher degrees of entanglement (Li et al., 2002). The cooperative behavior between firms in a Cournot duopoly following the entanglement of their strategies is another novel result that is not observed in the classical version of the game, where firms simply maximize individual profits without regard for combined profits. The overall application of quantum mechanical concepts in sequential games seems to create strategic links that lead to novel outcomes of cooperative behavior and “fair” results.

**DISCUSSION**

This review demonstrates that the quantum mechanical concepts of entanglement and superposition are readily applicable to game theory, producing novel results that can be employed to better players’ payoffs in a wide range of games. These results are not only absent in the original classical games, but also interesting because they pose a solution to the problems of these classical games, ultimately leading to beneficial results for players. For instance, the classical PD highlights the issue of an inefficient equilibrium dominating the efficient outcome; this problem is solved by quantization as superposition and entanglement lead to strategic links conducive to cooperation (Eisert et al., 1999). Similarly, the problem of coordination between players is solved in the BoS as quantization leads to a payoff where the two players choose the same strategy simultaneously (Marinatto and Weber, 2000). These solutions to the problems highlighted in classical games are found in zero-sum games, coalitional games and sequential games (Brassard et al., 2004; Chen et al., 2002; Iqbal and Toor, 2000; Meyer, 1999). Using quantization in these ways to solve issues of cooperation and coordination is the key idea of quantum game theory.

A fruitful direction for future research in quantum game theory is the role of strategic coordination in quantum simultaneous games. It was observed through the QPD and the QBoS that the final outcome of the quantum game suggests the existence of strategic coordination through quantization. Whereas the original classical games exhibited inefficient outcomes due to the failure of coordination among players, the quantum games exhibited outcomes in which players were better off due to successive coordination. A deeper investigation could elucidate the details of how the quantization schemes lead to this successful strategic coordination. Further research could also be conducted on the precise mechanisms through which quantization leads to novel results. It was noted in the section on quantum coalitional games that different quantization schemes produce varied results in different games, exemplified by the differences between the quantum version of the “Minority Game” and “Public Goods Game.” The current literature does not provide an explanation for this inconsistency in the effects of particular quantization schemes across games. Researching the specific mechanisms that are behind quantization schemes could shed light on why these quantization schemes lead to varied results in different games.

**REFERENCES**


ABOUT THE AUTHOR

Gaon Kim is currently a first-year undergraduate economics student at the University of Cambridge. The paper A Review of Quantum Games was written while Gaon was a high school student at K. International School Tokyo. Gaon had a combined interest in theoretical physics and economics as a sophomore in high school, so he decided to pursue the econophysical topic of quantum game theory in his paper. He then worked under the supervision of Professor Nho, completing the review paper on quantum game theory. Gaon looks forward to pursuing his interests further into the future.
Varying Amount of Social Information in an Image Affects Facial Processing Strategies of Participants with an Autism-related Phenotype

Nidhila Masha*, Jeff J. MacInnes¹, and Elizabeth N. Johnson¹

Autism spectrum disorder (ASD) is a developmental condition that presents with a tendency to experience sensory overload as well as deficits in social cognition and communication which may be associated with differences in facial processing strategies. Previous studies have shown that, when viewing a facial image, participants with ASD spend less time on the eyes and lips — which contain more emotional and social information than other areas of the face. This study investigates whether individuals with an autism-related phenotype avoid the eyes of facial images in order to reduce their risk of experiencing sensory overload. Neurotypical participants, either possessing or lacking an autism-related phenotype, viewed images drawn from two stimuli sets: a control set of color images and an experimental set consisting of grayscale and reduced contrast images. Humans have been shown to use color as a source of social information (e.g. relative health, sex, emotion, etc.); the grayscale images in the experimental set thus contained less socially relevant information than the color images in the control set. The color images also contained more brightness and contrast—both of which are potential triggers of sensory overload — than the reduced contrast images. The results revealed that participants with an autism-related phenotype spent more time focusing on the eyes of grayscale images than on the eye region in color images. However, this effect was not observed when reduced contrast images were compared to color images. These results, when extrapolated to a population with a true autism phenotype, suggest that individuals with autism may process grayscale images differently than color images.

INTRODUCTION

Humans spend their lives in environments that contain more detail than they have the capacity to process. Thus, the ability to focus attention on only the most salient stimuli in an environment prevents humans from living in a state of perpetual sensory overload.

Developmental studies have shown that infants direct their gaze to faces more than to any other stimuli (Johnson et al., 1991), implying that humans have evolved to consider faces as particularly valuable and salient. Faces provide a rich source of social information, and this ability to perceive facial cues aids communication. Even brief exposure to a static facial image allows humans to make trait inferences about the face in question while gauging characteristics such as warmth and threat (Barry, 1990). Accordingly, being able to quickly identify potential threats provides an important evolutionary survival advantage.

When viewing faces, most individuals tend to spend the most time on the eyes, nose, and mouth. As a result, these three features have been dubbed the core areas of the face (Hernandez et al., 2009). Of these three core areas, neurotypical people tend to spend the most amount of time on the eyes (Ristic et al., 2005). Since the eyes contain more social information than any other area of the face (Ristic et al., 2005), a preference for the eyes provides a distinct evolutionary advantage and is a crucial facilitator of social interaction. This preference is diminished in individuals with autism spectrum disorder (ASD) (Jones et al., 2008), a developmental condition that presents with deficits in social cognition and communication. Eye-tracking studies exploring how participants with and without autism view faces suggest that those with ASD tend to spend more time on the mouth than the eyes (Klin et al., 2002) and tend to spend less time on the core facial features overall (Pelphrey et al., 2002).

Researchers have advanced a variety of theories as to why individuals with autism tend to spend less time on the eyes and mouths of facial images — and why, between these two features, individuals with autism tend to spend...
This study investigated the facial processing strategies of two groups of neurotypical participants—one group with an autism-related phenotype, and one group without. All participants were asked to view a series of color, grayscale, and reduced contrast facial images. Afterwards, the amount of time each participant spent fixated on the eyes, mouth, and nose of these images was measured. We hypothesized that participants with the autism-related phenotype would spend more time on the eyes of the grayscale and reduced contrast images which were less likely to trigger sensory overload, and found that participants did spend more time on the eyes of grayscale images than they did on color images. This result lends support to the theory that individuals with autism view images differently perhaps in order to guard against sensory overload.

**MATERIALS AND METHODS**

**Participants**

25 adult participants aged from 18 – 28 years (mean age: 20.8, SD: 2.64 years) were recruited through DukeList, an online advertising site to which all current Duke University employees and students have access, for a larger eye-tracking study. All participants consented to perform a research study following procedures approved by Duke University’s Institutional Review Board.

All participants had normal or corrected to normal vision, none had been diagnosed with autism, and most were students enrolled at Duke University. Five participants were eliminated from the data set due to equipment malfunctions during testing. One participant was excluded due to experimenter error as their ID number was not recorded on their copy of the Broad Autism Phenotype Questionnaire and their scores on this task were lost.

**Broad Autism Phenotype Questionnaire**

None of the participants had been diagnosed with autism; however, the disorder exists on a spectrum and individuals can present with sub-clinical levels of the traits associated with the condition. These traits compose the Broad Autism Phenotype. The Broad Autism Phenotype Questionnaire (BAPQ; Hurley et al., 2007) is a task designed to measure the Broad Autism Phenotype in neurotypical adults.

The BAPQ measures adherence to the autism phenotype on three different subscales: rigidity, aloofness, and pragmatic language. The questionnaire is composed of 36 questions divided up evenly between the three subscales. Scores on each subscale are calculated using the results of the 12 questions which pertain to it. Each question asks the participant to rate (on a six-point Likert scale) how well a particular characteristic applies to them. A participant’s scores on each of the three subscales are then averaged to calculate that participant’s total BAPQ score. Thus, the highest possible score on the BAPQ is six, and the lowest
possible score is one. If a participant’s total BAPQ score fell above a (3.15), that participant was said to present with an autism-related phenotype. The official cutoff for the BAPQ test is 3.15, as set by the design of the questionnaire (Hurley et al., 2007).

After completing the eye-tracking portion of the study, participants were asked to take the BAPQ. The questions composing the BAPQ were administered through a multiple choice Qualtrics survey, which participants completed on the computer used for the eye-tracking task.

Stimuli
Participants were shown a total of 110 stimuli drawn from diverse, emotionally neutral, image categories. For the purposes of this study, a subset of 32 images was analyzed, all of which came from Nina Strohminger’s MR2 database (Strohminger et al., 2016). All 32 images were of forward-facing adults photographed against a plain white background and under controlled, even studio lighting. Images were selected to have a 1:1 ratio of male to female faces, and a near even racial distribution (11 African American, 10 Caucasian, and 11 Asian face images).

The 12 images in the control set represented the “more facial information” condition and were in full color. The 20 images in the experimental set represented the “less facial information” condition. Ten of these 20 images were in grayscale (black and white). The remaining 10 images were created by overlaying an opaque grey layer over a set of color images and then reducing the transparency of this top layer to 75%. The underlying image was visible but tinted grey with diminished overall contrast and brightness.

Other Testing
Since this experiment was conducted as part of a larger eye-tracking study, not all of the tasks participants completed were relevant to this analysis. In addition to the tasks outlined below, participants also completed the Kaufmann Intelligence Test, a Social intelligence Test, a personality questionnaire, and a demographics questionnaire.

Eye-tracking and Task
A Tobii T60XL eye-tracker with a high-resolution 24-inch monitor and a sampling rate of 60 Hz was used to collect the eye-tracking data. Participants were asked to seat themselves at a comfortable distance from the monitor, with their heads unrestrained.

Before presenting the stimuli, the eye-tracker was calibrated using a nine-point procedure. A series of nine rotating shapes (e.g. triangles or squares) appeared on different areas of the screen. Participants were asked to direct their gaze to the center of each shape as it appeared and maintain their gaze until the shape grew too small to see.

At the start of the experiment, participants were instructed to view the images as they would normally view objects on a screen. Each of the 110 stimuli was presented for five seconds, and the order of presentation was randomized across stimulus categories. Before each image was presented, a fixation cross would appear on the screen in an unpredictable location (locations constrained to an area centered on the screen and 66% of the total screen extent). After each fixation cross appeared, participants pressed a key in order to advance to the next stimulus. After every 30 images, participants were given the option to take a short break.

Processing Eye-Tracking Data
The Tobii eye tracking system measured the location of each participant’s gaze at 60 Hz. A Dispersion-Threshold Identification system (Salvucci and Goldberg, 2000) was used to define a fixation as a period of 100 ms or more, during which a participant’s gaze did not deviate more than 1.5° of visual angle from a given point. The analysis pipeline (MacInnes, 2016) was designed to exclude the first fixation of each viewing period if that fixation corresponded with the location of the fixation cross. The pipeline also compiled the number and duration of fixations occurring on pre-defined areas of interest, reporting the sum amount of time a participant spent on each of these areas for a specific image.

Areas of interest (AOIs) were defined on each stimulus by having four independent researchers manually trace separate regions for the left eye, right eye, mouth, and nose. The four tracings for each region were aggregated into a master AOI for that region on a given stimulus. If a fixation occurred on any other region of the image, it was labeled as a fixation outside an area of interest. The pipeline also reported the amount of time participants spent viewing the image without fixating on any specific AOI.

The dependent variable of this experiment was time spent on the eyes, which was calculated by adding the combined amount of time a participant spent on the left and right eyes. The independent variables of this experiment were whether the participants scored above or below the cutoff on the BAPQ and image type (color, grayscale, or reduced contrast).

Analysis
BAPQ Analysis
Though none of the participants in this experiment had been diagnosed with autism, those who scored above the cutoff on the Broad Autism Phenotype Questionnaire (BAPQ) were labeled as having an autism-related phenotype. The BAPQ measures levels of rigidity, aloofness, and use of pragmatic language; these are traits that have been linked to autism but do not comprise the full range of symptoms associated with the condition. As a result, there are certain traits associated with autism that the BAPQ fails to measure. For example,
In order to test this hypothesis, participants’ BAPQ scores were compared against the time they spent on eyes of color images. Previous studies suggested that participants with autism tend to spend less time on the eyes of color images than participants without autism (Jones et al., 2008; Klin et al., 2002; Neumann et al., 2006). If BAPQ+ participants spent less time on the eyes of color images than BAPQ- participants, then this would suggest that the BAPQ is an accurate measure of the autism phenotype with regards to facial processing.

Eye-tracking Data Analyses

An independent t-test was used to compare the time spent on the eyes of images in the control set (color images) between BAPQ- participants and BAPQ+ participants. The threshold used for statistical significance was \( p \leq 0.05 \). A two-way ANOVA was used to investigate the effect of group (BAPQ+ vs. BAPQ-) and image category (grayscale vs. color vs. reduced contrast) on eye-dwell times.

Due to the small sample size of the BAPQ+ group, a follow-up analysis was run in order to measure the effect of image category on participants in the BAPQ+ group alone. A repeated measures ANOVA was used to test for differences in the time spent on the eyes across each of the image sets (color, grayscale, reduced contrast). The threshold used for statistical significance was \( p \leq 0.05 \). A second follow-up analysis was run to measure the effect of image category on participants in the BAPQ- group alone. A repeated measures ANOVA was used to test for differences in the time spent on the eyes across each of the image sets (color, grayscale, reduced contrast). The threshold used for statistical significance was \( p \leq 0.05 \).

RESULTS

BAPQ Score Distribution

Out of 19 participants, five had a total BAPQ score above 3.15 and were subsequently labeled “BAPQ+,” while the remaining 14 participants had a total score below the cutoff and were labeled “BAPQ-” (Figure 1). The total average BAPQ score was 2.89 with a standard deviation of 0.4927. The total average BAPQ score within the BAPQ+ group was 3.54 with a standard deviation of 0.3290, and the total average BAPQ score within the BAPQ- group was 2.66 with a standard deviation of 0.2874.

Time Spent on the Eyes of Color Images was Greater in BAPQ+ than BAPQ- Participants

It was hypothesized that BAPQ+ participants would spend less time on the eyes of color images, compared to BAPQ- participants. An independent t-test was used to test this prediction. It was observed that BAPQ+ participants spent less time on the eyes of color images than the BAPQ- participants, however this difference failed to reach statistical significance in this sample: \( t(16.475) = -1.6441, p = 0.1191 \), with means (SD) of 0.14 (0.06) for the group with the autism related phenotype and 0.22 (0.14) for the group without the autism related phenotype (Figure 2).
Time Spent on the Eyes of Grayscale and Reduced Contrast Images was not Significantly Different Between BAPQ+ and BAPQ- Participants

It was hypothesized that BAPQ+ participants would spend more time on the eyes of grayscale and reduced contrast images than they would on the eyes of control color images. A two-way ANOVA within group (BAPQ+, BAPQ-) as the between subjects variable and image category (grayscale, color, reduced contrast) as the within subjects variable was used in order to test this prediction.

There was a main effect of image category \( F(1, 2) = 3.6060, p = 0.03737 \) (Figure 3). Post hoc comparisons using pairwise comparison tests indicate that there is a significant difference in the eye dwell time for grayscale images (\( M = 0.22, \ SD = 0.034 \)) and color images (\( M = 0.186, \ SD = 0.034 \)); \( p = 0.0322 \). There was no significant difference in the eye dwell time for color images (\( M = 0.186, \ SD = 0.034 \)) and reduced contrast images (\( M = 0.198, \ SD = 0.034 \)); \( p = 0.6623 \). There was no significant difference in the eye dwell time for grayscale images (\( M = 0.22, \ SD = 0.034 \)) and reduced contrast images (\( M = 0.198, \ SD = 0.034 \)); \( p = 0.1957 \).

The BAPQ+ participants did not significantly differ from BAPQ- participants in the amount of time they spent on the eyes of images, \( F(1, 2) = 0.7367, p = 0.40267 \) (Figure 3). While the two-way ANOVA showed no main effect of group, this result may have been due to the small sample size of the BAPQ+ group. Follow up analyses were run independently in each group.

Follow Up Analysis: Among BAPQ+ Participants, Time Spent on the Eyes of Grayscale Images was Greater Than for Reduced Contrast and Colored Images

A repeated measures ANOVA was used in order to test the prediction that BAPQ+ participants would spend more time on the eyes of grayscale and reduced contrast images than they would on the eyes of control color images. There were significant differences in the amount of time BAPQ+ participants spent on the eyes of grayscale, color, and reduced contrast images, \( F(2,8) = 8.857, p = 0.00937 \) (Figure 4). Post hoc comparisons using paired t-tests indicate that there is a significant difference in the eye dwell time for grayscale images (\( M = 0.21, \ SD = 0.07 \)) and color images (\( M = 0.14, \ SD = 0.06 \)) or images under a contrast filter (\( M = 0.16, \ SD = 0.07 \)).

Follow Up Analysis: No Significant Difference in Time Spent on the Eyes of Grayscale, Reduced Contrast, and Color Images Among BAPQ- Participants

A repeated measures ANOVA was used in order to test the prediction that the amount of information present in an im-
age would have no effect on eye-dwell time in BAPQ- participants. There was no significant difference in the amount of time BAPQ- participants spent on the eyes of grayscale, color, and reduced contrast images: $F(2,26) = 0.06114, p = 0.377$ (Figure 5).

**DISCUSSION**

We tested the overall time that participants spent on the eyes of three categories of facial images: grayscale, reduced contrast, and color images. The BAPQ+ participants were found to spend significantly more time on the eyes of grayscale images than they did on color images. However, there was no significant difference between the time they spent on the eyes of reduced contrast versus color images.

Before testing the effect of image category on eye-dwell time, an analysis was run to see whether or not the BAPQ+ participants spent more time on the eyes of color images than the BAPQ- participants did. The purpose of this analysis was to test whether or not our findings about individuals with an autism-related phenotype could potentially be extrapolated to individuals with an autistic phenotype. Previous studies have shown that individuals with autism tend to spend significantly less time on the eyes of color images than neurotypical individuals. However, while BAPQ+ participants did spend less time on the eyes of color images than BAPQ- participants, the difference was not statistically significant. Nevertheless, this lack of significance could be a consequence of the small sample size of the cohort as only five participants were labeled as BAPQ+ participants. Additionally, though the $p$-value of the test was above the cutoff required for statistical significance, it was approaching trend level ($p = .119$). Future studies should revisit this hypothesis with a larger subject pool as well as an adult clinically-diagnosed ASD participant pool.

Follow up analyses were conducted to investigate the effects of image category on the BAPQ+ group and the BAPQ- group separately. These analyses showed that BAPQ+ participants spent significantly more time on the eyes of grayscale images than they did on the eyes of color images, while BAPQ- participants did not spend significantly more time on the eyes of grayscale images.

Such results suggest that the increase in eye-dwell time amongst grayscale images may be attributed to the fact that grayscale images contain reduced amounts of information, since full-contrast color images are a richer source of social information than grayscale images are. Seeing certain hues in a facial image can make participants more likely to associate the face with a specific emotion. For example, a red-tinted face is more likely to be perceived as angry (Valdez and Mehrabian, 1994). This association indicates that humans use color as a source of social information, making grayscale images a poorer source of social information than color images (Valdez and Mehrabian, 1994). Color images are thus potentially more likely to trigger sensory overload than their grayscale counterparts, as grayscale images provide viewers with less socially relevant information to process and may also be less realistic and therefore perceived as less threatening. Reducing the contrast of a color image may similarly diminish its risk of triggering sensory overload — by virtue of reducing potential risk factors such as glare and color range.

Neither BAPQ+ or BAPQ- participants spent significantly more time on the eyes of reduced contrast images than they did on the eyes of color images. These results may suggest that either reducing glare and color range does not decrease an image’s potential to trigger sensory overload, or individuals with an autism-related phenotype do not avoid the eyes of images in order to decrease risk of experiencing sensory overload. However, it is likely that these results can be traced back to the fact that the 75% contrast filter used for the purposes of this experiment may not have been sufficient to make a perceptible difference in the amount of glare or saturation that the reduced contrast images contained. A more opaque contrast filter which diminishes brightness and color range to a greater degree may have succeeded in eliciting an increase in eye-dwell time among participants in the BAPQ+ cohort.

The results of this experiment suggest that BAPQ+ participants process grayscale images differently than BAPQ- participants. Unlike BAPQ+ participants, BAPQ- participants did not show an increase in eye-dwell time for grayscale images. Yet, some limitations to this analysis exist, due to the fact that all participants tested were undiagnosed with autism and, to the best of our knowledge, neurotypical. The facial viewing patterns of neurotypical participants with a BAPQ score above the cutoff may not be comparable to the facial viewing patterns of participants diagnosed with ASD. Nonetheless, these findings suggest that using a grayscale filter may affect the gaze patterns of certain population groups more than others.

Since the facial processing strategies of neurotypical BAPQ+ individuals may not fully reflect the facial viewing patterns of individuals diagnosed with ASD, further studies can strengthen this research by testing a population of individuals diagnosed with ASD in comparison with a control group of neurotypical individuals. However, future studies should avoid using contrast-filters as a way to diminish an image’s risk of triggering sensory overload. It is difficult to determine, without prior experimentation, the level to which an image’s contrast needs to be reduced before the decrease in brightness and color range can have a perceptible effect on the image’s ability to trigger sensory overload.

Several studies have used eye tracking to investigate the ways in which individuals with autism process facial images differently from neurotypical individuals. Many of these studies use grayscale images as a substitute for color images since grayscale images are easier to control and manipulate (Johnson et al., 1991; Pelphrey et al., 2002; Dalton et al., 2005). However, grayscale images are also less naturalistic than color images and have been allowed to stand substitute.
because of the assumption that a lack of image color will not affect the strategies individuals use to process these visual stimuli. The results of the experiments outlined in this study contradict this assumption and suggest that presenting images in grayscale does affect gaze patterns in individuals with an autism-related phenotype. This finding suggests that future eye-tracking studies on autistic populations should be wary of using grayscale images as a substitute for color images.

ACKNOWLEDGEMENTS

NM is extremely grateful for her mentors, Elizabeth Johnson and Jeff Maclnnes, for their guidance and support. NM would also like to thank Jeff Maclnnes, Anuhita Basavaruju, Eduardo Salgado, Chris Yoo, and Peter Cangialosi for implementing the experimental task and analysis pipeline, as well as Lily Chaw, Elaine Cox, and Sophie Katz for their contributions to the data collection.

REFERENCES


ABOUT THE AUTHOR

Nidhila graduated with distinction from Duke University in 2019 with a B.S. in biology. During her undergraduate years she fostered her love of research and writing by serving as a publishing editor for Neurogenesis—an undergraduate neuroscience research journal. In 2017 she conducted research aimed at elucidating differences in facial processing in individuals with an autism-related phenotype. The results and implications of this study are detailed in her featured article. She currently attends the Duke University School of Medicine where she is active in Root Causes—an organization devoted to improving food security in Durham, especially in the wake of the COVID-19 pandemic.
Scientists at Temple Health Find Potential Cure for HIV

Tanvee Sinha

Affecting over 35 million people a year, the number of infected individuals continues to grow because there is currently no cure to eliminate HIV.

Two scientists at Temple Health have manipulated mouse genomes to display human immunity and the effect of two different treatments on the mice after HIV is injected into the rodents. They have found promising results in ridding the mouse cells of any traces of inducible HIV DNA, and are looking to further their research in hopes of soon using human subjects.

The Human Immunodeficiency Virus (HIV) is a sexually transmitted disease primarily spread by infected bodily fluids. This virus inhibits the body’s ability to fight infections by targeting helper T cells, immune cells responsible for coordinating the body’s response to disease. Once HIV deprives the immune system of these fighter T cells, they are not able to fight off infections and diseases that they normally would be able to without the virus. HIV fuses with the cell, converts its viral RNA to DNA, and replicating the DNA through reverse transcription. This duplicated DNA leaves itself in the host cells while the original copy leaves the host cell and moves to infect other cells.

Since HIV remains in an individual’s body for life, and can switch from being dormant to active, the number of infected individuals is constantly increasing. Those who have the dormant virus could potentially not even know they contracted HIV until much later.

While HIV may seem somewhat benign, the longer the HIV-infected individual goes without treatment, the risk of obtaining Acquired Immune Deficiency Syndrome (AIDS) significantly increases. Because of low T-cell counts caused by the disease, the immune system is unable to fight off infections that a healthy person could, leading to an increased risk of opportunistic infections. For an individual diagnosed with AIDS, they could have a lower T-cell count than the baseline and have one or more of these opportunistic infections. These infections are significantly harder to control due to the established weakness of the immune system and are so malignant, they often kill patients with AIDS. It is vital, therefore, that more drugs develop to stagnate HIV in its earlier stages, to decrease the number of AIDS-related deaths worldwide.

While there is currently no cure for HIV, there are a number of medicines that can help an individual stay healthy. These medicines prevent the spread of this virus to others, limit the amount of HIV in the blood, and dramatically stagnate the progression of the disease.

One of these medicines includes pre-exposure prophylaxis, also known as PrEP, for those who don’t currently have HIV but are at a significantly high risk of infection. PrEP is a pill (brand name Truvada) that is taken in combination with other medicines to help keep the virus from establishing itself for HIV prone individuals. If used properly, and combined with physician oversight, PrEP reduces the risk of contracting HIV by about 99 percent.

Regardless, it does not actively eliminate the virus from the body if the individual contracts HIV. Another defense against HIV includes Standard antiretroviral therapy (ART), a technique consisting of drugs to suppress the virus and stop the progression of the disease in the body once an individual already has already contracted the disease, while preventing its transmission to others. Despite this treatment suppressing the effects of the virus, it is unable to completely eliminate it from the body.

Researchers at Temple University, however, have been able to completely eliminate the replication-competent HIV-1 DNA from genomes of living animals. Dr. Kamel Khalili and Dr. Howard Gendelman, the two senior investigators on this study have successfully combined the use of CRISPR-Cas9 technology with Long Acting Slow Effective Release (LASER) antiretroviral therapy (ART) to eliminate HIV DNA from rat and mice cells.
HIV, with its deadly progression to AIDS has never seen any potential traces of a cure until this experiment where researchers completely eliminated HIV viral DNA in the genomes of living animals.

At first, the researchers tested the use of only the CRISPR-Cas9 technology, which is a gene editing technology that can excise large fragments of HIV DNA from infected cells. This disrupts viral gene expression but unfortunately, similar to ART, this novel gene editor is unable to eliminate HIV on its own. However, Gendelman and his partner Dr. Edagwa had developed LASER ART, a technique that Gendelman utilized in this research to rid HIV DNA from affected cells. This technique targets viral sanctuaries to maintain lower HIV replication levels for longer periods of time. LASER ART therapy is coupled with long-lasting medications which were packed into nanocrystals and distributed meticulously to tissues still infected with dormant HIV. These nanocrystals were stored in tissues for weeks, slowly releasing the drug. This combination of therapy and medication, however, was not enough in eliminating HIV either.

Gendelman and Edagwa questioned whether these two treatments could be used in parallel. Hopefully, combining the advantageous traits of each technology would create a synergistic relationship between them. They wanted to see whether LASER ART could potentially suppress the HIV DNA replication long enough for CRISPR-Cas9 technology to eliminate viral DNA from cells.

To test this theory, researchers infected special mice with HIV, genetically engineered in order to produce human T-cells that were susceptible to HIV. In order to affirm the relevance of this mouse model for studies of HIV-1 elimination from cells, the scientists accurately evaluated each of the human cell-virus model components to parallel in mice models, rather than solely injecting them with the immune cells and virus. Human immunocytes (body’s fighting mechanism) in the mouse blood, injected into mice from human cord blood, were confirmed through flow cytometry. Only after a few months were mouse models injected with the virus, and the spread of the virus was confirmed through staining cells.

Following the validation of mouse models itself, the mice were split into four different groups with six mice in each group. These groups consisted of the six mice in the Control Group (left untreated), six mice in the group injected with CRISPR-Cas9 units, ten mice in the group administered LASER ART and seven mice in the group receiving both treatments. After the treatments, the animals were observed to see whether they had any evidence of HIV in their systems.

All groups still had some evidence of HIV infection present, except for the last group, where two of the mice that received LASER ART with subsequent CRISPR-Cas9 had no signs of HIV in their cells. This analysis revealed that in about one-third of the HIV-infected mice, there was complete elimination of HIV. To validate this experiment, replicate experiments were performed on a different set of mice, who were all infected with a second type of HIV-1 strain, which confirmed the first experiment. This ground-breaking discovery, “confirmed the ability of LASER ART and CRISPR-Cas9 to eliminate viral rebound in a new cohort of CD34 + HSC-reconstituted animals infected with HIV-1ADA HIV.”

HIV, with its deadly progression to AIDS has never seen any potential traces of a cure until this experiment where researchers completely eliminated HIV viral DNA in the genomes of living animals. With this study in hand, scientists Dr. Khalili and Dr. Gendelman and their teams are ready to move to trials with non-human primates, and potentially clinical trials with humans within the year. While not 100 percent effective, the side effects were negligible in mice, and as we witness the progression of these two therapies, we could see a cure for HIV in humans after all.

REFERENCES

ABOUT THE JOURNALIST
Tanvee Sinha is an upcoming senior and is part of the University of Alabama at Birmingham’s Early Medical School Acceptance Program, with a dual degree in Neuroscience and Philosophy. During her time in college, she has been involved with a variety of things, from research and shadowing, to volunteering and club activities, to dancing and journaling. JYI allows her to explore her passion for science through research, interviews, and current news, and present it into a format appreciable to readers not necessarily in the science field. She is thankful for JYI and how it has helped her improve her technical writing skills, and collaborate effectively to spread the love for science to the world!
Understanding a Physicist’s Work to Explore the Stars and His Community: An Interview with Dr. Jorge Lopez from the University of Texas at El Paso

Andrew Lowrance

The work of a nuclear physicist requires continued dedication to unravel the secrets of the universe, and Dr. Jorge Lopez from the University of Texas at El Paso exemplifies these qualities, demonstrated through his reception of the Presidential Award for Excellence in Science, Mathematics and Engineering Mentoring. Lopez, an expert in the field of nuclear physics who specializes in the molecular composition of stars and the geometric formation of nucleons upon cooling, sees this award as a testament to his future work in advancing the field of physics, both in research and in the classroom.

Lopez’s path to such an award began with the exploration of physics in middle school.

“Growing up in Juarez, Mexico, I was advised by my teachers to explore mechanical engineering instead of physics as an academic career because of the afforded opportunities in the region,” said Lopez.

After moving to the U.S., however, Lopez attended the University of Texas at El Paso with a scholarship, earning a bachelor’s in physics. He then attended Texas A&M University where he received his doctorate.

Following his education, Lopez pursued various post-graduate opportunities, including conducting research at the Niels Bohr Institute in Copenhagen, the Lawrence Berkeley Lab, and the Texas A&M Cyclotron Institute. Lopez began to focus his time on publishing articles about the structure of the crust of neutron stars, gravity waves, and the radio telescope built at UTEP. Now, he is intent on studying the “nature of neutron stars,” which includes utilizing a machine learning program to compute Minkowski functionals.

“Minkowski functionals can be thought of as values that characterize the geometric formation of nucleons in neutron stars,” says Lopez.

As part of this study, Lopez is working with different faculty members and undergraduate students to collect data from stimulations that involve firing nucleons through an apparatus that measures three-dimensional positions, velocities, and particle charge. Data from these stimulations are then run through code that computes the values of the Minkowski functionals. These functionals are a series of numbers that provides characteristics for the “nuclear

“Studying physics is something that takes passion and dedication... A career that is so obscure prior to entering college that it requires a serious self-contemplation on behalf of the student before he or she declares their major.

Image courtesy of Dr. Jorge Lopez.
pasta” that is formed in neutron stars. A complex formation of nucleons that mimics the physical composition of actual pasta, the work on nuclear pasta ultimately serves as a study of the origin of clustering in the early universe, a path for understanding the beginning of the universe.

Beyond his research, Dr. Lopez’s work is also founded on his dedication to helping students understand their academic interests and decide what area of physics they should explore.

“Studying physics is something that takes passion and dedication,” says Lopez. “A career that is so obscure prior to entering college that it requires a serious self-contemplation on behalf of the student before he or she declares their major.”

Lopez uses this advice to help undergraduates decide what major they should choose, and whether physics is a pathway they’d like to pursue. Accordingly, Lopez strives to provide them with as much advice as possible early in their academic careers so that they have enough time to deliberate their true academic passions before declaring their major.

As both a researcher and a professor, Lopez also dedicates much of his time to addressing his students’ questions in his office.

“Really, any time that I am in my office is an office hour for them,” says Lopez.

A man dedicated to helping his students, Dr. Jorge Lopez doesn’t stray from helping those around him and making UTEP a more inviting environment through his provision of advice and his work to provide a diverse selection of courses for students to explore their interests.

“As a professor for 30 years, I’ve taught every course that’s in the catalog for the physics department at UTEP, from introductory physics to quantum mechanics... Ultimately, I’ve grown to see the physics department as something of a department that serves students, where I’ve invented courses for education majors, pre-med students, and engineering majors.”

These courses act as branches to other academic departments in order to enhance the overall academic life at UTEP.

Alongside his passion for mentoring, Dr. Lopez feels the greatest advice to give undergraduates is to remind them to be attentive to the truth behind a life in research.

“If you have a strong will and dedication to the understanding of life’s most widely-recognized mysteries, then you should go for it,” says Lopez.

ABOUT THE JOURNALIST

Andrew Lowrence is a rising junior studying Physics with a minor in Statistics at the University of Pennsylvania. As a Gates Scholar and Hispanic Scholarship Fund Leadership Scholar, he serves as a News and Careers Journalist for the Journal of Young Investigators, a Writing Committee member for the PennScience Journal for Undergraduate Research, and an Undergraduate Fellow with the Collegium Institute. He has studied the rheology of active fluids at the Penn Complex Fluids Laboratory and has aided in the research of the topological characteristics of neutron stars using a machine learning algorithm. He is pursuing a Data Analytics internship with FourFront, LLC this summer.
Acknowledgements

The Journal of Young Investigators would like to thank the following individuals for their contributions towards composing JYI’s Best of 2019...

Aalim Khaderi
Managing Editor

Amelia Powell
Editor In-Chief

Emily Letscher
Director of Publication

Matthew Hill
Graphic Artist

Executive Board

Amelia Powell Managing Editor, Editor In-Chief
Alexis Gkantiragas Chief Executive Officer, Chief Development Officer
Sheridon Ward Senior News & Careers Editor
Gavin Davis Chief Technical Officer
Divyam Goel Chief Financial Officer
Maggie Chen Chief Development Officer
Ushashi Basu Chief Communications Officer
Margaret Cho Chief Operations Officer
Jacquelyn Cobb Editor In-Chief
Peter Mikhael Chief Executive Officer
Nicholas Geringer Senior Research Editor
Jonathan Van Buskirk Senior Research Editor
Grace Niewijk Senior News & Careers Editor
Adam Sychla Chief Technical Officer
Jenna Burr Chief Technical Officer

Muhammad Hamza Waseem Chief Development Officer
Eesha Kodi Chief Operations Officer
Helena Woroniecka Chief Communications Officer

Board of Directors

Dr. Nafisa Jadavji, PhD Chair
Dr. Yun (Rose) Li, MD/PhD Vice Chair
Dr. Alexander Patananan, PhD Vice Chair
Dr. Courtney Peterson, PhD Fiscal Subcomittee
Dr. Tiffany-Rose Sikorski, PhD
Alaina Talboy, PhD
Dr. Sravisht (Chevy) Iyer, MD
Matthew Brousil, MS
Isaac Song
Jeff Chen
Gabe Dell

JYI would like to thank the College of Biological Sciences at University of Minnesota for their continuing support.

College of Biological Sciences
University of Minnesota

: www.facebook.com/jyijournal
: www.twitter.com/jyijournal
: www.linkedin.com/company/the-journal-of-young-investigators/
: www.instagram.com/jyi_org/
WE’RE RECRUITING

Communications Officer

Development Officer

Graphic Artists

Journalists

Copy Editors

and more!

go to jyi.org/join/ourteam for more information

Who Are We?
The Journal of Young Investigators is an independant, non-profit, peer-reviewed, online science journal run entirely by undergraduate students.

www.jyi.org | direct all inquiries to: sre@jyi.org
CALL FOR PAPERS

JYI accepts research manuscripts from undergraduates anywhere in the world!

- Physical Sciences & Mathematics
- Psychology & Social Sciences
- Engineering & Applied Sciences
- Biological & Medical Sciences

Who Are We?
The Journal of Young Investigators is an independent, non-profit, peer-reviewed, online science journal run entirely by undergraduate students.

www.jyi.org | direct all inquiries to: sre@jyi.org