

# CURJ

The Cornell Undergraduate  
Research Journal

Spring 2022  
Vol. 1, Issue 1

## DEEP LEARNING THE SEARCH FOR AN ALGORITHM THAT GOVERNS LEARNING IN THE BRAIN

### Rheumatoid Arthritis

How sex, gender,  
and environmental  
factors contribute  
to the likelihood of  
disease

### 2D microwave simulation

Creating and test-  
ing a new numerical  
method for model-  
ing wave behavior

### Spatial Distribution and Regional Agglomeration

Relating economic  
sociology to the study  
of venture capital and  
high tech regions







CORNELL UNDERGRADUATE RESEARCH JOURNAL

Volume I, Issue 1 | Spring 2022

Ithaca, NY 14850

Cornell Undergraduate Research Journal, an independent student organization located at Cornell University, produced, and is responsible for the content of, this publication. This publication was not reviewed or approved by, nor does it necessarily express or reflect the policies or opinions of, Cornell University or its designated representatives.

# Letter from the Editor

Dear Reader,

We are incredibly excited to present the inaugural issue of the Cornell Undergraduate Research Journal (CURJ), Cornell's student-run bi-annual research publication featuring the exemplary scholarly work of Cornell undergraduates across all disciplines and fields. In creating this journal, we provide a platform for Cornell undergraduate students to showcase their exceptional scholarly work to the student body and to the general public, and offer the student body a wide range of academic perspectives, provoking intellectual pursuits and collaboration.

I would like to thank tremendously our fantastic team for their incredible work. This past academic year, our team has been hard at work building up this publication from the ground up, which is no easy feat. Our team has risen to the occasion and has overcome the many challenges along the way to create this publication.

This issue comes during a time of turmoil, from the ongoing Covid pandemic to the war in Ukraine. Throughout all this, research is a constant that continuously contributes to the betterment of society, the advancement of knowledge, and the improvement of lives. We are honored and proud to support and showcase the outstanding contributions of Cornell undergraduates to the world of research.

We received many excellent submissions spanning fields within STEM, humanities, and the social sciences. The selected submissions, presented here, have undergone an extensive review process by our editorial board, graduate student reviewers, and professors. We would like to thank immensely our authors, reviewers, and faculty advisors for their thoughtful contributions that greatly enriched this publication.

We would also like to express much gratitude to Ellen Hartman, Research Communications Director of Cornell Research, our organization's advisor, without whom this effort would not have been possible. Additionally, we would like to thank Gail Steinhart of the Cornell University Library for the library hosting and her advice and support.

We are thrilled to share with you this inaugural issue of CURJ and to present the outstanding research of Cornell undergraduates.

Sincerely,

A handwritten signature in black ink that reads "Victoria Alkin". The script is fluid and cursive, with the first letter of each name being capitalized and prominent.

Victoria Alkin  
Founder and Editor-In-Chief



CORNELL UNDERGRADUATE RESEARCH JOURNAL

## EXECUTIVE BOARD

### Founder and Editor-in-Chief

Victoria Alkin

### Managing Editor of Content

Emily Pollack

### Graduate Coordinator

Melia Matthews

### Managing Editor of Production

Sasha Boguraev

### Secretary

Shiveen Kumar

### Recruitment Chair

Siddhi Balamurali

### Editorial Team

Adithya Prabakaran

Ashira Weinreich

Chris Cizmeciyan

Cici Zhou

Connor Rosenthal

James Jabara

Josh De Leeuw

Megan Zhang

Siddhi Balamurali

Yakov Perlov

### Graphic Design Team

Joanna Moon

Lexie Shi

Minji Kim

Sage Rebello

### Outreach Team

Ann Yeung

Peter Minneci

### Finance Team

Jonas Jacobson

Rose Peruso

Theodore Collins

### Operations Team

Timothy Johnson

Yash Kumar

## ADVISORS

### Faculty Advisors

Dr. Joseph R. Fetcho, Dr. Jim Alexander, Dr. Timothy R. Riley, Dr. Daniel T. Lichter

### Cornell Library Advisor

Gail Steinhart

### Organization Advisor

Ellen Hartman, Research Communications Director

## GRADUATE STUDENT REVIEWERS

Karina Beras

Bren Castañeda

Justin Cha

Philippa Chun

Lili Dodderidge

Nan Feng

Ivy Gilbert

Li Guan

Kathryn Harlan-Gran

James Hart

Megan Keller

Kapil Khanal

Sam Lagasse

Hyo Joo Lee

Rebecca McCabe

Erica Secor

Leah Simon

Shayne Wierbowski

Xuwen Yan

# CONTENTS

- 04 The Considerations of Biological Plausibility in Deep Learning
- 13 State of Hate in Greater Buffalo: A Community Perspective
- 23 Sex and Gender in Rheumatoid Arthritis: Considering a Risk Factor Hierarchy
- 30 Spatial Distributions and Regional Agglomeration of High-Tech Regions and Venture Capital
- 36 Employment-Related Depression and Analyses of Potential Treatment
- 44 Closer to Cayuga's Waters: An Evaluation System of the Invasive *Hydrilla* Species
- 55 A Content Analysis on Fitspiration and Thinspiration Posts on TikTok
- 63 The Male Fertilization Fantasy: Gendered Language in Biology Textbooks
- 74 2D Microwave Simulation Using Finite Differences

# The Considerations of Biological Plausibility in Deep Learning

---

By James Campbell

*Department of Physics, College of Arts and Sciences at Cornell University*

## Abstract

---

In this literature review, we examine several deep learning algorithms in the context of biological plausibility and, in turn, argue that a backprop-like algorithm is the most likely candidate for how learning operates in the brain. Although there are numerous difficulties in how the backpropagation algorithm might be implemented in neural circuitry, we note that slight variations of the algorithm have been found to circumvent biological constraints and that seemingly unrelated algorithms can often be theoretically related to it. In particular, we examine the literature behind feedback alignment, target propagation, and equilibrium propagation, after giving some general background on learning in biology, AI, and their intersection. Ultimately, we acknowledge that there is no true consensus as to which learning algorithm the brain actually uses, but suspect that the answer is backprop-like in nature.

## Introduction

With the recent successes of deep learning algorithms, it has become a topic of interest to see whether such algorithms (or variations of them) could potentially be the same as those used by biological systems. This has led to the question of biological plausibility, which measures the extent to which a learning algorithm could hypothetically be realized in the brain's hardware (Illing, 2019).

It is widely known that deep neural networks, consisting of layers of neurons and synaptic connections, are loosely based on the structure and function of the brain. Nevertheless, backpropagation, the central algorithm used to train deep neural networks, is considered by many to be incompatible with leading theories in neuroscience (Lillicrap et al., 2020).

In the following section, we provide some

background on learning in the brain and in artificial neural networks. We then examine the implementational constraints imposed by neural hardware and why the backpropagation algorithm violates them. In response to these constraints, several learning algorithms, such as feedback alignment, target propagation, and equilibrium propagation, have been devised, each of which attempts to overcome some of the difficulties encountered by backprop. The majority of this review consists of an analysis of these methods, including their successes and failures. Some of these successes are rather surprising and suggest that backprop-like algorithms are not as infeasible for the brain as previously thought. It is for this reason that we contend that the true function of the brain is likely similar in nature to backpropagation.

## Background

### Learning in Brains: Synaptic Plasticity

Today, it is widely believed that learning in

the brain happens at the synapses between neurons. This idea was first supported in experiments by Bliss and Lomo (1973) where they demonstrated that rapid stimulation of pre-synaptic neurons can lead to long-term changes in the activity of post-synaptic neurons. However, while they presented a mechanism (long-term potentiation) for learning via synapses, the exact details of synaptic plasticity remain largely elusive today. Part of the reason for this is the sheer complexity of biochemical processes present at any synapse; it is well known that synaptic behavior can depend on countless properties of neurons' vesicles, ion concentrations, receptors, proteins, and other structures.

Another prominent, though not necessarily contradictory, theory of learning is that of Hebbian learning. Propounded by Donald Hebb (1949), the general principle is that neurons that spike together most frequently will result in stronger synaptic connections. Since its origin, this notion has matured into what is now known as spike-timing-dependent plasticity (STDP), which is supported by a body of work better detailing the relationship between synaptic strength and the relative timing of pre- and post-synaptic neuron firings (Markram et al., 2011). Though it has come to inspire some neural network models (with limited success), STDP seems more likely to be an emergent phenomenon than a fundamental learning rule (Shouval et al., 2010).

Though synaptic plasticity represents the neuroscientific consensus with respect to learning in the brain, it is worth noting that there is some work challenging this idea or at least suggesting that it is incomplete. For instance, animals are able to perform one-shot learning over time periods much longer than those dictated by STDP (Gallistel and Balsam, 2014) and researchers were able to induce long-term learning through epigenetic means (Bedecarrats et al., 2018). For

the purposes of this review, however, the main takeaway from this section is that it is largely sufficient to think of the brain as a network of neurons that learn via synaptic changes and that this theory is well supported in the neuroscience literature from both old and recent experiments alike (Bliss and Lomo, 1973; Nabavi et al., 2014).

## Learning in Artificial Neural Networks: The Backpropagation Algorithm

Whereas our knowledge of learning in the brain remains amorphous, there is one learning procedure that is ubiquitous in deep learning today: the backpropagation algorithm. Despite having traces in the early twentieth century, backpropagation first gained prominence in artificial intelligence when it was discussed in a paper by Rumelhart and Hinton (1986) as a means of training multi-layer perceptrons. The algorithm relies on the notion of automatic differentiation, in which the chain rule of calculus is used to differentiate along a computation graph (Millidge et al., 2020). Used in conjunction with iterative optimizers such as gradient descent, backprop gives a closed-form expression for the gradient of the loss function with respect to every weight in the network in terms of other weights and activations. In other words, gradient descent states that

$$\Delta W_{ij}^l = -\alpha \frac{\partial L}{\partial W_{ij}^l} \quad (1)$$

and backpropagation uses the chain rule to obtain a recursive definition for the derivative,

$$\frac{\partial L}{\partial W_{ij}^l} = a_j^{l-1} \delta_i^l \quad (2)$$

$$\delta^l = (W^{l+1})^T \delta^{l+1} \odot \sigma'(z) \quad (3)$$

Here there are 'k' training examples and 'l' layers, and 'z' is simply the matrix-vector multiplication of each layer's activations with its weight matrix. Moreover, the dotted circles represent element-wise multiplication and L is the loss function. Of particular importance for biological



plausibility is the delta term in the last layer of the network:

$$\delta^{last} = \nabla_a L \odot \sigma'(z^{last})_{(4)}$$

This is because it illustrates that the delta terms in fact correspond to error signals, where “error” is interpreted as the gradient of the loss function. In the case of a squared loss, for example, this quantity is the difference between the model’s prediction and the labeled target (Lillicrap et al., 2020). That is to say, backpropagation relays information about how different a model’s perception of the world is from reality.

## Backpropagation’s Biological Incompatibility

While backpropagation has been extraordinarily successful in deep learning, there are several reasons why it is considered biologically implausible.

One major reason is that it is hard to come up with neural circuits that can implement the feedback computations specified by backpropagation. As can be seen in equation (4), backprop says that feedback error signals must be multiplied by the transpose of their layers’ weight matrix. Because feedback connections in the brain can either be implemented by sending error signals back along the original network or by allocating a separate feedback network, the requirement that error signals be multiplied by the transpose matrix gives rise to the weight symmetry and weight transport problems, respectively. Specifically, if error is propagated back along the feedforward network, then in order to implement backprop, the brain would have to enforce a synaptic weight matrix that is equal

to its transpose, which is to say symmetric (Bengio et al., 2016; Lillicrap et al., 2016; Lillicrap et al., 2020; Whittington & Bogacz, 2019). On the other hand, if the brain were to use separate feedback networks, then the weight transport problem addresses how the feedback synapses could possibly gain access to the strengths of the feedforward synapses (because unlike in a computer, the brain can’t just copy the weights to some memory address) (Grossberg, 1987).

Beyond the use of the transposed weight matrix, Bengio et al. (2016) note (as can be seen in equation (4)) that backpropagation also requires multiplication by the derivative of the activation function and that implementing this computation biologically is non-trivial. More generally, activation functions represent another source of biological constraint: neurons in the brain are known to fire discretely whereas the backpropagation algorithm, which contains derivative terms, benefits from continuous functions (Bengio et al., 2016; Whittington & Bogacz, 2019). Indeed, the very fact that backpropagation communicates error signals with floating-point precision casts major doubt on its biological plausibility (Neftci et al., 2017).

Another contention is that backpropagation learning contains two temporally alternating phases: one for the forward pass and another for the backward pass (Neftci et al., 2017). Moreover, whereas the forward pass performs nonlinear calculations, the equations of backpropagation are linear. This disparity would likely require distinct biological mechanisms that are unlikely to be found in the brain (Bengio et al., 2016). In addition, in deep learning, performing the backwards pass doesn’t influence the feedforward activations, though this does not seem to be the case in the brain (Lillicrap et al., 2020). Even more basic is the question of how the brain’s



neural networks could obtain targets or labels in order to compute the original error signal in the final layer.

Overall, many of the above restrictions stem from the simple principle of locality: that neurons in the brain can only interact with neighboring neurons (Whittington & Bogacz, 2019). As we will see, finding algorithms that can learn while maintaining the physical proximity of interacting components can go a long way towards obtaining biological plausibility.

## Feedback Alignment

The method of feedback alignment offers to resolve many of the difficulties encountered in trying to implement backpropagation in the brain. The breakthrough paper for feedback alignment came in 2016 by Lillcrap et al. (2016). The main idea is that one can avoid the weight symmetry and weight transport problems by using a completely separate and unrelated weight matrix for feedback. In other words, the authors attempt to perform backpropagation but replace the transposed feedforward matrix with a random one. For the  $l$ th layer, call the random matrix  $B_l$ . Then equation (4) is transformed to

$$\delta^l = B^l \delta^{l+1} \odot \sigma'(z)_{(5)}$$

In addition to feedback alignment, another method, termed direct feedback alignment was introduced by Arild Nøkland (2016). In this variation, the final error gets used as the one and only error signal for each layer. In other words, direct feedback alignment, in making yet another tweak to the equations for backpropagation, is able to remove the need to propagate error back through multiple layers of the network in the first place.

Direct feedback alignment is described by

$$\delta^l = B^l \nabla_a L \odot \sigma'(z^l)_{(6)}$$

It is of note that both direct and indirect feedback alignment seem downright counter-intuitive. Indeed, the authors themselves acknowledge that their results are surprising. Why, one may wonder, should using a random matrix result in a performance that rivals the precisely computed gradients of traditional backprop? In short, as the authors prove, even though a random matrix is not the same as the feedforward transposed matrix, it can still become aligned with it.

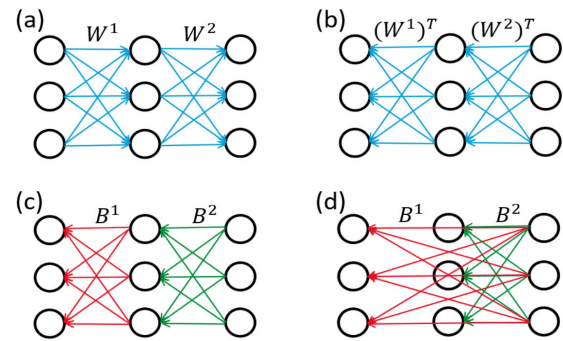


Figure 1: Diagram (a) depicts a feedforward neural network with the blue arrows representing the standard matrix-vector multiplication. Diagram (b) portrays the backpropagation algorithm where error signals are sent back through the network. The arrows are blue to represent the fact that backpropagation makes use of the transpose of the feedforward weights. Diagram (c) displays feedback alignment. As can be seen, the 'B' matrices have no relation to the feedforward weights, but error signals are still propagated back through the network. Diagram (d) shows direct feedback alignment. Here the error found in the output layer is combined with random matrices to compute the weight updates for all prior layers.

One may also wonder what the purpose of direct feedback alignment is considering the relative success of indirect feedback align-

ment. Arild Nøkland, the author of the direct feedback alignment paper, provides two reasons. The first is that while feedback alignment demonstrated high performance on a variety of complex tasks, its success plummeted as it was applied to deeper networks. Direct feedback alignment, by contrast, does much better, even when used in networks as large as 100 layers.

The second advantage of direct feedback alignment is that it does not require error signals to be propagated through many layers. Accordingly, it can be implemented via local interactions, which alleviates many biological constraints. In fact, direct feedback alignment has an incredible degree of flexibility; as Nøkland notes, under direct feedback alignment, a neuron can receive its error signal from a post-synaptic neuron, from a reciprocally connected neuron, from a pre-synaptic neuron, or from any location further upstream in the informational pathway.

In this sense, in spite of the fact that the specifics of the brain's error propagation mechanism remain unknown, a range of possible alternatives are all compatible with direct feedback alignment. Still, as Nøkland remarks, this is far from saying that direct feedback alignment is the exact learning algorithm employed by the brain; there is a lot that simply remains unknown, though direct feedback alignment is a step in the right direction.

## Target Propagation

Pioneered by Yoshua Bengio (2014) and Yann LeCun (1986), target propagation is a method that uses auto-encoders to facilitate local feedback connections. Auto-encoders are unsupervised models that seek to predict their own input and will often have a hidden layer of reduced dimension. In target propagation, auto-encoders are stacked atop one

another in parallel to the main network. In short, if an auto-encoder can be trained to act like an inverse function, then the labeled targets can be propagated back through the auto-encoders, forming “hidden” targets to be compared to the hidden activations. By taking the difference between these “hidden” targets and their corresponding activations, one arrives at a local form of error that can be used to direct learning in the network (Lillicrap et al., 2020).

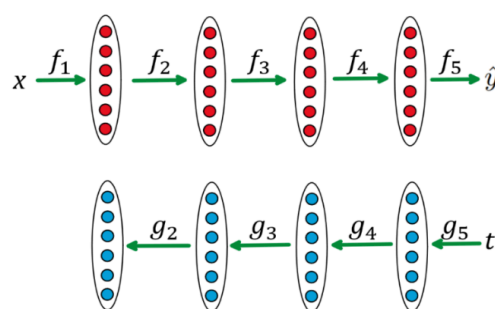


Figure 2: Target propagation utilizes auto-encoders to generate feedback that doesn't involve any gradient computations. It does this by propagating the labeled targets back through a series of operations that approximately invert the forward operations of the network. In this sense, a specialized target (in blue) is created for each hidden activation (in red), the effect of which is a feedback mechanism that is local in nature. For each layer in Figure 2, the error is given by the difference between the activations (in red) and the “hidden” targets (in blue). This error value can be used to nudge a given layer's synapses in a way that facilitates learning. Unlike a gradient, subtraction is a computation that can be more easily implemented biologically.

For some time, the main problem with target propagation was the inability to obtain auto-encoders that act as perfect inverses without resorting to backpropagation. This, however, was solved by difference target propagation (Lee et al., 2015), which is a simple linear correction to target propagation that is achieved by turning the network itself into a stack of autoencoders. For a

more in-depth explanation of difference target propagation, we direct our readers to Lillicrap et al. (2020).

As it turns out, difference target propagation performs decently on a variety of tasks and in many cases approaches the results of backpropagation (Lee et al., 2015). It therefore makes a formidable case for a biologically plausible learning algorithm. In terms of how it could be implemented by the brain, there are two main options; one would be to allocate a separate feedback network, in which the auto-encoders live. Again, this is a questionable hypothesis within neuroscience (Stork, 1989).

Another possibility is that all the various targets, activations, and reconstructions for a node dwell within a single neuron. This idea derives from recent research that neurons possess numerous spatial compartments that can perform far more nuanced calculations than the simplified model of the point-particle neuron would suggest (Körding & König, 2001; Urbanczik & Senn, 2014; Naud & Sprekeler, 2018). Ultimately, though, even if it cannot be implemented in neural circuitry, difference target propagation demonstrates how relatively mild architectural modifications can make backprop-like algorithms comply with many more biological constraints than originally thought.

## Equilibrium Propagation

Another prominent biologically plausible algorithm is equilibrium propagation. It was introduced by Scellier and Bengio (2017) and uses an energy function to train a Hopfield model. More specifically, they define an “energy function”  $E$ , a “cost function”  $C$ , and a “total energy function”  $F$  as follows

$$E(u) := \frac{1}{2} \sum_i u_i^2 - \frac{1}{2} \sum_{i,j} W_{ij} p(u_i) p(u_j) - \sum_i b_i p(u_i) \quad (7)$$

$$C := \frac{1}{2} (y^* - t)^2 \quad (8)$$

$$F := E + \beta C \quad (9)$$

By varying the “clamping factor,”  $\beta$ , one is able to influence the effect that the cost function has on the system. In fact, equilibrium propagation occurs in two phases. In the “free phase,”  $\beta=0$  and the system is allowed to establish equilibrium. In the second, “weakly clamped phase,”  $\beta>0$  and the system is again allowed to settle to equilibrium. Because the potential energy will exert a force on the state of the system, the weights within the network will be nudged in a meaningful direction and moreover, in a local manner. In this way, learning is able to take place, even as equilibrium propagation offers an entirely new framework for thinking about the system.

The dynamical systems framework also results in behavior that deeply resembles that of spike-timing-dependent plasticity. At this point, one would think that equilibrium propagation is largely unrelated to backpropagation; interestingly, however, it can be shown that equilibrium propagation approximates the gradients computed in backpropagation-through-time. Unlike backprop, though, equilibrium propagation only requires one type of computation and one neural circuit.

But while it may check many of the boxes of biological plausibility, equilibrium propagation still requires two phases, which alternate temporally. As for performance, the original equilibrium propagation algorithm presented by Scellier and Bengio was not all that impressive, although recent work has added slight modifications that enable more competitive accuracy (Laborieux et al., 2021).

## Conclusions

Having reviewed three major attempts at enforcing biologically plausibility



in deep learning, we now take a moment to reflect on some general trends.

For one, it is astonishing how relatively minor tweaks to existing algorithms have resulted in major progress toward biological plausibility: going from feedback alignment to direct feedback alignment enabled local connectivity and dramatically improved performance in deeper networks; going from target propagation to difference target propagation allowed for the natural approximation of inverse functions; modifying the architecture marginally in equilibrium propagation resulted in major performance boosts (Laborieux et al., 2021).

It is moreover curious just how rudimentary many of these tweaks were at heart. Feedback alignment simply fixed a variable in the equations for backprop; direct feedback alignment merely fixed a different quantity. The central insight of target propagation was to substitute gradient computations for auto-encoders; difference target propagation simply added more auto-encoders in different places. Equilibrium propagation, while a less trivial modification to backprop, was itself enhanced tremendously by a comparably trivial design alteration. All this is in spite of the fact that many of these adjustments addressed problems that were previously considered to be unyielding.

In this sense, we suspect that the learning algorithm actually employed by the brain is indeed rather similar to backpropagation. It is, after all, the starting point of many of the other algorithms. Additionally, even for algorithms that initially seem unrelated to backprop, such as equilibrium propagation, it is almost always the case that they can be related mathematically to it (Lillicrap et al., 2020). Furthermore, backprop is universally accepted as the algorithm with the best performance, and one would imagine that natural selection would favor such efficacy in humans.

It is worth acknowledging that, in spite of these suspicions, the brain's true learning algorithm remains utterly unknown (Stork, 1989). Nevertheless, after considering a sizable number of algorithms, we can say that the general idea behind backprop, which is that computed error signals inform the update of synaptic strengths, is almost certainly the basic mechanism that allows the brain to learn. One can only wonder, then, what other tweaks to the backpropagation algorithm might exist out there; perhaps at the core of human cognition lays something surprisingly simple.

## References

- Bedecarrats, A., Chen, S., Pearce, K., Cai, D., & Glanzman, D.L. (2018). RNA from Trained *Aplysia* Can Induce an Epigenetic Engram for Long-Term Sensitization in Untrained *Aplysia*. *eNeuro*, 5(3). <https://doi.org/10.1523/ENEURO>
- Bengio, Y. (2014). How auto-encoders could provide credit assignment in deep networks via target propagation. ArXiv preprint. <https://arxiv.org/abs/1407.7906>
- Bengio, Y., Lee, D., Bornschein, J., Mesnard, T., & Lin, Z. (2016). Towards Biologically Plausible Deep Learning. ArXiv preprint. <https://arxiv.org/abs/1502.04156v3>
- Bliss, T.V. & Lomo, T. (1973). Long-lasting potentiation of synaptic transmission in the dentate area of the anaesthetized rabbit following stimulation of the perforant path. *The Journal of Physiology*, 232(2), 331-356. <https://doi.org/10.1113/jphysiol.1973.sp010273>
- Gallistel, C.R., & Balsam, P.D. (2014). Time to rethink the neural mechanisms of learning and memory. *Neurobiology of*

Learning and Memory, 108(1), 136-144.  
<https://doi.org/10.1016/j.nlm.2013.11.019>

Grossberg, S. (1987). Competitive learning: from interactive activation to adaptive resonance. *Cognitive Science*, 11(1), 23-63. <https://doi.org/10.1111/j.1551-6708.1987.tb00862.x>

Hebb, D. (1949). *The Organization of Behavior: A Neuropsychological Theory*. Psychology Press.

Illing, B., Gerstner, W., & Brea, J. (2019). Biologically plausible deep learning—But how far can we go with shallow networks? *Neural Networks*, 118(1), 90-101. <https://doi.org/10.1016/j.neunet.2019.06.001>

Körding, K., & König, P. (2001). Supervised and unsupervised learning with two sites of synaptic integration. *Journal of Computational Neuroscience*, 11(1), 207-215. <https://doi.org/10.1023/A:1013776130161>

Laborieux, A., Ernoult, M., Scellier, B., Bengio, Y., Grollier, J., & Querlioz, Q. (2021). Scaling Equilibrium Propagation to Deep ConvNets by Drastically Reducing Its Gradient Estimator Bias. *Frontiers in Neuroscience*, 15(1), 129-130. <https://doi.org/10.3389/fnins.2021.633674>

LeCun, Y. Learning processes in an asymmetric threshold network. (1986). *Disordered Systems and Biological Organization*, 1(1), 233-240.

Lee, D.H., Zhang, S., Fischer, A., & Bengio, Y. (2015). Difference Target Propagation. *Joint European Conference on Machine Learning and Knowledge Discovery in Databases*, 498-515. [http://dx.doi.org/10.1007/978-3-319-23528-8\\_31](http://dx.doi.org/10.1007/978-3-319-23528-8_31)

Lillicrap, T.P., Cownden, D., Tweed, D.B., & Akerman, C.J. (2016). Random synaptic feedback weights support error back-propagation for deep learning. *Nature Communications*, 7(1), 13276. <https://doi.org/10.1038/ncomms13276>

Lillicrap, T.P., Santoro, A., Marris, L., Akerman, C.J., & Hinton, G. (2020). Backpropagation and the brain. *Nature Reviews Neuroscience*, 21(1), 335-346. <https://doi.org/10.1038/s41583-020-0277-3>

Markram, H., Gerstner, W., & Sjöström, P.J. (2011). A history of spike-timing-dependent plasticity. *Frontiers in Synaptic Neuroscience*, 3(1). <https://doi.org/10.3389/fn-syn.2011.00004>

Millidge, B., Tschantz, A., & Buckley, C.L. (2020). Predictive coding approximates backprop along arbitrary computation graphs. *ArXiv preprint*. <https://arxiv.org/abs/2006.04182v5>

Nabavi, S., Fox, R., Proulx, C.D., Lin, J.Y., Tsien, R.Y., & Malinow, R. (2014). Engineering a memory with LTD and LTP. *Nature*, 511(1), 348-352. <https://doi.org/10.1038/nature13294>

Naud, R. & Sprekeler, H. (2018). Sparse bursts optimize information transmission in a multiplexed neural code. *Proceedings of the National Academy of Sciences*, 115(27), 6329-6338. <https://doi.org/10.1073/pnas.1720995115>

Neftci, E.O., Augustine, C., Paul, S., & Detorakis, G. (2017). Event-Driven Random Back-Propagation: Enabling Neuromorphic Deep Learning Machines. *Frontiers in Neuroscience*, 11(1). <https://doi.org/10.3389/fnins.2017.00324>

Nøkland, A. (2016). Direct feedback alignment provides learning in deep neural networks. *Advances in Neural Information Processing Systems*, 29(1), 1037–1045. <https://proceedings.neurips.cc/paper/2016/file/d490d7b4576290fa60eb31b5fc917ad1-Paper.pdf>

Rumelhart, D., Hinton, G., & Williams, R. (1986). Learning representations by back-propagating errors. *Nature*, 323(1), 533–536. <https://doi.org/10.1038/323533a0>  
Scellier, B., & Bengio, Y. (2017). Equilibrium propagation: Bridging the gap between energy-based models and backpropagation. *Frontiers in Computational Neuroscience*, 11(1), 24–37. <https://doi.org/10.3389/fncom.2017.00024>

Shouval, H.Z., Wang, S., & Wittenberg, G.M. (2010). Spike timing dependent plasticity: a consequence of more fundamental learning rules. *Frontiers in Computational Neuroscience*, 4(1). <https://doi.org/10.3389/fncom.2010.00019>

Stork, D. (1989). Is backpropagation biologically plausible? *International Joint Conference on Neural Networks*, 2(1), 241–246. <https://doi.org/10.1109/IJCNN.1989.118705>

Urbanczik, R. & Senn, W. (2014). Learning by the dendritic prediction of somatic spiking. *Neuron*, 81(3), 521–528. <https://doi.org/10.1016/j.neuron.2013.11.030>

Whittington, J., & Bogacz, R. (2019). Theories of Error Back-Propagation in the Brain. *Trends in Cognitive Science*, 23(3), 235–250. <https://doi.org/10.1016/j.tics.2018.12.005>



# State of Hate in Greater Buffalo: A Community Perspective

By Raquel Zohar  
*The Industrial and Labor Relations School*

---

## Abstract

In a time of increased hate, understanding hate in the immediate world that surrounds us has become essential to engaging with greater society. This report discusses hate and inter-community relations in the Buffalo-Niagara region of Western New York, one of the most segregated metros in the nation and the second most densely populated area in New York State. Data from the New York State Division of Criminal Justice Services (DCJS), Federal Bureau of Investigation (FBI) Uniform Crime Reporting (UCR) Program, and Anti-Defamation League (ADL) indicate that hate and hate crimes, specifically antisemitic hate crimes, maintain a pervasive presence in Buffalo-Niagara. To address antisemitism, Buffalo-Niagara's Jewish community has successfully come together with the help of community organizations. Their model of addressing hate can be applied more generally across the region. Interviews with 18 community members and leaders were conducted to gather insights into intra-community realities and inter-community relations of living in Buffalo-Niagara. These insights reflect lacking measures for anti-hate action within communities and, in many cases, non-existent relationships between communities. This report thus seeks to serve as a resource for community members to identify allies across Buffalo-Niagara that seek to develop inter-community relationships and address hate in all its forms. Knowledge of reporting mechanisms and organizations across Buffalo-Niagara will enable the region's communities to find allyship among one another, promote mutual respect, facilitate cultural understanding, and unearth common ground that will undercut and contribute to driving out hate. Lists and maps of these organizations have been generated and included below using information collected through interviews as well as online listings. The report closes with final takeaways to keep in mind moving forward.

---

## Background on Buffalo-Niagara

Buffalo is the second largest city in New York State (NYS) after New York City. The city is located in Erie County and is surrounded by suburbs in both Erie and Niagara Counties. While many people live outside Buffalo city limits, they consider themselves Buffalonians. To be inclusive, this report will focus on the Buffalo-Niagara Falls Metropolitan Statistical Area which encompasses both Erie and Niagara Counties. For the purposes of this report, Erie and Niagara Counties will hereafter be referred to as Buffalo-Niagara and/or Greater Buffalo.

According to Partnership for the Public Good (PPG), Buffalo-Niagara is one of the most racially and economically segregated metros in the nation (Blatto, 2018). Decades of federal, state, and local policies that were either plainly discriminatory or more subtly undercut equity have made Buffalo the city it is today,

the sixth most segregated metro in the nation on the white-Black index (Census Scope, 2012). According to the 2013 Greater Buffalo Jewish Community Study, it is estimated that approximately 97% of Western New York's Jewish households are located in Erie County and of them, approximately fifty-seven percent reside in Williamsville, Amherst, and Tonawanda (Boxer et al. 2013). These three areas directly neighbor each other and as such, these statistics indicate that Buffalo-Niagara's Jewish population is concentrated in the suburbs of the City of Buffalo. The Jewish community, like the rest of the Buffalo-Niagara's communities, is geographically separate and thus disconnected from neighboring communities. Across Buffalo-Niagara, neighborhood lines are rigid and segregation, inequity, food insecurity, job insecurity, and educational inequality run rampant.

Criminologists argue that hate-motivated crimes generally ensue from segregation, discrimination, and the marginalization of people who have historically been

viewed as different. Criminologist Barbara Perry asserts that individuals who reflect society's dominant identity traits and physical attributes more easily amass social and political power. These power dynamics paired with existing segregation create rifts between different racial, cultural, religious, and ethnic groups (Perry, 2001). The more divides have deepened over time, the more lacking inter-community relationships have become. Our ability to empathize with others is a function of our proximity, and because people of different communities live, learn, and exist apart from one another, they understand each other less. Ultimately, less empathy has resulted in more hate and less progress.

In this era of heightened hate and louder calls for equality, it is imperative that we understand hate in the immediate world that surrounds us, engage with our neighbors to generate empathy, and join in concerted efforts to create common good and improve our shared society.

## Hate in Buffalo-Niagara

### Understanding How Hate Crimes Differ from Bias or Hate Incidents

At the federal level, the United States Department of Justice defines a hate crime as a crime motivated by bias against race, color, religion, national origin, sexual orientation, gender, gender identity, or disability (United States Department of Justice, 2021). As defined by Article 485 of New York State Penal Law, *a person commits a hate crime when they commit a specified offense and either:*

*Intentionally selects the person against whom the offense is committed or intended to be committed in whole or in substantial part because of a belief or perception regarding the race, color, national origin, ancestry, gender, gender identity or expression, religion, religious practice, age, disability or sexual orientation of a person, regardless of whether the belief or perception is correct, or*

*Intentionally commits the act or acts constituting the offense in whole or in substantial part because of a belief or perception regarding the race, color, national origin, ancestry, gender, gender identity*

*or expression, religion, religious practice, age, disability or sexual orientation of a person, regardless of whether the belief or perception is correct* (New York State Senate, 2020).

New York State does not provide a legal definition of a bias or hate incident. Deferring to the federal definition, hate incidents are *acts of prejudice that are not crimes and do not involve violence, threats, or property damage*. In short, hate crimes are different from bias or hate incidents in that the actions and expressions involved in a hate crime constitute criminal activity whereas actions and expressions in an incident do not break any law. There is no statutory mandate to report hate incidents, and federal and state law enforcement agencies solely publish statistical reports on hate crimes, not hate incidents. In the last year, hate crime bills have been worked on at both the federal and state levels. In May 2021, President Biden signed the COVID-19 Hate Crimes Act which aims to increase public outreach and ensure bias-reporting resources exist in multiple languages to make hate crime reporting accessible (Hirono, 2021). The New York State Senate is also working to pass Senate Bill S70A, which relates to “enacting the hate crimes analysis and review act” (New York State Senate, 2021). The Hate Crimes Analysis and Review Act will ensure that the State will collect and report data on the sexual orientation, gender identity, and racial or ethnic identity of victims and alleged perpetrators to better understand LGBTQIA+ experiences in NYS. Similar to how both bills focus on hate crimes and not hate incidents, data included in this report solely covers hate crimes, not hate incidents.

### What does Hate Crime Frequency in Buffalo-Niagara look like?

Hate crime frequency data for Buffalo-Niagara has been analyzed, compiled, recorded, and reported by the New York State Division of Criminal Justice Services (DCJS) and the FBI's Uniform Crime Reporting (UCR) Program. The Uniform Crime Reporting (UCR) Program generates reliable statistics for use in law enforcement and includes data from more than 18,000 city, university and college, county, state, tribal, and federal law enforcement agencies. Agencies participate voluntarily and may submit their crime data either through a state UCR program or directly to the FBI's UCR Program (FBI, 2018). In New York State, the DCJS is authorized by statute to serve as the central repository of crime and

arrest information. DCJS oversees the UCR Program for the State and reports crime data to the FBI. New York State law enforcement agencies submit monthly crime reports to DCJS which are reviewed for completeness and accuracy before being added to the statewide database and submitted to the FBI (NYS Division of Criminal Justice Services).

DCJS reports for Erie and Niagara Counties respectively specified the type of bias involved in reported hate crimes. The data for Erie and Niagara counties for 2016 through 2019 are as follows:

### *DCJS Data by County*

Table 1. *DCJS Hate Crime Data for Erie County, 2016 through 2019*

Year	Anti-Black	Anti-White	Anti-Asian	Anti-Arab	Anti-Jewish	Anti-Gay Female	Anti-Gay Male	Anti-Trans-gender	Anti-Multi Racial Groups
2016	8	2	1	0	4	0	2	3	0
2017	4	2	0	0	0	1	2	0	1
2018	10	1	0	0	0	0	0	1	0
2019	5	1	0	1	1	0	0	0	0

Table 2. *DCJS Hate Crime Data for Niagara County, 2016 through 2019*

Year	Anti-Black	Anti-White	Anti-Asian	Anti-Arab	Anti-Jewish	Anti-Gay Female	Anti-Gay Male	Anti-Trans-gender	Anti-Multi Racial Groups
2016	2	0	0	0	0	1	1	0	0
2017	1	1	0	1	0	0	0	0	0
2018	1	0	0	0	0	0	0	0	0
2019	0	0	1	0	0	0	0	0	0

Data included in these figures was reported by the NYS DCJS to the FBI's Uniform Crime Reporting (UCR) Program (New York Division of Criminal Justice Services, 2021).

These data sets are reviewed by DCJS and submitted annually to the FBI's UCR, which breaks down the crime reports by municipality and city and categorizes them into six different categories: race/ethnicity/ancestry, religion, sexual orientation, disability, gender, and gender

identity. The data below includes all municipalities and cities in Erie and Niagara Counties that were recorded by the FBI UCR as having submitted hate crime reports between 2016 and 2019.

### *FBI UCR Data by Municipality and City*

Table 3. *FBI UCR Crime Data for Municipalities and Cities in Erie and Niagara Counties, 2016*

Location	Race/Ethnicity/Ancestry	Religion	Sexual Orientation	Disability	Gender	Gender Identity	Total
Amherst Town	2	0	0	0	0	1	2
Buffalo	5	0	1	0	0	1	7
Cheektowaga Town	1	0	0	0	0	0	1
Hamburg Town	1	0	0	0	0	0	1
Niagara Falls	0	0	1	0	0	0	1
North Tonawanda	2	0	0	0	0	0	2



Table 4. *FBI UCR Crime Data for Municipalities and Cities in Erie and Niagara Counties, 2017*

Location	Race/Ethnicity/ Ancestry	Religion	Sexual Orientation	Disability	Gender	Gender Identity	Total
Amherst Town	6	0	2	0	0	1	9
Buffalo	1	0	0	0	0	0	1
Niagara Falls	3	0	0	0	0	0	3

Table 5. *FBI UCR Crime Data for Municipalities and Cities in Erie and Niagara Counties, 2018*

Location	Race/Ethnicity/ Ancestry	Religion	Sexual Orientation	Disability	Gender	Gender Identity	Total
Amherst Town	5	0	0	0	0	0	5
Buffalo	5	0	0	0	0	1	6
Hamburg Town	1	0	0	0	0	0	1
Niagara Falls	1	0	0	0	0	0	1

Table 6. *FBI UCR Crime Data for Municipalities and Cities in Erie and Niagara Counties, 2019*

Location	Race/Ethnicity/ Ancestry	Religion	Sexual Orientation	Disability	Gender	Gender Identity	Total
Amherst Town	0	1	0	0	0	0	1
Buffalo	5	0	0	0	0	0	5
Tonawanda	1	0	0	0	0	0	1

Data included in this figure was analyzed, compiled, and recorded by the FBI's Uniform Crime Reporting (UCR) Program (FBI, 2010).

The Anti-Defamation League (ADL) elaborated on some of the incidents occurring in Buffalo-Niagara between 2016 and 2019 behind these statistics in their Hate, Extremism, Antisemitism, and Terrorism dataset, listed here: (ADL H.E.A.T. Map)

1. Antisemitic Incident – Vandalism, 03/2016 in Buffalo, NY: “Antisemitic graffiti reading ‘kill all kikes’ discovered in campus bathroom.”
2. Antisemitic Incident – Vandalism, 04/2016 in Buffalo, NY: “Swastika found spray-painted on wall.”
3. Antisemitic Incident – Harassment, 12/2018 in Buffalo, NY: “Individual drove down a street shouting ‘The Holocaust was a hoax. The Jews are lying.’”
4. Antisemitic Incident – Harassment, 09/2019 in Buffalo, NY: “A synagogue received a handwritten antisemitic letter.”
5. Antisemitic Incident – Vandalism, 11/2019 in Buffalo, NY: “Graffiti that included two swastikas, the n-word, and homophobic slurs was found written on a bathroom stall in Knox Hall at the University of Buffalo.”

(ADL H.E.A.T. Map)

Taking these three data sets together, it is clear that antisemitism has maintained a consistent presence in Buffalo-Niagara across the four-year period spanning 2016 through 2019.

## Interviews with Community Members and Leaders

Numerous members of Buffalo-Niagara's Jewish community shared stories of their firsthand experiences as victims of antisemitism. For one, a long-time resident family of Buffalo who wished to remain unnamed was victim of an antisemitic act of harassment in the first degree (New York State Senate, 2020). During the 2020 winter holiday season, the family was mailed threatening messages, letters, and propaganda to their home. The threatening messages read “Die Jews” and “We're coming for you” and were believed to have been prompted by the placement of a menorah in this family's home window.

Students in Buffalo-Niagara's schools have also encoun-

tered antisemitism. Jewish college freshman Adam Beiter who, at the time of his interview, had just recently graduated from high school recounted multiple antisemitic acts committed by his peers. In his economics class, students worked in teams on a project and one team of students named themselves the Einsatzgruppen after the Nazi death squads in the Holocaust. Beiter noted that throughout his middle school and high school years, Holocaust jokes and Nazi references were made on numerous occasions, even as recently as directly prior to his high school graduation. “We do what’s called a memory walk where we walk through our old elementary school and middle school,” said Beiter. “As we were walking through the old middle school... we happened upon a group of middle schoolers who were all huddled together doing the Nazi salute.”

Many of the Jewish community’s leaders have noted that hate continues to abound because of lacking understanding. Chair of the Buffalo Jewish Federation’s Jewish Community Relations Council Deborah Goldman shared her belief that “[t]here should be more opportunities for people to get to know Jews not as Judeo-Christians and [she] would say the same thing about other communities, too. If you know people, it’s harder to hate them.” CEO of the Buffalo Jewish Federation Rob Goldberg similarly believes that the best ways of combating hate and antisemitism are through deepening cultural understanding. “I think our role is education, I think our role is... bridge-building,” said Goldberg. “I think we have to confront hate and be honest that hate exists.”

For some community members, however, confronting hate head-on poses a challenge. According to Minister Denise Walden, Lead Faith & Live Free Organizer for social justice group VOICE Buffalo, some victims of hate crimes have historically refrained from reporting their experiences to law enforcement either because it is traumatic for them to talk about their experience or because they may not trust law enforcement. People may also not know where to turn to report a crime and may not know that bias-reporting systems exist. Similar views were reflected by members of Buffalo’s Chinese community. Founder and President Yan Liu of Bridges from Borders, a non-profit focused on bridging gaps between different cultures, noted increased xenophobia towards the Chinese community in the region relating to COVID-19 and noted that nobody did much to re-

port such incidents. “Chinese don’t really put a spotlight on racial things because we have disciplined ourselves to follow white so-called culture,” said Liu. “We shrink ourselves and make ourselves as small as possible but even with this, we realize we cannot survive... We have learned that we should promote, together, that we are human beings. We should align on that common thread alone and we have started moving in that direction with coalitions.”

Many note that concerted efforts have already proved impactful. Rene Petties-Jones, president of the National Federation for Just Communities (NFJC), noted that the NFJC helped the Jewish Federation argue on behalf of the movement of the first day of school to a date that would not create a religious conflict for Jewish students observing Rosh Hashanah, the Jewish new year. In working together with other communities, Petties-Jones noted that “[i]t just makes you feel good that you’ve got allies and that someone’s got your back. When you’ve got an issue, you know who you can go to to talk and say hey, what do you think of this and if there is something you don’t quite understand or need to learn more of, you’ve got people willing to step up.”

## Community and Anti-Hate Organizations ‘Doing This

### The Organizations

Seeing as Buffalo-Niagara is one of the most segregated metros in the United States, it takes a great deal of effort to connect with others. As previously mentioned, many organizations in Buffalo-Niagara seek to uplift their own communities while learning to understand and work with other communities. There are also several organizations in Buffalo-Niagara that are committed to addressing hate and educating against prejudices and biases.

Community leaders who engage in these activities have noted that while there is a great number of organizations that work in community development and addressing hate, most community members outside organizations are not always aware of the work being done. Moreover, community leaders observe that because many individuals do not engage with community development or anti-hate work, they do not see the work that their

communities do together with others. Community leaders worry that because of this unawareness, people may be more likely to maintain prejudices and remain susceptible to hating others. Reverend Denise Walden of VOICE Buffalo shares that “[m]ost hate comes from a place of ignorance and not understanding other folks and where they are coming from.” To shatter community prejudices, community leaders believe that they need to make their inter-community relationships more visible and work more consistently with their community partners. For them, this will ensure that community members understand the scope of their communities’ relationships with others and how valuable they are to achieving social justice and a better shared society for all. “The more that they see the partnership, the more

that it will become part of the norm, so it is not so unusual,” says Rene Petties-Jones, President of the National Federation for Just Communities. “We do not have to work in silos, we can work together.”

For the purposes of this report, there are over 60 community organizations focused on promoting community through bridge building. These organizations have been included in this report because they expressed in their mission statements and/or values one or multiple of the following keywords: “Community”; “Promote Understanding”; “Services”; “Assist Families”; “Cultural”; “Serve Our Community”; “Cultural Diversity”; “Facilitate Understanding”; “Legacy”; “Civil Society”; and “Just Society.”

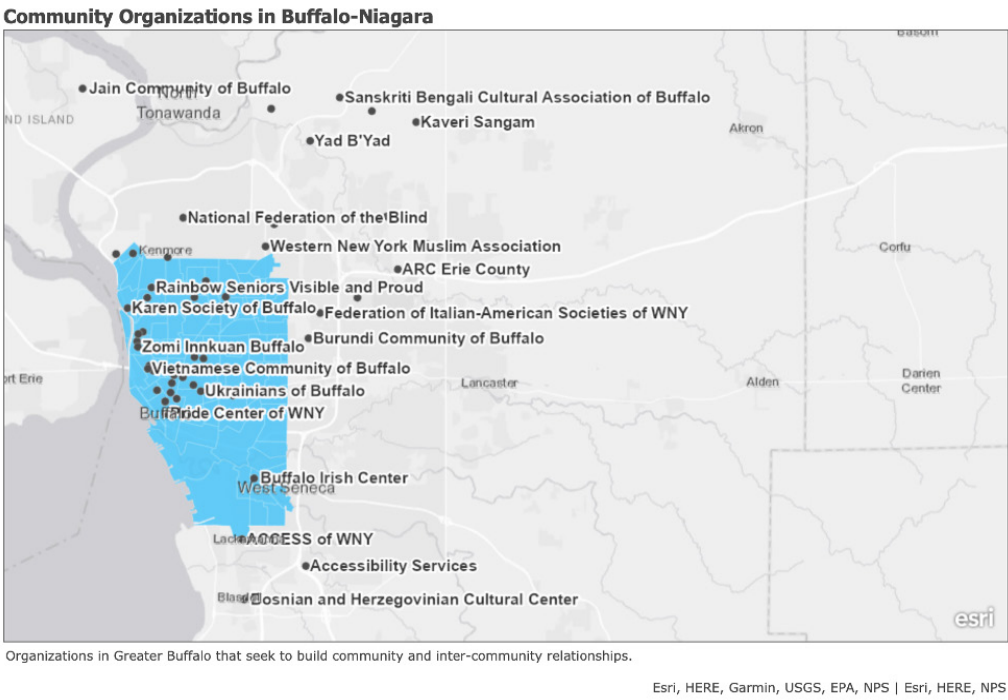


Figure 1. Community Organizations in Buffalo-Niagara. This map pinpoints over 60 community organizations working towards serving their own communities and building relationships with other communities in Buffalo. This figure was created by inputting independent research into ArcGIS Mapping Software.

The full list of community organizations is as follows:

Table 16. List of Community-Oriented Organizations in Buffalo-Niagara

ACCESS of WNY	Accessibility Services
African American Cultural Center	African Heritage Food Co-op
ARC Erie County	Asian Indian Community Foundation of WNY
Aspire of WNY	Autism Services, Inc.
Bhutanese-Nepali Hindu Community of Buffalo	Bosnian and Herzegovinian Cultural Center
Buffalo Belles	Buffalo Gurdwara Sahib
Buffalo Hearing and Speech Center	Buffalo Irish Center
Buffalo Jewish Federation	Buffalo Zen Dharma Community
Burmese Community Services, Inc.	Burundi Community of Buffalo



Centro Culturale Italiano di Buffalo	Chin Community of Buffalo
Chinese Club of WNY	Community Services for Every1
Congolese Community of Buffalo	Deaf Access Services
Embrace of Western New York	Eritrean Community of St. George
Ethiopian Community Association of Buffalo, Inc.	Federation of Italian-American Societies of WNY
Gay and Lesbian Youth Services	Global Bridge Impact, Inc.
Hindu Cultural Society of WNY	Hispanic Heritage Council of WNY
India Association of Buffalo	Iraqi American Society, Inc.
Islamic Society of Niagara Frontier	Jain Community of Buffalo
Jewish Community Center	Jewish Family Service of Buffalo and Erie County
Karen Society of Buffalo	Karenni Community of Buffalo
Kaveri Sangam	Kongo Dia Ntotila Solution
Lt. Col Matt Urban Human Services Center	MOCHA Buffalo
National Federation of the Blind	Native American Community Services
PFlag	Pride Ability of WNY
Pride Center of WNY	RAHAMA
Rainbow Seniors Visible and Proud	Sanskriti Bengali Cultural Association of Buffalo
Service Bridges	Sierra Leone Cultural Alliance of WNY, Inc.
Somali Bantu Community Organization of Buffalo	Spectrum Transgender Group of WNY
Sudanese American Community of Buffalo	Ukrainians of Buffalo
Vietnamese Community of Buffalo	Western New York Muslim Association
WNY Women's Foundation	Yad B'Yad
Zomi Innkuan Buffalo	Zonta Club Buffalo

Buffalo-Niagara is also home to over 30 anti-hate organizations. These organizations have been included in this report because they expressed in their mission statements and/or values multiple of the following key-

words: “Combat”; “Racism”; “Discrimination”; “Hate”; “Antisemitism”; “Foster Inclusion”; “Coalition”; “Human Rights”; “Combating Hate”; and “Combating Violence.”

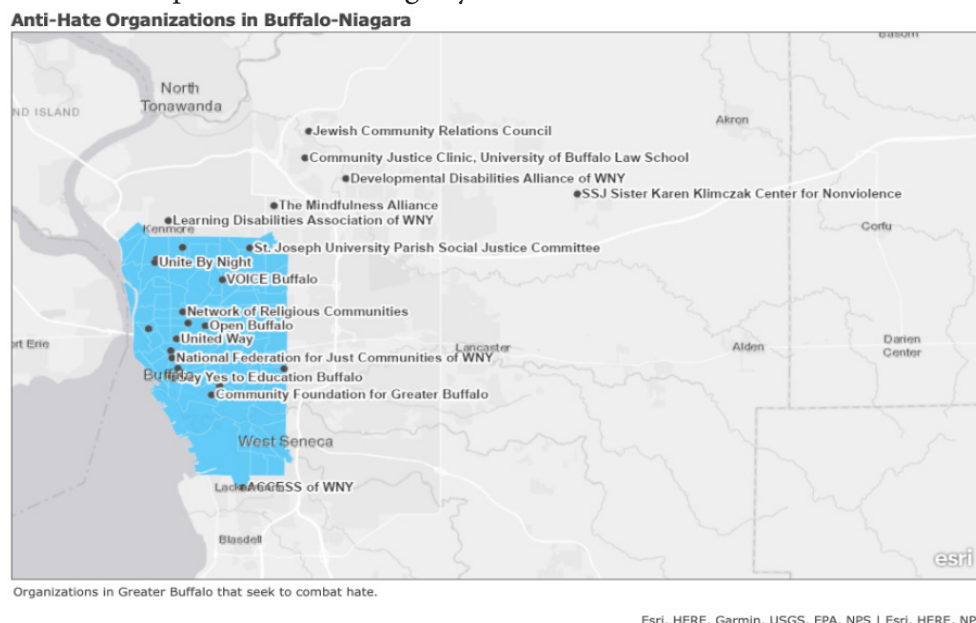


Figure 2. Anti-Hate Organizations in Buffalo-Niagara. *This map pinpoints over 30 anti-hate organizations working towards combating hate in all its forms throughout Buffalo. This figure was created by inputting independent research into ArcGIS Mapping Software.*

The full list of anti-hate organizations is as follows:

Table 16. *List of Anti-Hate Organizations in Buffalo-Niagara*

ACCESS of WNY	Anne Frank Project
Buffalo Human Rights Center	Buffalo Urban League
Center for Elder Law and Justice	Center for Self Advocacy
Citizen Action	Civil Rights and Transparency Clinic, University of Buffalo Law School
Community Action Organization	Community Foundation for Greater Buffalo
Community Justice Clinic, University of Buffalo Law School	Developmental Disabilities Alliance of WNY
Erie County Restorative Justice Coalition	Holocaust Resource Center
International Institute of Buffalo	Jewish Community Relations Council
Junior League of Buffalo	Learning Disabilities Association of WNY
NAACP Buffalo	National Federation for Just Communities of WNY
Network of Religious Communities	Open Buffalo
Peace of the City Ministries	Peaceprints of WNY
Pride Center of WNY	Say Yes to Education Buffalo
SSJ Sister Karen Klimczak Center for Nonviolence	St. Joseph University Parish Social Justice Committee
The Mindfulness Alliance	Unite By Night
United Way	VOICE Buffalo

## Jewish Community Relations

Many general community leaders in interviews expressed their pride in working with the Jewish community to achieve a better shared society in Buffalo-Niagara. They have found that being present for one another has been powerful and comforting. “It makes you feel good that... someone’s got your back. When you’ve got an issue, you know who you can go to talk to and say hey, what do you think of this and if there is something you don’t quite understand... you’ve got people willing to step up,” says Rene Petties-Jones.

Beyond working alongside the Jewish community to affect change, some communities look to the Jewish community as an example. Members of the region’s Chinese community have noted that at times where the Asian community may struggle to respond to local hate, they find their strength with other minority communities, and they have found that strength with the Jewish community. “[T]he Jewish community is a model for us in terms of their organization and structure,” says Yan Liu, Founder of Bridges from Borders. Yan also said the JCRC-powered Multicultural Women’s Group is a best practice model where people from other backgrounds make friends and show respect to each other.

While the Jewish community already has some strong ties to other communities in Buffalo-Niagara, some relationships may be lacking and in need of attention. “I haven’t personally encountered negative things said about the Jewish community but there isn’t a lot of inter-connectivity there between the Latinx and Jewish communities,” says community activist Alexsandra Lopez.

Relationships need constant care and there is always room to build new ones. The Jewish community should both continue to build on existing relationships and foster new ones.

## Conclusion

Hate continues to exist in Buffalo-Niagara, and in response to it, there is work to be done. Community members in the region agree that they need to build on the strong foundation of networking, allyship, and shared programming to build a tolerant shared society in the region.

Most Buffalonians do not engage with social justice issues and/or other communities than their own.



[justice.gov/hatecrimes/learn-about-hate-crimes](https://www.justice.gov/hatecrimes/learn-about-hate-crimes)

*Legislation.* NY State Senate. Retrieved July 1, 2021, from [www.nysenate.gov/legislation/laws/PEN/485.05](https://www.nysenate.gov/legislation/laws/PEN/485.05)

New York Division of Criminal Justice Services. (2021) *Hate Crimes by County and Bias Type: Beginning 2010: State of New York, Hate Crimes by County and Bias Type: Beginning 2010 | State of New York*. Retrieved July 17th, 2021, from [data.ny.gov/Public-Safety/Hate-Crimes-by-County-and-Bias-Type-Beginning-2010/6xda-q7ev](https://data.ny.gov/Public-Safety/Hate-Crimes-by-County-and-Bias-Type-Beginning-2010/6xda-q7ev)

*NY State Senate BILL S70A.* (2021) NY State Senate. Retrieved June 30, 2021, from [www.nysenate.gov/legislation/bills/2021/S70](https://www.nysenate.gov/legislation/bills/2021/S70)

Perry, Barbara. (2001) *In the Name of Hate: Understanding Hate Crimes*. Psychology Press. Retrieved July 2, 2021, from [books.google.com/books/about/In\\_the\\_Name\\_of\\_Hate.html?id=doDHZXvq19YC](https://books.google.com/books/about/In_the_Name_of_Hate.html?id=doDHZXvq19YC)

*Segregation Results from 2010.* (2012) Census Scope. Retrieved July 1, 2021, from <http://censusscope.org/dev/content/segregation-results-2010>

*Uniform Crime Reporting (UCR) Program.* (2018) FBI. Retrieved June 28, 2021, from [www.fbi.gov/services/cjis/ucr](https://www.fbi.gov/services/cjis/ucr)



# Sex and Gender in Rheumatoid Arthritis: Considering a Risk Factor Hierarchy

By Melanie Valencia  
*Division of Nutritional Sciences, College of Human Ecology*

## Abstract

Is sex or gender a greater risk factor for Rheumatoid Arthritis (RA)? Identifying how gender and sex mediate RA is important because women and females make up the majority of RA patients. Additionally, rheumatoid arthritis is a serious immune disease that greatly affects an individual's quality of life. The reason behind the difference in RA diagnosis by gender and sex is important to guide how the difference can be mitigated. In this study, it is hypothesized that susceptibility to RA is mediated more by factors associated with sex, rather than behavioral and environmental factors associated with gender. Females are more susceptible to autoimmune diseases due to the skewed inactivation that can occur when half of the x-chromosome genetic material, which plays a role in the immune response, is silenced. During skewed inactivation, maternal and paternal x-chromosomes are not silenced in the same proportions, leading to two different self-antigens that cause a stronger immune response and can react to each other, which can produce an auto immunological response, such as RA. A secondary data analysis was performed using the National Library of Medicine database to search for genetic, behavioral, and environmental risk factors that were measured using an odds ratio. The behavioral and environmental risk factor odds ratio was compared to the skewed x-linked odds ratio to compare the effects of sex and gender. It was determined that there are greater odds that RA will be mediated by skewed x-linked chromosomal inactivation than any individual aspect of gender, however there is room for uncertainty regarding whether if either sex or gender definitively has a greater impact on RA diagnosis.

## Introduction

Rheumatoid Arthritis (RA) is the most commonly diagnosed systemic inflammatory disease (Wasserman, 2018). When a person has RA, the body attacks joint tissues, produces antibodies, and causes the joint to swell (Wasserman, 2018). As the disease progresses, the joint tissue can be completely destroyed, leading to inflammation, bone erosion, misshapen or fused joints all of which limit physical abilities and cause pain. This is considered a chronic disease, but long-term remission is available and is more successful in the earlier stages of the disease (Wasserman, 2018). The inequality present in RA is described by literature as “disease patterns vary between sexes; the condition is more commonly seen in women (3 women for every one man), who exhibit a more aggressive disease and poorer long-term outcome” (Da Silva and Hall, 1992). It is surprising that the article claims that there is a difference in disease patterns between sexes, but puts the scale of the difference in terms of gender. This prompts interests as to which

category, sex or gender, has a greater effect on mediating RA.

The exploration of the gender and sex disparity in RA is just starting to be uncovered. In the 1930's researchers implicated sex hormones to be contributing to RA due to the temporary remission that occurred during pregnancy (Lampner, 2018). Then at the start of the 2000's the disparity was thought to exist due to less intensive prescriptions for women, however, this assumption was proven to be incorrect by a national committee that confirmed that women and men receive similar proportions of prescription treatments (Lampner, 2018). Rheumatologists have noticed greater disease activity and disability scores in women, which they attribute to women being more vocal about their symptoms which they suggest alter the scores generated from disease activity and disability tests (Lampner, 2018). Several studies have come to the same conclusion that men and women do not differ in disease activity score, with a few caveats, that men more often meet criteria for remission, and that RA disease scores between men and women

only differ in subjective measures (women experiencing higher scores), not in objective measures (Lampner, 2018). This has led to disagreement in the field, some believing that gender and sex-based treatment is not needed and others thinking it should be available due to physiological changes during pregnancy and lactation and the greater likelihood of comorbidities in women and differences in coping strategies (Lampner, 2018).

It is hypothesized that the susceptibility to RA is mediated more by factors associated with sex, rather than behavioral and environmental factors associated with gender. This hypothesis is based on the higher prevalence of all immune diseases in females compared to males. It is suspected that this is due to skewed inactivation that can occur during x-chromosome inactivation in females. Half of the x-chromosome genetic material must be silenced because females have two x-chromosomes. However, not all females have equal proportions of cells with the paternal or maternal x-chromosome activated (Shvetsova et al., 2018). The x-chromosome that cells receive is randomly distributed, therefore females have what is considered a mosaic expression (Shvetsova et al., 2018). The mosaic expression leads females to have two populations of dendritic cells that either express maternal or paternal x-linked self-antigens for negative regulation (Libert et al., 2018). The expression of both types of dendritic cells allows for a stronger immune response, but the presence of two types of antigens may cause the breakdown of self-tolerance, where the immune system begins to respond to self-produced antigens (Shvetsova et al., 2018). The breakdown of self-tolerance in individuals with skewed x-linked inactivation can lead to autoimmune diseases, where the body attacks and destroys its own tissues, like RA. This hypothesis was supported by the secondary data analysis, which found that RA has greater odds of being mediated by skewed x-linked inactivation, a proxy for sex-related risk factors, than any single gender-related risk factor.

## Methodology

A quantitative systematic literature review was performed using the National Library of Medicine database to search for genetic, behavioral, and environmental risk factors that had been measured in the last twenty years using an odds ratio or provided raw data

allowing for the odds ratio to be calculated. An odds ratio is a measure of association between exposure and outcome, the outcome of interest being RA diagnosis. Using the odds ratios collected from the primary literature studies, a forest plot was constructed to display the average odds of a behavioral or environmental risk factor being associated with RA. The behavioral and environmental risk factor odds ratios were compared to the skewed x-linked odds ratio to compare the effects of sex and gender. Sex is a biological category, that can be defined using the X-Y determination system. Skewed x-link inactivation was used as the risk factor for sex because it can only occur in females. Gender is a social category, so it takes into account how the person interacts with their environment and the behaviors they are expected to perform. The behavioral and environmental risk factors range from substance use, nutrition, social networks, socioeconomic status, and pollution. A forest plot was utilized to display this information, so the individual and average odds of environmental and behavioral factors associated with RA can be visualized.

## Results

The odds ratio of behavioral and environmental factors being associated with RA is 2.07, 95% CI (1.26, 3.52) (Table I). The odds ratio of skewed x-linked inactivation being associated with RA is 4.13, 95% CI (2.11, 8.10) (Chabchoub et al., 2009) (Table II). The odds ratio and 95% confidence intervals of individual behavioral and environmental factors are listed in Table I and displayed in a forest plot in Figure I. The odds ratio and 95% confidence interval for skewed x-linked inactivation are in Table II.

### Substance use-related Risk Factors Results

Smoking is the most well-supported risk factor for RA; the odds ratio was calculated by comparing those that have zero pack-years to those who have 10 pack-years (one pack-year is equivalent to smoking twenty cigarettes a day for a year) (Pederson et al., 2006). The reason behind the connection between smoking and RA occurs via oxidative stress, inflammation, auto-antibody formation, and epigenetic changes (Chang et al., 2014). The alcohol consumption odds ratio was calculated by comparing those who do not consume alcohol at all to those who drink one to five drinks a week

**Table I. Odds Ratio and Confidence Intervals for Behavioral and Environmental Risk Factors.** The behavioral and environmental risk factors serve as a proxy for gender since gender identity reflects the manner individuals behave and interact with their environment. The behavioral and environmental risk factors used fall under the broader categories of substance use, nutrition, social networks, socioeconomic status, and pollution.

Behavioral or Environmental Risk Factors	Provided Odds Ratio	95% Confidence Interval	Source
Smoking Tobacco	1.65	1.03, 2.64	(Pederson et al., 2006).
Alcohol Consumption	1.98	1.22, 3.19	(Pederson et al., 2006).
Remaining Unmarried	1.71	1.14, 2.58	(Pederson et al., 2006).
Coffee Consumption	2.18	1.07, 4.42	(Pederson et al., 2006).
Inadequate Vitamin D Consumption	2.46	1.14, 5.32	(Lee and Bae, 2016)
Consumption of Sugar-sweetened Beverages	2.65	1.56, 4.46	(Alpizar-Rodríguez et al., 2017)
Occupational Exposure to Dust	2.80	1.60, 5.20	(Alpizar-Rodríguez et al., 2017)
Low Educational Level	2.43	1.31, 4.16	(Pederson et al., 2006)
Ground Level Ozone at Residence	1.26	1.18, 1.36	(DeRoos et al., 2014)
Reside in Low Socioeconomic Status (SES) Neighborhoods	1.73	1.23, 2.44	(DeRoos et al., 2014)
Residential Proximity to Highway	1.39	1.16, 1.68	(Xu and Lin, 2017)
Living in Poverty	2.96	1.77, 4.65	(Philippou and Nikiphorou, 2018)
Consumption of Red Meat	2.30	1.10, 4.90	(Philippou and Nikiphorou, 2018)
High Sodium Intake	1.50	1.10, 2.20	(Philippou and Nikiphorou, 2018)

**Table II. Odds Ratio and Confidence Interval for Innate Biological Risk Factors.** Skewed x-linked inactivation was used as the risk factor for sex because it can only occur in females and is the only known innate biological risk factor associated solely with sex.

Risk Factor	Calculated Odds Ratio	95 % Confidence Interval	Source
Skewed X-linked Inactivation	4.13	2.11, 8.10	(Chabchoub et al., 2009)

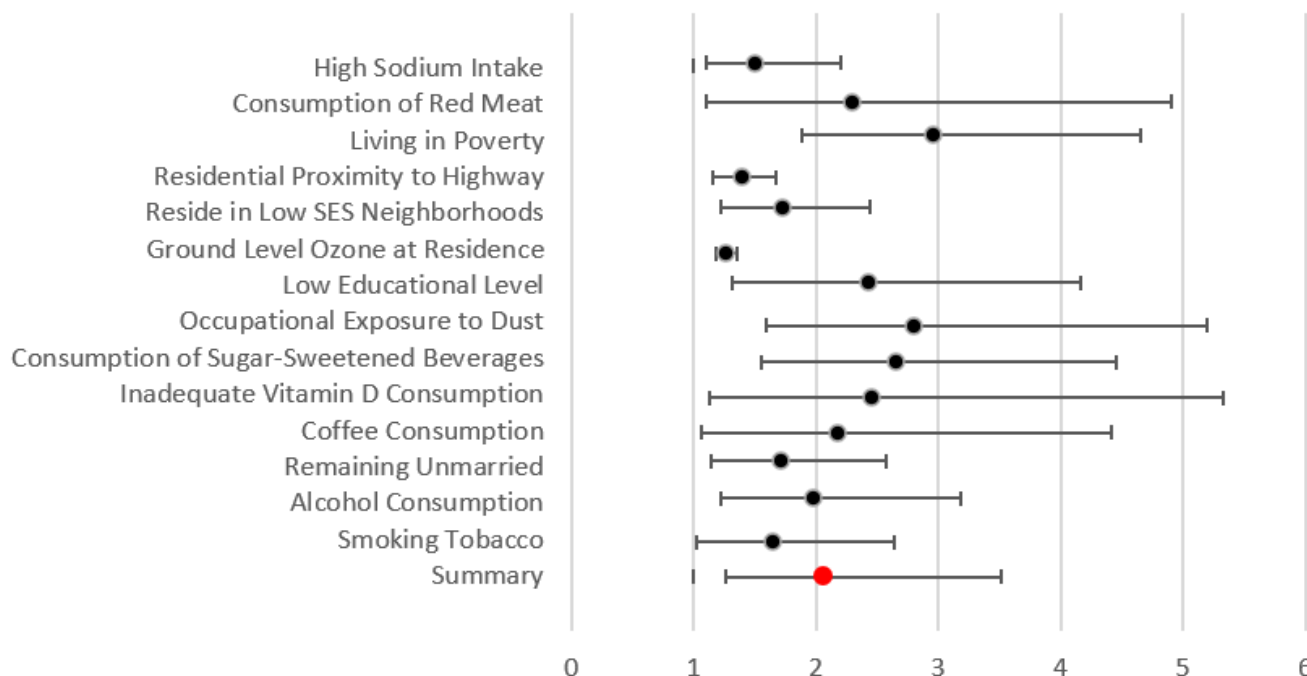
(Pederson et al., 2006). The relationship of alcohol to RA is unexpected since alcohol is an immunosuppressant (since RA occurs with an overactive immune system), however, it is thought that because alcohol use is positively correlated with smoking, the effect of alcohol on RA diagnosis is skewed by the effect of smoking on RA diagnosis. (Pederson et al., 2006).

### Socioeconomic Status-related Risk Factor Results

Poverty was measured using the Family Monthly Poverty Level Index and those that lived with less than 300% of the poverty level were counted as living in poverty and compared to those who lived with greater than 300% of the poverty level (Xu and Lin, 2017). Living in

poverty may decrease access to healthy foods, increase substance use as a coping mechanism and increase exposure to polluted environments that are typically less expensive to live in, all of which are risk factors for RA. The education odds ratio was formed by comparing those with no education to those with over four years of advanced schooling. This study was performed in Denmark, where there is universal health care, so health insurance status and wealth are unlikely to mediate this relationship (Pederson et al., 2006). Education plays a role in mediating RA because educated individuals are more likely to seek medical advice at an earlier stage in the disease than less educated people (Pederson et al., 2006). The neighborhood socioeconomic status (SES)

## Odds Ratio for Behavioral and Environmental Factors



**Figure I. Forest Plot of the Odds Ratio for Behavioral and Environmental Factors.** The forest plot displays the odds the exposure to a given risk factor will lead to RA diagnosis. The summary point and confidence interval in the figure displays the average odds and confidence interval of an individual behavioral and environmental risk factor leading to RA diagnosis. The summary point does not reflect the average risk of gender, as it does not account for exposures to multiple risk factors for RA.

odds ratio was made by comparing the lowest two quintiles of SES neighborhoods to the highest three quintiles of SES neighborhoods (DeRoos et al., 2014). The low SES neighborhoods may have a higher odds ratio of being diagnosed with RA due to the prevalence of smoking and second-hand smoke (DeRoos et al., 2014).

### Pollution- related Risk Factor Results

Ground-level ozone was measured in  $\mu\text{g}/\text{m}^3$  and compared the highest quintile to the lowest quintile (DeRoos et al., 2014). Ozone is proposed to lead to RA via oxidation of biomolecules, causing DNA methylation, and altering the DNA protein binding sites (DeRoos et al., 2014). The biological changes can trigger the generation of autoantigens that lead to autoimmune logical conditions, like RA (DeRoos et al., 2014). Interestingly, ozone was found in the highest concentrations within suburban and higher SES neighborhoods (DeRoos et al., 2014). The parameters for occupational exposure to dust are not specified. Occupational exposure to dust impacting RA is said to be caused by silica, silica particles can trigger the innate immune system, causing inflammatory cytokine release (Alpízar-Rodríguez et al.,

2017). Residential proximity to a highway was defined as those who live less than or equal to 50 meters from a highway, which was compared to those who lived greater than 150 meters away from a highway (DeRoos et al., 2014). However, the reasoning behind the relationship between the proximity to a highway and RA remains unclear because noise levels and vehicle-related pollutants were shown to not be responsible for this relationship (DeRoos et al., 2014).

### Nutrition-related Risk Factors Results

Both high sodium intake and consumption of red meat are considered to trigger RA and exacerbate inflammation (Philippou and Nikiphorou, 2018). This is thought to occur via the enhancement of the autoimmune cascade response through the production of inflammatory cytokines and chemokines that destroy joint tissues like synovial membranes and cartilage. Increased red meat consumption was considered to be greater than 88 g/day and was compared to less than 49 g/day to generate the odds ratio. The fat, nitrates, and iron from meat are also suspected to contribute to the inflammation. Specifically, the consumption of red meat is a concern



because it may be taking the place of protective food in a meal, such as omega-3 rich fish. The parameters for what was considered high consumption of sodium were not included in the study. Sugar-sweetened beverages were also shown to affect the odds of being diagnosed with RA, however, the parameters of the odds ratio were also not provided (Alpizar-Rodríguez et al., 2017). The mechanism of sugar sweetened-beverages mediating RA is likely due to excess sugar in the vascular system, which activates the pathway for reactive oxidative species, which produces similar effects as ozone. Vitamin D was measured in serum, however, the parameters for what was considered a vitamin D deficiency were also not included (Lee and Bae, 2016). Vitamin D plays a role in mediating RA because it is an immunosuppressant and it inhibits immune cell proliferation, therefore without vitamin D the immune system will not receive negative feedback and the immune system's self-tolerance is decreased (Lee and Bae, 2016). The coffee consumption odds ratio was calculated by comparing those that consume no coffee to those who consume over ten cups of coffee, but the connection of coffee consumption to RA is not well understood (Pederson et al., 2006).

### **Social network-related Risk Factor Results**

The odds ratio for remaining unmarried was calculated by comparing those that are married or cohabiting with their partner to those who are unmarried, widowed, or divorced (Pederson et al., 2006). The reason for not being married affecting RA diagnosis may be due to decreased access to social capital, which leads to poorer health outcomes.

## **Discussion**

### *Interpretation of Result*

When comparing the odds ratios collected in this study, there are greater odds that RA will be mediated by skewed x-linked chromosomal inactivation than an individual behavioral or environmental factor. The association made between the factors (x-linked chromosomal inactivation, behavioral, and environmental factors) measured and the purpose of this research lead to the conclusion that sex as an individual risk factor puts a person at a greater risk for RA than any individual risk factor related to gender. However, there is room for uncertainty since there is no certainty as to how many

behavioral and environmental risk factors an individual may experience, if any at all. In addition, a limitation of this study is that it is not known what effect the compounding of several risk factors could have. For example, an individual may have a high sodium intake, consume alcohol, and live in a low SES neighborhood. This brings into perspective the idea that there is no definitive gender experience, so the effect size of gender becomes more unclear. It seems like both sex and gender play a role in mediating RA and determining which plays a greater role would require determining an average definitive gender experience. Determining an average gender experience could have serious implications, for example marginalizing non-average gender experiences, like those of gender minorities.

Aside from the focus on gender and sex, in this study there was also a focus on risk factors for RA, but not on protective factors. While there is a gender and a sex that have a greater prevalence of RA, there may be protective factors that females and women may have, and exploring those may be important so they can be emphasized in the prevention of RA.

Additionally, in the realm of risk factors, they are framed in a binary manner, not in terms of a spectrum (i.e. drinks a day), so these may misconstrue the odds ratio. While there was data that did separate factors into brackets of exposure or a spectrum, not all data had this separation. Adding several categories of the same risk factor (i.e. smoking) would then lead to the average behavioral and environmental risk factors to be more greatly influenced by that risk factor, and lead the odds ratio to not be as representative of the average behavioral and environmental risk factor.

### *Challenges*

There were some challenges of using a systematic review as the research method, including finding data in similar terms (for comparison) and the limitation of using already published data. Information on risk factors of RA was not hard to find, however finding all the risk factors measured using an odds ratio was difficult. As a result, there are many more environmental and behavioral risk factors that show an association with RA, but could not be included in this study, for example, stress. Another limitation was the uncertain effects of estrogen since no studies have studied the serum levels of endog-

enous estrogen, only the effect of exogenous estrogen, used for hormone replacement therapy or birth control. These forms of estrogen may not be a great way to study the effect of higher levels of endogenous estrogen in females, since they may be influenced by confounding factors, like age, environmental factors, and access to healthcare. While there were challenges due to research design, there were also limitations due to the topic being studied. It was challenging to select risk factors that were strictly related to sex or gender. One major risk factor that was excluded as a consequence was excluding other medical conditions as risk factors. For example, obesity is a major risk factor for RA, but there are environmental (obesogenic environments), behavioral (overeating), and sex-related factors (distribution of body fat), that all play into this condition. Despite these challenges, it was determined there was sufficient data to analyze the effects of gender and sex on RA.

### *Sources*

The critiques of the sources used are mostly based on their stance in terms of the disparity at hand, rather than the validity of their data. “The X Chromosome in Immune Functions: When a Chromosome Makes the Difference” by Libert, Dejager, and Pinhero, presents ideas in an androcentric manner. For example, they consider the female immune system to be hyperresponsive in comparison to the male immune system, however, the male immune system could have been framed as having a dull response, instead of being the norm. Androcentrism was also present in “Sex-based Differences in Rheumatoid Arthritis: Clinical Implications and Patient Management” as well as gender stereotypes in the case where professionals were interviewed and claimed women to be more vocal in reporting symptoms (rather than men under-reporting symptoms in an attempt to maintain the hegemonic masculinity). Although women are more likely to care for their health, accusing them of over-reporting is a rash accusation, because the measures used to gauge the disease progression of RA objectively are most likely based on disease patterns of men, so women are most likely not over-reporting, they are just not reporting what is expected based on the androcentric standard. Then in “Are We Really What We Eat? Nutrition and its Role in the Onset of Rheumatoid Arthritis,” it is surprising to see that instead of making policy recommendations, the authors claim that they trust that elucidating the impact of nutrition on RA will

encourage the involvement of registered dieticians in RA management. The authors seem too ambitious in their prediction that this will occur on its own, without considering structural factors that may prohibit registered dietician involvement, for example, doctors will need to facilitate the referral to the dieticians and patients will need to also value the importance of a dietician, so it seems that educational programs that cover current research for both medical professionals and patients are necessary to increase the involvement of registered dietitians. Their suggestion to decrease the intake of meat, without providing replacements or addressing why meat is eaten in large quantities appears unlikely to persuade the target demographic to change their behavior. I would urge the authors to provide a reasonable manner of making this dietary change and to take into consideration any structural reasons, for example, food deserts, that may lead people to consume meat over fresh produce.

## **Conclusion**

The hypothesis of this study was centered on finding a definitive ranking for the effects of gender and health, but the research performed was not sufficient to draw these conclusions. However, the research did provide insight into the many risk factors of RA both gender and sex mediate as well as implications for policy and future research.

### *Implications on Policy*

In consideration that skewed x-linked inactivation is the single greatest risk factor for RA, the genetic screening of skewed x-linked inactivation should be performed as part of female preventative medical visits. This should be implemented early on in life since the earlier RA is detected, the greater likelihood there is of achieving remission and the less damage to joint tissues the patient will incur. This is particularly important as females may report symptoms of RA, like diffuse joint aches, and be ignored due to the stereotype that women are more vocal and tend to complain. Instead, if there is a previously-noted genetic susceptibility to RA, then a diagnosis of this condition is more likely to occur, and management of the condition is likely to occur earlier. To address the role of gender via health policy, environmental and behavioral risk factors that an individual faces should be tracked via electronic medical records,

so physicians can take these into account when making a differential diagnosis. In terms of addressing the risk factors directly, large-scale policy changes would have to be implemented, like addressing poverty, so individuals can afford healthy foods, choose to live and work in safer environments, and afford an education.

### Future Research

To elucidate the effects of gender and sex on RA, research should be directed towards the outcomes of those skewed linked x-activation to the behavioral and environmental factors differ from those without skewed linked x-activation, to investigate if skewed x-linked inactivation has a causal relationship with RA, not only a correlational relationship. Additionally, it would be interesting to see how male and female odds ratios of being diagnosed with RA differ with exposure to the same risk factors since this could bring to light any epigenetic mechanisms at play in the RA disease activity.

## References

Alpízar-Rodríguez, D., & Finckh, A. (2017). Environmental factors and hormones in the development of rheumatoid arthritis. *Seminars in Immunopathology*, 39(4), 461-468. <https://doi.org/10.1007/s00281-017-0624-2>

Chabchoub, G., Uz, E., Maalej, A., Mustafa, C. A., Rebai, A., Mnif, M., Bahloul, Z., Farid, N. R., Ozcelik, T., & Ayadi, H. (2009). Analysis of skewed X-chromosome inactivation in females with rheumatoid arthritis and autoimmune thyroid diseases. *Arthritis Research & Therapy*, 11(4), 106. <https://doi.org/10.1186/ar2759>

Chang, K., Yang, S., Kim, S., Han, K., Park, S., & Shin, J. (2014). Smoking and rheumatoid arthritis. *International Journal of Molecular Sciences*, 15(12), 2279-2295. <https://doi.org/10.3390/ijms151222279>

Da Silva, J., & Hall, G. (1992). The effects of gender and sex hormones on outcome in rheumatoid arthritis. *Baillière's Clinical Rheumatology*, 6(1), 196-219.

De Roos, A. J., Koehoorn, M., Tamburic, L., Davies, H. W., & Brauer, M. (2014). Proximity to traffic, ambient air pollution, and community noise in relation to incident rheumatoid arthritis. *Environmental Health Per-*

*spectives*, 122(10), 1075-1080. <https://doi.org/10.1289/ehp.1307413>

Lampner, C. (2018). Sex-Based Differences in Rheumatoid Arthritis: Clinical Implications and Patient Management. *Rheumatology Advisor*.

Lee, Y. H., & Bae, S.-C. (2016). Vitamin D level in rheumatoid arthritis and its correlation with the disease activity: a meta-analysis. *Clinical and Experimental Rheumatology*, 34(5), 827-833 <https://doi.org/10.26226/morreissier.56e174d4d462b8028d88a790>

Libert, C., Dejager, L., & Pinheiro, I. (2010). The X chromosome in immune functions: When a chromosome makes the difference. *Nature Reviews Immunology*, 10(8), 594-604. <https://doi.org/10.1038/nri2815>

Pedersen, M., Jacobsen, S., Klarlund, M., Pedersen, B. V., Wiik, A., Wohlfahrt, J., & Frisch, M. (2006). Environmental risk factors differ between rheumatoid arthritis with and without auto-antibodies against cyclic citrullinated peptides. *Arthritis Research & Therapy*, 8(4), 133. <https://doi.org/10.1186/ar2022>

Pederson, M., Jacobsen, S., Karlund, M., & Frish, M. (2006). Socioeconomic status and risk of rheumatoid arthritis: a Danish case-control study. *The Journal of Rheumatology*, 33(6), 1069-1074.

Philippou, E., & Nikiphorou, E. (2018). Are we really what we eat? nutrition and its role in the onset of rheumatoid arthritis. *Autoimmunity Reviews*, 17(11), 1074-1077. <https://doi.org/10.1016/j.autrev.2018.05.009>

Shvetsova, E., Sofronova, A., Monajemi, R., Gagalova, K., Draisma, H. H., White, S. J., Santen, G. W., Chuva de Sousa Lopes, S. M., Heijmans, B. T., van Meurs, J., Jansen, R., Franke, L., Kielbasa, S. M., den Dunnen, J. T., & Hoen, P. A. (2018). Skewed X-inactivation is common in the general female population. *European Journal of Human Genetics*, 27(3), 455-465. <https://doi.org/10.1038/s41431-018-0291-3>

Xu, B., & Lin, J. (2017). Characteristics and risk factors of rheumatoid arthritis in the United States: An nhanes analysis. *PeerJ- Life & Environment*, 5(4035). <https://doi.org/10.7717/peerj.4035>

# Spatial Distributions and Regional Agglomeration of High-Tech Regions and Venture Capital

By Mia Krishnamurthy

*Department of Sociology, College of Arts and Sciences*

## Introduction

In this paper, I will closely examine the Mark Granovetter's theories related to economic sociology and embeddedness. I will then apply those theories to the study of venture capital and high technology regions. My main research question encompasses the role of networks and social relations and their impact on the formation and development of high-technology clusters. Regions such as Silicon Valley (Greater Bay Area) and Route 128 (Greater Boston Area) are known as knowledge economies and contribute to great economic growth and innovation. While AnnaLee Saxenian spent her time researching the sociology of the emergence of Silicon Valley as a high-tech cluster, I will add to this research by applying the framework she used to study the role of networks within venture capital in Silicon Valley. Venture capital is particularly fascinating to study since this funding is the main driver stimulating local entrepreneurship and the regional economy.

## Economic Sociology and High-Technology Regions

Mark Granovetter is a sociologist and Professor at Stanford University. Considered one of the fathers of economic sociology, he is well known for his theory on 'The Problem of Embeddedness'. Classical and neoclassical economists emphasized the formalist approach and believed that "rational, self-interested behavior [is] affected minimally by social relations" (Granovetter 1985, pp. 22). Mark Granovetter also discusses the other extreme: embeddedness. Embeddedness is essentially the interwoven nature of relationships in a social system. Granovetter's theory is supported by reformist economists and is known, within economic sociology, as the substantivist school of thought, "the argument that the behavior and institutions to be analyzed are so constrained by ongoing social relations that to construe

them as independent is a grievous misunderstanding" (Granovetter 1985, pp. 22). In other words, social relations and networks should not be ignored when analyzing economic transactions. Whether you are a venture capitalist deciding to invest in a startup or a student investigating the rise of Atlanta as a technology region, social relations matter. Networks are important because they help develop trust and "discourage malfeasance" (Granovetter 1985, pp. 27). The Stanford Professor highlights the unique business culture in Japan, where personal relationships and friendships are the most important aspect of economic transactions. He explains that after work hours, businessmen go to bars and nightclubs, "where the vital personal contacts are established and nurtured slowly. Once these ties are set, they are not easily undone" (Granovetter 1985, pp. 33). People in business often speak about the distinct social norms and business culture in Japan, and most Americans and Europeans are shocked when they conduct deals with the Japanese. Here, Granovetter stresses the influence of longstanding interpersonal relationships on business in Japan. Similar elements reveal themselves in my exploration of the sociological structures and culture that exist in high-technology regions, specifically in Silicon Valley.

## Methodology

Before diving right into the venture capital aspect of my research, I concluded that it would be necessary to explore high-technology regions. More specifically, I wanted to apply Saxenian's case study of Silicon Valley and further examine the sociological structures that contributed to the distinct collaborative culture that emerged in this tech-region. I selected Saxenian's case study because it highlights certain sociological elements including the Wagon Wheel, job-hopping, and the importance of social networks in the knowledge economy. These are phenomena that I will explore in the next sec-



tion. After researching the sociology of Silicon Valley as a high-tech cluster, I then focused on the role of venture capital as an economic agent within Silicon Valley. Compared to other regional economies, venture capital plays a distinct role in the Bay Area by linking the twelve economic agents together – this is another concept I will examine in the next section. In this paper, you will find my discoveries about the emergence of high-technology regions, the sociological structures that exist in Silicon Valley, and the distinct role that venture capital firms play in this high-tech cluster.

## Findings

As I mentioned in the introduction, my fascination with knowledge economies and high-technology regions emerged from my exploration of AnnaLee Saxenian's case study on the rise of Silicon Valley. My interest in technology, start-ups, and entrepreneurship leads me to question why high-tech clusters are regionally concentrated. I will introduce this section by exploring Saxenian's case study because I believe it is critical in understanding the process of the emergence of a high-technology cluster.

### Silicon Valley as a 'Distinctive Technology Community'—Saxenian Case Study

Saxenian classifies high-tech clusters as 'regional industrial systems' that are composed of three key dimensions: local institutions and culture, industrial structure, and corporate organization (Saxenian and Societies 1996, pp. 7). These three dimensions are interwoven within the economy and shape the "social and institutional setting" of the regional economy. These dimensions are closely interconnected, and one dimension cannot function without the other.

A crucial point of study in her research is a comparison of Route 128 and Silicon Valley during the rise of the semiconductor computer industry; I will focus primarily on her analysis of Silicon Valley. She explains that Silicon Valley started as an agricultural economy, known for its fruit orchards, food processing industry, and distribution networks. In the 1940s, when Route 128 had become the center of electronics manufacturing, Santa Clara Valley was home to only a handful of electronics companies. However, during World War II,

the Bay Area was the ideal gateway to the Pacific theater, so many government military contracts were sent to the region, contributing to regional economic development. The valley wanted to model its own technology hub after Route 128 (Powell, 2005), which would result in a "distinctive technological community" (Saxenian and Societies 1996, pp. 13).

One of Saxenian's crucial arguments is the concept of the 'Wagon Wheel', which was a famous bar in Silicon Valley that became a social gathering place for networking (1996, pp. 32). The Wagon Wheel represents a social setting where information is shared, and knowledge circulates. The Wagon Wheel represents the uniqueness of Silicon Valley infrastructure in the sense that relationships are easier to develop than in any other region in the country. She claims that "informal communication was often of more value [...] in an industry characterized by rapid technological change" (1996, pp. 33). This ties into Mark Granovetter's theory of embeddedness and social relations: Granovetter highlights that social relations matter in economic transactions due to the development of trust (Granovetter 1985, pp. 24). Saxenian emphasizes the importance of social relations, explaining that people from competitor firms would exchange information to help themselves and each other. This was a foreign concept to people working on the East Coast in the 1940s where employees would be shunned for socializing with a competing firm. However, in Silicon Valley, people understood the benefit of feedback through personal ties: "Here [in Silicon Valley] they will not only sit down with you, but they will share the problems and experiences they have had. This is a culture in which people talk to their competitors" (Saxenian and Societies 1996, pp. 33).

In addition to employees engaging with people from competitor firms in the Wagon Wheel, Silicon Valley employees would switch around companies. Saxenian refers to this phenomenon as "job-hopping" and notes that this was a way for employees to gain fresh perspectives in the workplace (1996, pp. 34). Employees would bring previous knowledge and learning outcomes and apply them to new settings, where they would meet an entirely new team of colleagues, therefore expanding their social network. Saxenian explains that job-hopping not only became socially acceptable, but it became the norm in Silicon Valley. Silicon Valley employees

were confused as to why people on the East coast were staying at firms for the entirety of their careers (1996, pp. 35).

Now that I have provided an overview of the distinct sociological structures that are embedded in the high-technology region of Silicon Valley, I will now look at the way the venture capital industry operates. Many of the sociological structures put in place in Silicon Valley are also prevalent in the world of VC.

### **Venture Capital in Silicon Valley**

It is important to analyze Saxenian's case study of the sociological structures and culture of Silicon Valley when studying the venture capital community. The ways in which Silicon Valley defined itself — with the Wagon Wheel and job-hopping — strongly influenced venture capital. While venture capital was prevalent in Route 128, the role of the firms was drastically different from the role of VC firms out in Silicon Valley, and it is important to acknowledge these differences.

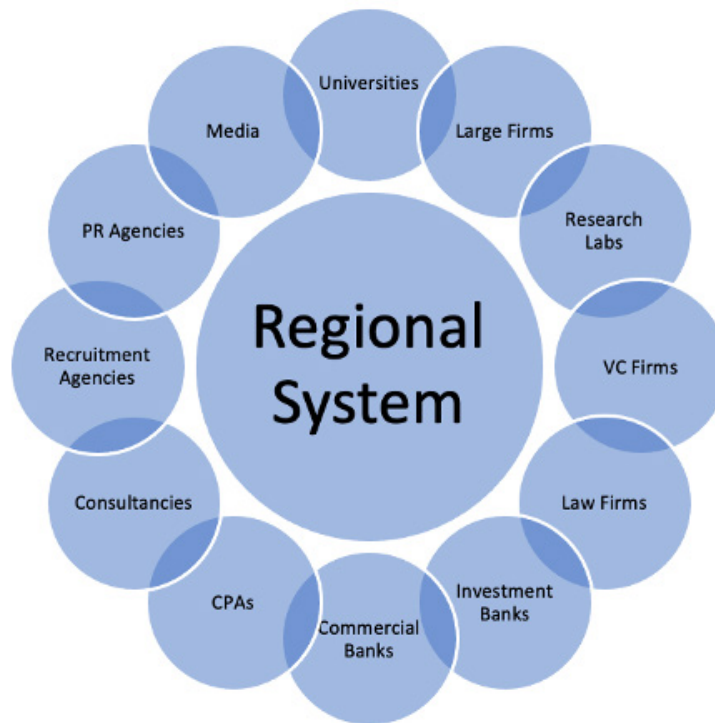
During the rise of the semiconductor industry, wealthy individuals started investing in early-stage startup companies in Route 128. However, venture capital solely consisted of providing financial support for a startup. Silicon Valley revolutionized venture capital since investors tended to be successful technology entrepreneurs themselves. Not only did venture capital investors provide funding, but they also provided mentorship and introductions to people in their social network to help their portfolio companies grow.

While there are numerous individual actors that make up a complex industrial system, venture capital was a critical catalyst in the creation of Silicon Valley as a high-technology region as it helped develop certain industries, contributing to overall macroeconomic health. Mark Granovetter and Michel Ferrary, a professor at the University of Geneva, published a study on *The Role of Venture Capital Firms in Silicon Valley's Complex Innovation Network*. In their paper, they introduce the Complex Network Theory (CNT), which stressed inter-firm interactions and social networks within venture capital specifically in Silicon Valley. The main purpose behind CNT is to analyze the variety of interactions among numerous actors in an industrial system (Ferrary and Granovetter 2009, pp. 326). For instance,

Frederick Terman, the father of Silicon Valley and a Professor at Stanford University, gave the initial \$500 to his students, the co-founders of Hewlett-Packard (Saxenian and Societies 1996, pp. 35). In this case, Stanford University, an actor in the complex network, had ties to students. The students became founders and joined the startup network. Economic and financial ties were formed between these agents, and as Granovetter and Ferrary note, "Innovation and entrepreneurship are understood as resulting from the interactions of numerous economic agents" (2009, pp. 326). The idea behind their paper is that complex industrial systems are made up of nodes and ties — nodes being agents (companies, universities, venture capital firms) and ties being financial and economic linkages. Thus, innovation occurs.

When entrepreneurs are more embedded within social networks and have more ties to economic agents, there is a greater chance they relate to venture investment, which ultimately accelerates regional development, "The more connected an entrepreneur is, the better is his access to financial resources, to advice, to partners, and experts. According to CNT, the quality of interactions between agents determines the success of each agent and finally the achievement of the entire system" (Ferrary and Granovetter 2009, pp. 337). We can see this process if we look at the founding story of HP. The co-founders of HP were embedded in the network of Stanford University, so they were able to access the help of experts and investors, and they built HP in their garage. This ultimately benefited the entire entrepreneurial ecosystem — Silicon Valley. When entrepreneurs have more ties or relationships in the system — including organizations such as the university, venture funds, or corporate organizations — they are more likely to have access to the necessary resources to grow their business.

Venture capital played a uniquely critical role in the development of Silicon Valley as a high-tech region. Many high-tech clusters around the world have large universities, companies, and high-quality research laboratories, but the distinguishing feature of the Bay Area is the significant establishment of VC firms. In the next section, I will delve into the integration of venture capital firms within the overall high-technology cluster in Silicon Valley.



**Figure 1: 12 Actors in Regional System** (Ferrary and Granovetter)

## Venture Capital is an Integrated Agent in Silicon Valley

Ferrary and Granovetter argue that there are twelve key economic agents that play a role in the complex network of Silicon Valley, and that venture capital firms are the element that creates additional linkages and interactions, contributing to innovative dynamics that developed. There are twelve agents that are critical when creating a successful high-tech region and startup ecosystem: universities, large firms, research laboratories, VC firms, law firms, investment banks, commercial banks, certified public accountants (CPA), consulting firms, recruitment agencies, public relation agencies, and media (Ferrary and Granovetter 2009, pp. 335). Each of these agents must interact with each other as they each provide a different function. Going back to Saxenian's iconic example with HP, Professor Terman at Stanford University was the first angel investor of Hewlett-Packard when his two students wanted to create their own venture. The founders of HP also returned this favor and strengthened their relationship with Terman when it came to hiring and recruiting (Saxenian 1996, pp. 24). Terman introduced people who had come to him to the founders of HP, and they ended up getting jobs at the firm. This is just one example of how the different agents are intertwined in the creation of tech

regions and the development of successful startups. The role of the venture capitalist is not clearly defined, but VC investors provided guidance and connections for entrepreneurs so that they can grow their businesses. These connections could be a venture lawyer or an investment banker if the startup needs capital. Because of the uniqueness of the role of a venture capitalist, VC firms' roles in the complex network system "enables specific interactions between agents" that contribute to a successful startup ecosystem such as Silicon Valley. Below in Figure 1, is a representation of the twelve economic agents that comprise a regional technology cluster. From this we can visualize the variety and diversity of actors that are involved in the greater regional economy that Saxenian discusses in her examination of Silicon Valley.

When looking at the economic ties among the twelve agents in a high-technology region, the agents with the most ties are the VC firms. There are the most interactions between the VC and the other eleven agents. The reason for this is because of informal functions. While there is one formal function of a venture capitalist, to finance startups, venture firms have infinite informal functions. According to Granovetter and Ferrary, some of these informal functions include selecting or sourcing start-ups, accumulating entrepreneurial knowledge,

embedding start-ups, and networking the cluster.

While it may be difficult to argue that VC firms are the ‘glue’ that hold the cluster of agents together, VC firms are the agents that ultimately fund start-ups and the additional ten agents:

*VC firms fund start-ups directly and other agents of an innovative cluster indirectly. A start-up partly uses its funding to pay for the services of law firms, consulting groups, PR agencies, and recruiting agencies. Through the funding of start-ups, VC investments sustain different service providers. Start-ups also use their funding to recruit employees trained in local universities. Thus, indirectly, VC funds the labor market of the cluster. The creation of start-ups is thus a business activity that involves different agents that are indirectly paid by VC money. For this reason, VC investment is more than just the funding of start-ups; it is, more broadly, a source of funding for the entire innovative cluster (Ferrary and Granovetter 2009, pp. 334).*

It is essentially venture capital firms that empower the network, starting with the funding of a startup. An example of this would be when a VC funds a start-up, and then the start-up needs to hire a law firm to patent an idea and needs to hire a consulting firm to get expertise on a product strategy. Technically the VC funds that go to the start-up are funding the operations of the law firm and the consulting agency.

Throughout my research, I focused on the applications of economic sociology, more specifically highlighting networks and social relations, on the emergence of high-technology regions and the role that venture capital plays as an economic actor in Silicon Valley. In the next section, I will elaborate on a few research limitations and future directions that I can take in the next steps of my research.

## Limitations and Future Directions

I conducted this research primarily in one semester, and one of my goals was to interview key people in the venture capital industry. However, due to a time

constraint and conflicts of interest among firms, I was unable to include my interview findings in this paper. Furthermore, I also wanted to explore the role of universities in startup creation and the development of high-tech clusters. In both Route 128 and Silicon Valley, research universities stimulated top caliber research that led to university spin-offs. In other words, the university acted as an entrepreneurial ecosystem, further promoting the regional economy. This next semester, I will be conducting a case study on Cornell University as an entrepreneurial ecosystem, examining the organizations on campus (accelerators, incubators, student-venture funds, clubs, and research labs) and the relationships among these organizations. By looking at the organizational sociology of Cornell’s entrepreneurial ecosystem, we can better understand what it takes to make a university more entrepreneurial, further promoting Ithaca as a tech region.

## Conclusion: Importance of Using Sociology to Study High-Technology Regions and VC

At first, one might not see the connection between sociology, high-technology regions, and venture capital. Start-ups, entrepreneurship, and venture capital are all about the network effect and social relations. As Mark Granovetter argued, social relations and networks are critical in economics. Silicon Valley is probably the most successful and fastest-growing tech-region, and this is attributed to the collaborative sociological structures that existed in the first place. From colleagues chatting after work or entrepreneurs discussing their business ideas to investors at the Wagon Wheel, no other tech-region embraced these social norms. In order to recreate the emergence of tech clusters like Silicon Valley, other regions such as Austin, TX and Salt Lake City, UT should also embrace these distinct sociological structures and practice mimeticism of Silicon Valley.

## References

Anon. 2012. *Inequity in the Technopolis*. University of Texas Press.



- Bresnahan, Timothy, Alfonso Gambardella, and Annalee Saxenian. 2001. "Old Economy' Inputs for 'New Economy' Outcomes: Cluster Formation in the New Silicon Valleys." *Industrial and Corporate Change* 10:835–60.
- Bubna, Amit, Sanjiv R. Das, and Nagpurnanand Prabhala. 2020. "Venture Capital Communities." *Journal of Financial & Quantitative Analysis* 55(2):621–51. doi: 10.1017/S002210901900005X.
- Cravens, Hamilton. 2003. "Richard Swedberg: Max Weber and the Idea of Economic Sociology,." *Isis* 94(4):745–46. doi: 10.1086/386463.
- Feldman, Maryann P. 2001. "The Entrepreneurial Event Revisited: Firm Formation in a Regional Context." *Industrial and Corporate Change* 10(4):861–91. doi: 10.1093/icc/10.4.861.
- Ferrary, Michel, and Mark Granovetter. 2009. "The Role of Venture Capital Firms in Silicon Valley's Complex Innovation Network." *Economy and Society* 38(2):326–59. doi: 10.1080/03085140902786827.
- Fleming, Lee, Lyra Colfer, Alexandra Marin, Jonathan McPhie, John F. Padgett, and Walter W. Powell. 2012. "Why the Valley Went First: Aggregation and Emergence in Regional Inventor Networks." Pp. 520–44 in *The Emergence of Organizations and Markets*. Princeton University Press.
- Granovetter, Mark. 1973. "The Strength of Weak Ties | Sociology." Retrieved September 3, 2021 (<https://sociology.stanford.edu/publications/strength-weak-ties>).
- Granovetter, Mark. 1985. "Economic Action and Social Structure: The Problem of Embeddedness." *American Journal of Sociology* 91(3):481–510.
- Hamdouch, Abdelillah. 2007. "Innovation Clusters and Networks: A Critical Review of the Recent Literature."
- Mayer, Heike. 2011. "Entrepreneurship and Innovation in Second Tier Regions." *Entrepreneurship and Innovation in Second Tier Regions*. doi: 10.4337/9780857938695.
- Owen-Smith, Jason, and Walter W. Powell. 2004. "Knowledge Networks as Channels and Conduits: The Effects of Spillovers in the Boston Biotechnology Community." *Organization Science* 15(1):5–21. doi: 10.1287/orsc.1030.0054.

# Employment-Related Depression and Analyses of Potential Treatment

By Marah Selim

*Department of Science & Technological Studies, College of Agriculture and Life Sciences*

## Abstract

According to the National Institute of Mental Health Disorders, approximately 26% of Americans suffer from a diagnosable mental disorder any given year. An association between mental illness and socioeconomic status has been found in several studies. This project has both scientific and ethical goals. The scientific goals review the various treatments available to socioeconomic- and employment- related depression disorder. This includes identifying and comparing the efficacy of each treatment and describing any limitations of the methods used and subsequent findings. Ethically, this research aims to shed light on the limitations in our mental healthcare system and political biases that hold us back from development in this area. To provide a tentative solution for the aforementioned challenges, this paper provides a comprehensive analysis of several depression treatments, that cater to the patients' specific needs in terms of type of illness and social class, and explain the reality of treatment accessibility in today's climate. Our results showed that, although only 50% of depression patients are properly treated, it is within our power to treat many more individuals suffering from this illness. However, finding the right treatment requires a lot of patience and persistence which are two traits that depression tends to debilitate. From a safety perspective, this study emphasizes the need to discuss any potential route of treatment with a mental healthcare provider that can assist in narrowing down the most suitable options.

**Keywords:** quality of life, agency scope, depression, mental health, cognitive therapy, precarious prosperity, neo-liberalism, capitalism, poverty, insecurity, layoffs, insomnia

## Job Security and Mental Illness

Socioeconomic status, the social standing or class of an individual or group, is often measured as a combination of education, income, and occupation but it is also important to consider race, gender, and access to mental health services when assessing its association to mental illness. The type of occupation, stress levels, and precariousness of employment play a salient role in life satisfaction by determining income level and an overall sense of purpose. There are two proposed hypotheses for this correlation: the social causation hypothesis claims that low economic status causes depression while the social selection hypothesis states that it is actually depression that causes low economic status (Zimmerman & Katon, 2005). The primary aim of this multi-dimensional literature review is to assess the evidence of effects of low socioeconomic status on mental health. The purpose

is to (i) provide summary effect estimates and grading of evidence quality - where adequate evidence can be obtained - which can be used for policy and health economics decisions; (ii) determine the most effective intervention methods in helping people with mental illness in recovery and achieving a source of income; and (iii) raise attention to areas where evidence is scarce or lacking to provide directions for future research.

*Precarious employment* is defined as a "set of conditions such as temporary contact forms, lack of bargaining power and rights, vulnerability in the employee-employer relationship, employment insecurity, and insufficient wages" (Ronnblad et al., 2019). The three main groups of precarious workers are 'atavists', 'nostalgic' and 'progressives'. Atavists are former working class members who have lost their access to secure or meaningful employment and, thus, lost their 'past'. Nostalgic are migrants and ethnic minority members who have

left their home countries and, unable to find meaningful work in their new countries, lack a ‘present’. Progressives are educated members of the precariat who do not have access to a career path, thus also lacking a ‘future’ (Standing, 2014). What unifies them all is the overarching alienation and insecurity of precarity. This type of occupational instability is a social determinant that is strongly associated with adverse health outcomes.

These factors contribute to a turbulent work environment, in which employees do not have security or power. Not only is it unpredictable how long the individual will have the job, but even when they are employed, they aren’t guaranteed liveable wages as employees. In addition, there is no opportunity to develop new skills through internships and job training as there is in a more traditional work setting. This leaves so-called *Precariats* in stagnant positions with no career prospects, incapable of moving up the employment ladder since they are not given the time and resources to succeed.

Mental illnesses are health conditions involving changes in emotion, thinking, or behavior. Socioeconomic status and mental illness are both complex terms that constitute an array of causes and effects but several studies have reported that precarious workers have an increased vulnerability to psychological distress and suicidal ideation (Kachi et al., 2014). Employment status is one of the most important components of socioeconomic status, which is also related to an individual’s resource availability and psychosocial conditions associated with exposure to stress. The linkage between class position and mental disorders has been found to be especially strong in affective and psychotic disorders (Hollingshead & Redlich, 2007). This negative association is most common in individuals diagnosed with depression, bipolar disorder, and schizophrenia.

Since precarious employment is associated with several socioeconomic factors related to poorer mental health, socioeconomic factors could have inductive effects on the correlation between precarious employment and mental health in workers. However, it was found that even when controlling for potential confounding variables, precarious employment was significantly associated with experiencing depressive mood among adult wage workers (Han et al., 2017).

## Race and Gender

Given systemic and structural issues such as gentrification and the mass privatization of healthcare in America, it would be expected that racial/ethnic minorities would struggle more with mental illness. High unemployment is conceptualized as a stressor having serious effects on individuals’ mental health. Workers who lose employment due to economic downturn experience stress from economic hardship and the stigma of job loss. To regain employment, workers may settle for underemployment in low-skill, often part-time jobs, experiencing possibly steep declines in income. Exposure to structural risk, deriving from race-specific unemployment rates that exceed overall national rates, along with, during recession, their relative vulnerability to economic and emotional insecurity (fear of job loss or income loss, difficulty finding employment), means greater stress for Blacks compared to Whites, and higher probability of chronic mental illness. African Americans’ high unemployment rates are rather stable but susceptible to growth during recessions. Moreover, it was found that Whites are more likely to get mental health counseling during primary care consultations and more likely to have access to and to use mental health services to address symptoms of mental illness. This suggests that perhaps the reason for the NSDUH data showing that Whites suffer from more chronic mental illness may just be a factor of self-awareness and willingness to report.

With this considered, we would expect diversity training to be a major factor of psychotherapy—however, it is not. In their research, Hook and colleagues (2016) found that therapists, regardless of their race, all too often respond to Black, Indigenous, and other Persons of Color (BIPOC) clients with tell-tale signs of *cultural discomfort*, such as denial and avoidance. A therapist’s cultural comfort is defined as the ease, openness, and non-defensiveness with which one ought to address salient sociocultural issues with clients (Bartholomew et al., 2021). However, multicultural theory, teaching, and research in psychotherapy thus far has tended to focus on increasing knowledge of BIPOC in ways that center “Whiteness” or prioritize the feelings and experiences of White people, thus neglecting issues such as liberation, social justice, and racial and historical trauma (Singh et al., 2020). Of course, the experience of racialized emotions is often intersectional, so it cannot be divorced

from other systemic or social structures. As such, therapists' cultural comfort when discussing anti-Black racism in session may have added gendered, class-based, and other social dimensions worth addressing.

## Vocational Rehabilitation as a Form of Treatment

Persons with severe mental illness have lower employment rates than other disability groups and while there has been government initiative to tackle this problem, labor force participation is still generally reported to be less than 50% among individuals with severe mental illness living in the United States (Andrews et al., 1992). The two most prominent government-funded programs are SSI and SSDI: SSI provides a fixed amount of money for persons with a disability who are in financial need, without regard to their work history but the payments actually decrease as earnings increase. Specifically, earnings about \$65 in each month reduce benefits by \$1 for every \$2 earned. SSDI payments are based on the amount a person paid in Social Security payroll taxes prior to becoming disabled, meaning those who paid more receive higher benefits. However, even with financial stability, people with schizophrenia, bipolar disorder and similar illnesses often want to work in competitive jobs, for their own satisfaction as well as for economic reasons (Alverson et al., 1995).

Supported employment was defined, in the Rehabilitation Act Amendment of 1986, as a federal program intended for "individuals who, because of their handicaps, would not traditionally be eligible for vocational rehabilitation services" (Bond et al., 1997). There have been several programs developed over the years to tackle this issue of income insecurity in the disabled. The 'place-then-train' and 'choose-get-keep' were among the most common, and successful, models. In the 1950s, the Fountain House of New York City pioneered the innovative approach to helping people with severe mental illness adjust to community living. They created a space, which they named the clubhouse, where people suffering from mental illness can socialize and participate in work units as part of the work-ordered day. Researchers found that participants benefited from participation in the clubhouse, in large part because they felt needed in their micro-society (Beard et al., 1982). This program pioneered transitional employment by putting

people in these safe spaces where they feel comfortable and confident in the environment in which they work. Eventually, as patients seek treatment and build up their résumés, it becomes easier to participate as a working member of the larger community.

Since the establishment of the Fountain House, many other mental health treatment programs have taken a similar approach to assisting individuals get back into the real world; one such approach was Wehman's (1986) 'place-then-train' philosophy which targeted people with the most severe disabilities, who were mostly ignored by traditional employment programs, and minimized prevocational assessment. The program was supported by on-site job coaches who intensively trained clients in their work roles and provided unlimited support.

Another example is the 'choose-get-keep' model that was developed by Danley and Anthony (1987). The choose-get-keep model is a supported education program, meaning it allows people to participate in an education and/or training program, alongside their mental health services, that would allow them to achieve their learning and recovery goals and become gainfully employed in the job or career of their choice. This program places a larger emphasis on career planning over building a history so that clients can select, obtain, and maintain jobs. The idea behind this is that allowing the client to find a career path they feel happy in will only magnify the improvements from the mental health services they are enrolled in.

These rehabilitation programs proved to be successful but it was found that the time-frame of the study played a big role in client outcomes and job retention (Bond et al., 1997). Studies utilized either an accelerated program or a gradual one. Accelerated programs put participants onto supported employment services immediately after study admission. Examples include working as a store clerk or cashier, but having the support of job coaches providing systematic instructions and intensive preparation so that they may succeed in their tasks. On the other hand, gradual programs required four months of prevocational work readiness training before participants were eligible for supported employment. Though it was hypothesized that taking it slow and easy with a gradual program would produce the best results, this



method proved ineffective when looking at long-term outcomes. One year after the study, it was found that clients in the accelerated program had modestly better employment outcomes than clients in the gradual condition (Bond et al., 1997).

Evaluations of vocational interventions typically compare wages earned but fail to recognize how earnings affect participants' total income, including SSI, SSDI, food stamps, access to further education and training and so forth. Under current conditions, work appears to contribute relatively little to income growth for persons with mental illness, but it has been shown to help people out of social isolation and boost their self-confidence.

## Antidepressants, and Cognitive Therapy

The impact of depression on occupational productivity is an issue of profound social and economic importance. The direct workplace cost of depression to the United States in terms of lost time at work has been estimated at more than 172 million days yearly, based on 3% to 5% -month prevalence rates for major depression (Dew et al., 1991). Effective treatment of depression should thus reduce work impairments in individuals suffering from depressive disorders and speed their return to optimal occupational functioning. The success of mental disorder treatment can be measured according to incidence, re-entry into treatment, continuity of treatment, and prevalence.

The NIMH-funded Sequenced Treatment Alternatives to Relieve Depression (STAR\*D) trial is the largest and the longest study ever conducted to evaluate depression treatment. There were four stages of treatment examined in order to determine which is most effective in treating Major Depressive Disorder (MDD). Each of the four levels of the study tested a different medication or medication combination and those who did not become symptom-free could not proceed to the next level of treatment. In order to produce results that could be generalized to a broad group of real-world patients, most adults with MDD were eligible.

In most clinical trials of treatment for depression, the measure of success (outcome) is called 'response' to

treatment, which means that the person's symptoms have decreased to at least half of what they were at the start of the trial. In STAR\*D, the outcome measure was a "remission" of depressive symptoms—becoming symptom-free. This outcome was selected because people who reach this goal generally function better socially at work, and have a better chance of staying well than do people who only achieve a response, but not a remission.

In level 1, participants were given the antidepressant citalopram, a serotonin reuptake inhibitor (SSRI), for 12 to 14 weeks. Those who became free of their depression symptoms during this time could move on to a 12-month follow-up period during which the citalopram was continued, and patients were monitored. However, those who experienced intolerable side effects or did not become symptom-free during this level were moved up to level 2.

In this next level, participants had the option of switching to a different medication or adding on to the SSRI they had already been administered. Those who joined the 'switch' group were randomly assigned to either sertraline, bupropion-SR, or venlafaxine-XR. On the other hand, those who joined the 'add-on' group were prescribed either the non-SSRI antidepressant bupropion-SR or buspirone, which is not an antidepressant but enhances the action of an antidepressant medication. Participants also had the option to switch to, or add on, cognitive psychotherapy. As in level 1, those who became symptom-free with their level 2 treatment could continue with that treatment, and entered the 12-month-follow-up period. The cycle continued and the researchers continued finding alternative medication for those who were not symptom-free, or experienced intolerable side effects. The medications prescribed in levels 3 and 4 differed from SSRIs and other medications used for previous levels in the way they worked in the brain.

It took an average of six weeks of treatment for participants to improve enough to reach a response and nearly seven weeks of treatment for them to achieve a remission of depressive symptoms. Over the course of all four treatment levels, almost 70% of those who did not withdraw from the study became symptom-free, which should serve as a sign of hope for those suffering with treatment-resistant depression. These results should

further bolster psychiatrists looking into individualized treatment plans, emphasizing that, more often than not, there is a treatment to be found for each and every client. The optimism of these findings could help motivate patients to continue on their healing journey, with a high chance of being reintegrated into society through employment or any other sort of fulfillment they may have lost to the illness.

With the knowledge that depression can adversely affect occupational functioning, it is helpful to consider whether there is a relative advantage of cognitive therapy or antidepressant in improving employment status. Few studies have examined the differential effects of psychotherapy and medications on employment status. One of the most prominent is a 1992 study, by Mintz and colleagues, which was a comprehensive review of the association between therapy and antidepressant treatment, and improvements in occupational functioning by acquiring and examining data from ten treatment studies. However, the results of the study were rather dubious, indicating that psychotherapy was no more effective than the sugar-pill placebo. A more recent meta-analysis by Timbie and colleagues (2006) examined the effects of depression treatments on more objective indicators of work outcomes, such as number of hours

or days worked and employment status. Across all four studies they looked at, the estimated effect of treatment v. control on improving work-related functioning was small.

Fournier and colleagues (2015) also looked at this comparison between therapy and medication. Over a 28 month period, they randomly assigned participants either to cognitive therapy (n=48) or the SSRI paroxetine (n=93). Acute cognitive therapy and antidepressants were provided for 16 weeks and depression symptom severity was assessed weekly with the Hamilton Rating Scale for Depression (HRSD) while the Longitudinal Interval Follow-up Evaluation (LIFE) was used to track changes in employment status. For the first 8 weeks, antidepressant medication treatment was provided with paroxetine monotherapy. For the remaining 8 weeks, augmentation of paroxetine was desipramine, or lithium was allowed if clinically warranted. Following acute treatment, half of the antidepressant group responders were randomized to continuation medication (continuation antidepressant subgroup) and half to withdrawal onto a pill-placebo (placebo withdrawal subgroup). Cognitive therapy responders ceased regular contact with their therapists following acute treatment and were allowed up to three booster sessions.

Table 1 Intake employment status by condition and site

	University of Pennsylvania, <i>n</i> (%)	University of Pennsylvania, <i>n</i> (%)	Vanderbilt University, <i>n</i> (%)	Vanderbilt University, <i>n</i> (%)
	Antidepressant group ( <i>n</i> = 39)	Cognitive therapy group ( <i>n</i> = 22)	Antidepressant group ( <i>n</i> = 54)	Cognitive therapy group ( <i>n</i> = 26)
Full time	23 (59)	8 (36)	38 (70)	19 (73)
Part Time	10 (26)	7 (32)	9 (17)	3 (12)
Unemployed	6 (15)	7 (32)	7 (13)	4 (15)

*Note.* From "Gains in employment status following antidepressant medication or cognitive therapy for depression," by Fournier et al., 2015, *The British Journal of Psychiatry*, 20, p. 335.

It was found that individuals who responded to a 4-month course of cognitive therapy were more likely to be employed full time 2 years later than were participants who responded to antidepressant medication (Table 1). The rate of full-time employment improved from 56% at intake to 89% at the end of follow-up for the cognitive therapy group (33 percentage points in total), but it only improved by 5 percentage points in the

antidepressant group, from 66% at intake to 71% at the end of follow-up. The main difference between the two groups is that the effects of cognitive therapy seemed to have lasted beyond the actual treatment period, meanwhile, affect improvement by antidepressant treatment seemed to only be a temporary fix that relied on medication continuation.

## Discussion

From the two main forms of vocational rehabilitation (place-then-train and choose-get-keep) to the comparison between antidepressants and cognitive therapy, research has identified many methods that may assuage the negative association between socioeconomic status and depression. Evidently, there is some truth in both the social causation hypothesis and the social selection hypothesis.

The concept of transitional employment as seen in vocational rehabilitation programs adopts this philosophy of social causation, that low economic status causes depression, and aims to halt this cycle by helping unemployed persons find a stable income. On the other hand, studies looking at anti-depressant treatments and cognitive therapy – such as the STAR\*D study—take an approach following the social selection hypothesis. To reiterate, this hypothesis claims that it is actually depression that causes low economic status. Therefore, it should be expected that helping patients find treatment for their illness should serve as a preventative measure against financial instability. Of course, it is not black and white but understanding these two hypotheses allows us to adapt to any given situation.

The results from STAR\*D study emphasize the need for high-quality care and attention to the individual needs of patients. Doctors should provide medication at optimal doses, be aware of and offer treatment choices, and maintain diligent monitoring of patients both during treatment and after they become symptom-free so as to avoid relapse. Like other medical illnesses, depression affects different people in different ways, but a wide range of effective treatments exist. Using the rate of “remission” of depressive symptoms as a measure of success, the results of this study were very optimistic. The study showed that over the course of all four treatment levels, almost 70 percent of those who did not withdraw from the study became symptom-free. Considering that the typical statistics for antidepressants show a 50 percent success rate—if not less—these results offer promising hope of recovery if only doctors and patients are patient enough to see the treatment through. This also indicates that these individuals would be ready to get back into the employment field and find fulfillment in their contributions to society, while also being able to

support themselves financially. However, the employment field they enter is crucial to their wellbeing beyond treatment. Precariats, whether Atavists, Nostalgics, or Progressives, face a condition that is sure to bring about a lot of psychological distress for an individual but these findings present a compelling argument for future policy implications to mitigate these issues.

Taking into consideration the multi-faceted definition of socioeconomic status is an integral aspect to understanding the results of this work. All too often, race is disregarded in favor of a lens focusing solely on economic status. In most of the studies addressed in this meta-analysis, race and gender were sidelined in favor of other aspects of socioeconomic status but it is important to understand intersectionality and develop interventions on that basis. Moreover, future research should consider how earnings affect a participants' total income, including SSI, SSDI, food stamps, access to further training, and training and so forth.

## References

- Bartholomew, T., Perez-Rojas, A., Bledman, R., Joy, E., & Robbins, K. (2021). “How could I not bring it up?": A multiple case study of therapists' comfort when Black clients discuss anti-Black racism in sessions. <https://doi.org/10.31234/osf.io/4dbt5>
- Beard, J. H., Propst, R. N., Malamud, T. J. (1982). The Fountain House model of rehabilitation. *Psychosocial Rehabilitation Journal*, 5(1), 47-53.
- Bulhan, H. A. (1980). Frantz Fanon: the revolutionary psychiatrist. *Race & Class*, 21(3), 251–271. <https://doi.org/10.1177/030639688002100303>
- Danley, K. S., Anthony, W. A. (1987). The choose-get-keep model: a step into the future. *Psychosocial Rehabilitation Journal*. 13(4): 6-9, 27-29.
- Dew MA, Bromet EJ, Schulberg HC, Parkinson DK, Curtis EC. (1991). Factors affecting service utilization for depression in a white collar population. *Soc Psychiatry Psychtr Epidemiol*. 1991;26:230-237.
- Feather, N. (1990): The Psychological Impact of Unemployment. *Springer-Verlag*.

- Fournier, J. C., DeRubeis, R. J., Amsterdam, J., Shelton, R. C., Hollon, S. D. (2015). Gains in employment status following antidepressant medication or cognitive therapy for depression. *The British Journal of Psychiatry*, 206, 332-338. <https://doi.org/10.1192/bjp.bp.113.133694>
- Gary, T. L., Stark, S. A., & LaVeist, T. A. (2006, August 14). Neighborhood characteristics and mental health among African Americans and whites living in a racially integrated Urban Community. *Health & Place*.
- Hamilton, M. A. (1960). A rating scale for depression. *J Neurol Neurosurg Psychiatry*, 23: 56-62.
- Han, K.-M., Chang, J., Won, E., Lee, M.-S., & Ham, B.-J. (2017, April 28). Precarious employment associated with depressive symptoms and suicidal ideation in adult wage workers. *Journal of Affective Disorders*. <https://doi.org/10.1016/j.jad.2017.04.049>
- Hollingshead, A. B., & Redlich, F. C. (2007). Social class and mental illness: a community study. 1958. *American journal of public health*, 97(10), 1756-1757.
- Hollon, S. D., DeRubeis R. J., Shelton, R. C., Amsterdam, J. D., Salomon, R. M., O'Reardon J. P. (2005). Prevention of relapse following cognitive therapy vs medications in moderate to severe depression. *Arch Gen Psychiatry*, 62: 417-22.
- Hook, J. N., Farrell, J. E., Davis, D. E., DeBlaere, C., & Van Tongeren, D. R. (2016). Cultural humility and racial microaggressions in counseling. *Journal of Counseling Psychology*, 63, 267-277. doi:10.1037/cou0000114
- Kachi, Y., Otsuka, T., Kawada, T. (2014). Precarious employment and the risk of serious psychological distress: a population-based cohort study in Japan. *Scand. J. Work Environ. Health* 40, 465-472.
- Lo, C. C., & Cheng, T. C. (2014). Race, unemployment rate, and chronic mental illness: A 15 year trend analysis. *Social Psychiatry and Psychiatric Epidemiology*, 49(7), 1119-1128. <https://doi.org/10.1007/s00127-014-0844-x>
- Mintz, J., Mintz, L. I., Arruda, M. J., Hwang, S. S. (1992). Treatments of depression and the functional capacity to work. *Arch Gen Psychiatry*, 49: 761-8.
- Rönnblad, T., Grönholm, E., Jonsson, J., Koranyi, I., Orellana, C., Kreshpaj, B., Chen, L., Stockfelt, L., & Bodin, T. (2019). Precarious employment and mental health: a systematic review and meta-analysis of longitudinal studies. *Scandinavian Journal of Work, Environment, and Health*, 45(5). <https://doi.org/10.5271/sjweh.3797>
- SAMHSA (2009) National Survey on Drug Use and Health (NSDUH), *Department of Health and Human Services, Substance Abuse and Mental Health Services Administration*
- Singh, A. A., Appling, B., & Trepal, H. (2020). Using the multicultural and social justice counseling competencies to decolonize counseling practice: The important roles of theory, power, and action. *Journal of Counseling & Development*, 98(3), pp. 261-271. <https://doi.org/10.1002/jcad.12321>
- Spitzer, R., Williams, J., Gibbon, M., First, M. (1990). Structured Clinical Interview for DSM IIR Personality Disorders (SCID-II, Version 1.0). *American Psychiatric Press*.
- Stein, L. I., Test, M. A. (1980). Alternative to mental health program: conceptual model, treatment program, and clinical evaluation. *Archives of General Psychiatry*. 37: 392-397.
- Timbie, J. W., Horvitz-Lennon, M., Frank, R. G., Normand, S. L. T. (2006). A meta-analysis of labor-supply effects of intervention
- Warr, P., Jackson, P., Banks, M. (1988). Unemployment and mental health: some British studies. *J Soc. Issues*, 44: 47-68. <https://doi.org/10.1111/j.1540-4560.1988.tb02091.x>
- Wehman, P. (1986). Supported competitive employment for persons with severe disabilities. *Journal of Applied Rehabilitation Counseling*, 17:24-29.
- Zimmerman, F.J., & Katon, W. (2005, June 8). Socio-economic status, depression disparities, and financial



strain: what lies behind the income-depression relationship? *Health Economics*, 14: 1197–1215. <https://doi.org/10.1002/hec.1011>

# Closer to Cayuga's Waters: An Evaluation System of the Invasive *Hydrilla* Species

By Zichen Wang, Mo Lyu, and Franklin Deng

Department of Mathematics and

Department of Computer Science, College of Arts and Sciences

## Abstract

In recent years, an invasive plant species, *Hydrilla verticillate*, has been identified to pose significant threats to the local ecology of Cayuga Lake. This paper aims to provide a practical, quantitative, and real time evaluation system that helps monitor and predict the population dynamics of the plant. The system includes two main parts: sampling and simulation. In Section 3, we discuss in detail our stochastic Monte Carlo simulation based on the enhanced *Invasive Plant Population Dynamic* (IPPD) model. Human activities, such as boating, are identified to greatly accelerate the spread of *Hydrilla*. In Section 4, we employ statistical methods to promote confidence in the sample results, which in turn guarantees more accurate simulation results. We provide an adaptive algorithm to calculate the minimum sample size in real time. Other than the practical utility of our study, there is also the theoretical importance in that various approaches discussed in this paper, such as the IPPD model and the adaptive algorithm, can serve as the basis for future work on this subject.

## 1. Introduction

To the north of Ithaca, Cayuga Lake stands as a landmark of the state and contributes to the mild local climate and supreme natural beauty. However, in recent years, an invasive plant species, *Hydrilla verticillate*, has been identified to pose significant threats to the local ecology of Cayuga Lake. *Hydrilla* is an aggressive submersed perennial plant. As an invasive species, it out-competes native plants and creates a monoculture that disrupts the balance of the local ecosystem. *Hydrilla*'s potato-like "tubers" that grow in the bed of the lake make herbicides largely ineffective in the long term (New York Invasive Species Information, 2019). Despite various efforts to eradicate the species, new locations of *Hydrilla* have been continuously spotted, and early detection of these new locations remains at present the optimal way to control their spread. Given limited time and human resources, there is thus an urgent need of a scientific evaluation system that monitors new *Hydrilla* spots in real-time and predicts their future developments.

We come to our evaluation system by essentially answering the following questions:

- What factors contribute to the growth and

spread of the plant?

- What would the natural spread pattern of the plant be like?
- How can we accurately and timely monitor the current distribution of the plant?
- How do human activities, such as boating and chemical treatment, influence the plant?

## 2. Assumptions and Justifications

To answer the first question from above, we need a closer examination of the habits of *Hydrilla*. This will also lead to some important assumptions and simplifications of our model used to predict the future developments of the plant. *Hydrilla* is a perennial species with a normal life span of 7 to 12 years. Considering that the Cayuga Lake *Hydrilla* Management Plan is made for a 5-year interval (Cayuga Lake *Hydrilla* Task Force, 2021), we set our model's simulation time length to 5 years and assume that all *Hydrilla* will not die within this time period. *Hydrilla* propagates primarily by stem fragments, although turions and subterranean tubers also play an important role. The main means of the introduction of *Hydrilla* is as castaway fragments on recreational boats

and trailers and in their live wells. Once the stem pieces get carried away to a new place, they grew to root their tubers in the substrate to establish new colonies. It is thus reasonable to use the number of tubers to represent the overall density of Hydrilla. As Hydrilla grows rapidly and caps at 6000 tubers per square meters (Missouli Stream Team, 2020), we further simplify our calculation by substituting the conventional logistic population growth model with exponential growth model that caps at 6000 tubers per square meter. This also coincides well with Auld's observation that invasive plant species have an exponential growth rate for a relatively long period (see Section 3). Figure 1 shows that when the growth rate is high, exponential growth with cap is a good approximation of the logistic growth.

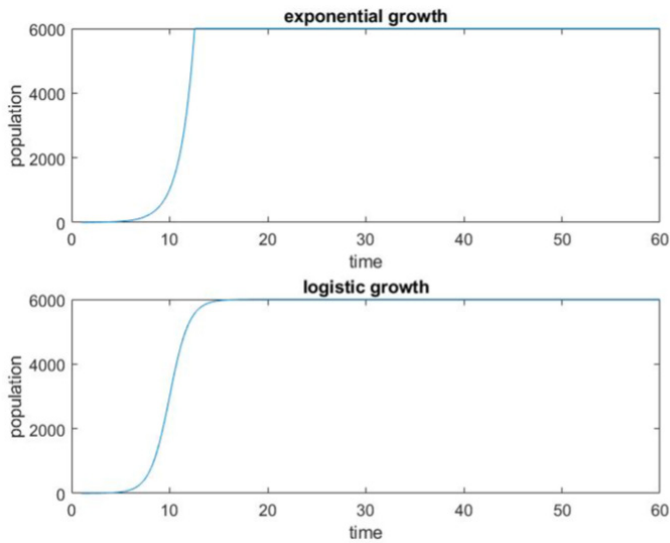


Figure 1: Comparison Between Two Population Growth Models

We also assume that the probability of spread fluctuates around a constant. That is, the probability of 35 spread at a certain area is independent of the population density at or around that area (Blackburn and Tueller, 1970). Finally, empirical evidence suggests that Hydrilla cannot grow in water regions deeper than 25 feet (7.62 meters) (New York Invasive Species Information, 2019), so we limit our consideration to water regions of 0-25 feet deep.

### 3. Simulation

In this section, we build a stochastic simulation model to predict the future spread of Hydrilla. We start by considering the simple setup where no human activity is present and identify plant growth and spread as two

main factors of our simulation model. Modifying historical models, we propose our Invasive Plant Population Dynamics (IPPD) model as a better fit for Hydrilla simulation. Geographical information and human activity are then supplemented to finish the simulation.

#### 3.1 Auld's Model

In 1980, Auld and Coote proposed the following classic model on invasive plant growth and spread in the natural environment (Auld & Coote, 1980).

$$P_n = P_{n-1}(1 + r)(1 - s) \quad (1)$$

Here  $P_n$  denotes the density of Hydrilla at time  $n$ .  $r$  is the population growth rate and  $s$  is the spread rate. According to Boughey in 1973, rather than the commonly used logistic function for population growth, empirical evidence suggests that invading plant species have a constant exponential increase rate for a relatively long period. Hence here  $(1 + r)$  indicates exponential growth. Auld further assumes that the fraction of spread  $s$  is a constant, given that the dispersing fraction from a location is relatively small in relation to the annual increment of the population. Thus  $(1 - s)$  denotes the remaining population that does not spread. As stated in Section 2, we will keep these two important assumptions in the following modeling.

#### 3.2 The IPPD Model

One major problem with Auld's model is that the already established plant and the newborn have the same probability of dispersing. Since Hydrilla has the distinctive feature that its tuber roots in the lake's bed, which makes it relatively immobile, not all population can spread. Instead, only the newly grown Hydrilla, whose root yet shallow and tuber not matured, should be able to spread. This leads us to revise the time-step equation as

$$\mathbb{E}[P_n(i, j)] = P_{n-1}(i, j)(1 + r(1 - s)) + \mathbb{E}[I_n(i, j)] \quad (2)$$

Here  $P_n(i, j)$  denotes the Hydrilla population (number of tubers) at position  $(i, j)$  at time  $n$ .  $I_n(i, j)$  is the spread increment at location  $(i, j)$  at time  $n$ , calculated by the increase in tubers via dispersing from other locations. Expected values are used to reflect the stochastic nature of our model.

Considering the rather mediocre mobility of Hydrilla, we adhere to Audl's model to set  $s = 0.05$  and the range of spread to be 3 units within the current location. Although such a  $s$  might seem arbitrary, later in sensitivity analysis we will show that the value of  $s$  would not effect the qualitative result of the simulation. The range of spread comes as a result of our choice of the bivariate normal distribution (see Section 3.2 for more detail). Since Hydrilla commonly grow to length over 9 meters and grow as fast as 0.3 meters a day (Schuyler County Soil and Water Conservation District), we make the assumption that every time a Hydrilla grows another 9 meters in length, it roots a new tuber in the lake's bed. In other words, a new Hydrilla is grown. Moreover, our time unit is set to a month and  $0.3m/day \times 30day/month = 9m/month$ , so the number of Hydrilla doubles in a month. Thus we have the formula for the growth rate:

$$r = \frac{9m}{0.3m \times 30day} = 1 \quad (3)$$

Another flaw of Audl's model is that for simplicity reasons, Audl assumes equal possibility to spread from a certain location to any place nearby within a certain range. This contradicts the simple intuition that more 75 population should disperse to locations closer to the source point. Hence, we keep the spread radius the same as 3 units nearby but change the probability distribution of the dispersal from a uniform distribution to a bivariate normal distribution. According to our setup, any place further than 3 units, by calculating the double integral of the normal distribution over the region, has probability near zero and can be omitted. The spread increment  $I(i, j)$  can be now calculated by the double integral of the population density times 80 the probability following normal distribution  $N(0, I)$ . Here  $f(x, y)$  denotes the probability density function of the normal distribution, which reflects the probability that Hydrilla spread from location  $(i+x, j+y)$  to  $(i, j)$

$$\mathbb{E}[I(i, j)] = \iint f(x, y) P(i+x, j+y) rs \, dx dy \quad (4)$$

Whether a newborn Hydrilla spread or not can be seen as a Bernoulli trial with probability  $s$  of success, so the total number of spread  $P_{n-1}rs$  follows a binomial distribution. As the number of tubers grows rapidly to a relatively large number, and according to the Central Limit Theorem, we can use normal distribution  $N(P_{n-1}(i, j)rs, P_{n-1}(i, j)rs(1-s))$  to approximate the ex-

periment result. In actual coding we introduce an intermediate variable  $E_n(i, j)$  as the Hydrilla population dispersing away from  $(i, j)$  at time  $n$ , generated by a random variable following the normal distribution. At program run time, we iterate all valid  $(i, j)$  in the map and calculate  $E(i, j)$  following the Bernoulli process. We then divide the dispersal by the bivariate 90 normal distribution and increment nearby units by the according amount. In other words,  $I(i, j)$  is not directly calculated during the simulation but comes as a sum of separate increments from nearby units. Theoretically we should obtain the same simulation result. To focus more on the change of a single unit within each iteration of time, we can express  $P_n(i, j)$  as

$$P_n(i, j) = P_{n-1}(i, j)(1+r) - E_n(i, j) + I_n(i, j) \quad (5)$$

We verify this approach by trying on a simple  $200 \times 200$  map, with the initial Hydrilla at the center 95 (100,100). The side length of a single unit is set as 44m in accordance to later simulations. After simulation of five years, the density of Hydrilla can be shown in the figure below:

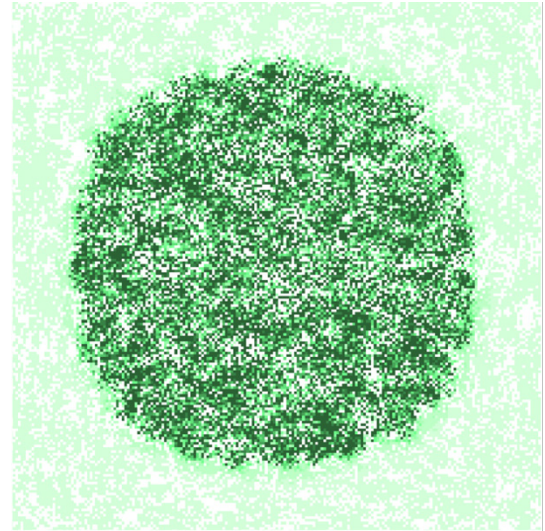


Figure 2: Single Source Spread Simulation

The darkest green signifies a density at 6000 tubers per square meters (the maximum density), while the lightest green represents a density of 0-42, as 42 is commonly used as a benchmark for high Hydrilla density (CMCM, 2021). In other words, a light green grid indicates that Hydrilla is at present in that grid, but only in a low density. After the region is left untreated for five years, Hydrilla has already spread across the entire region, and a large region around the center has a high level of density. Another interesting result is that instead



of a graduate change of color across the darkest-lightest boundary (we have in fact 10 different shades of greens in our program!), there is a clear, dramatic distinction between the dark green and the light green. That said, even though Hydrilla quickly spreads to cover the entire region, the area with high concentration grows at a slower rate. But once Hydrilla establishes itself at a new location, the area quickly grows into high concentration, which is explainable by the exponential setup of the model.

### 3.3 Running the IPPD Model over Cayuga Lake

The map of Cayuga Lake we use captures a region of  $51.04km \times 20.77km$  and is represented as a  $1160 \times 472$  matrix during coding. Each matrix unit thus represents a square with side length

$$\frac{51.04km \times 1000m/km}{1160} = 44m \quad (6)$$

Image processing technique based on OpenCV is employed to produce the gray-scale map that facilitates model coding. Canny edge detection algorithm is executed to produce the shoreline and the 25 feet water depth contour line. Since Hydrilla roots at most 25 feet deep water, we limit our consideration to the white region as seen in the following figures. According to the latest obtainable data from October 2020 (Hydrilla Community Conference, 2020), 36 spots of Hydrilla were found at the southern end of the lake and 3 spots found close to the town of Aurora. We set this as our model's initial state and obtain Figure 3 (see Appendix for high resolution Figure 3.3).

As can be seen in Figure 3, within one year of time dark green that signifies high concentrations of Hydrilla appears near initial spots. The initial small populations of Hydrilla start to establish themselves. Further away, more areas of light green cover nearby regions. This means that Hydrilla is at present at these places but has not established itself yet. By the end of the second year (Figure 3.2), the original light green areas have partially turned into dark green. A much larger area is now susceptible to high concentrations of Hydrilla. After five year's simulation, the Hydrilla continues to invade the rest of the east and south coasts. While the established areas turn darker in green, the spread speed of Hydrilla, to our surprise, dramatically slows down. In other words, the areas susceptible of high concentra-

tions of Hydrilla after five years differs little from the areas susceptible of high concentrations of Hydrilla after two years. Such results also attest the advantage of our model over Audl's model. By introducing geographical information into our IPPD model, we are able to not only predict the global developments, but also make local analysis of Hydrilla that are more sensitive to nearby geography, such as coasts and water depth. This is best seen in our analysis of how the west coast would be free of invasion. Tracking only the total number of Hydrilla, on the other hand, would lose all this information. As we will seen by the end of this section, this might also led to inaccurate results.

In comparison with the spread simulation in the plane (Figure 2), where the Hydrilla quickly spreads all over the map and continue to enlarge established areas, there seems to be an upper bound of the area that Hydrilla could spread. This gives the conclusion that certain geographical features of Cayuga Lake limits the spread of Hydrilla. One possible explanation is that the vast area with water depth more than 25 feet makes the growable region in long narrow strap shape, which in turn hampers the spread of the Hydrilla. Still, this is an unacceptably large area and certain actions need to be taken.

Next, we add boating to our model and verify it as a major contribution to the spread of Hydrilla. The magenta asterisks in the figures represent the marina locations (Tompkins County Planning and Sustainability Department, 2020). For simplicity reasons, we combine nearby marinas as one and give different weights to them according to their combined size (number of marinas, number of boats, etc.). This results in five locations to be considered: Beacon Bay (Cayuga), Frontenac Harbor (Union Springs), Don's (Genoa), Finger Lake Marine Svcs (Lansing), and City Harbor (Ithaca), with weight 3, 2, 1, 1, 3 at each location. We also make the assumption that there is one trip on the Cayuga Lake every day, whose departure and arrival location are randomly chosen from the marinas. In the real world, there are obviously much more boat trips, but for the purpose of this paper this simplification is sufficient to show how boating facilitates Hydrilla spread. Let  $m_i$  denote the weight of marina  $i$ , then the probability that on a given day, the trip is from marina  $a$  to marina  $b$  is:

$$p_{ab} = \frac{m_a m_b}{\sum_{i \neq j} m_i m_j} \quad (7)$$



Figure 3.1: After 1 Year.



Figure 3.2: After 2 Years.

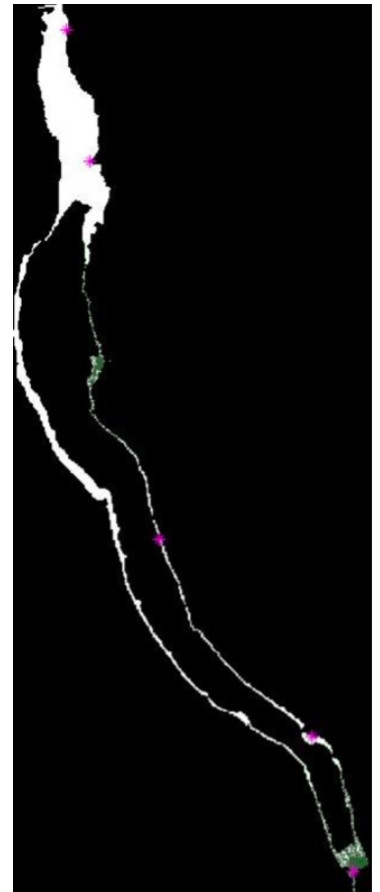


Figure 3.3: After 5 Years  
(No Boats).



Figure 4.1: After 1 Years.



Figure 4.2: After 2 Years.

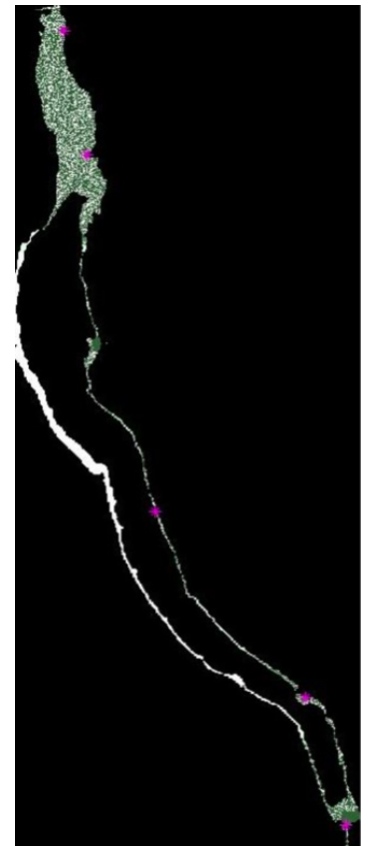


Figure 4.3: After 5  
Years (with Boats).

Therefore, we have the following matrix that represents each  $p_{ab}$  probability:

	Cayuga	Union Springs	Genoa	Lansing	Ithaca
Cayuga	0	$\frac{3}{38}$	$\frac{3}{76}$	$\frac{3}{76}$	$\frac{9}{76}$
Union Springs	$\frac{3}{38}$	0	$\frac{1}{38}$	$\frac{1}{38}$	$\frac{3}{38}$
Genoa	$\frac{3}{76}$	$\frac{1}{38}$	0	$\frac{1}{76}$	$\frac{3}{76}$
Lansing	$\frac{3}{76}$	$\frac{1}{38}$	$\frac{1}{76}$	0	$\frac{3}{76}$
Ithaca	$\frac{9}{76}$	$\frac{3}{38}$	$\frac{3}{76}$	$\frac{3}{76}$	0

Figure 5: Probability Matrix.

With the boating activity added to our model, we obtain our simulation results in Figure 4 (see Appendix for high resolution figure). Clearly a much larger area now has high concentrations of Hydrilla, including the entire north, east, and south part of the lake. The only part free of Hydrilla is the west coast of the lake. This makes sense as there is no marina on the west. In reality, however, boats might pass or temporarily stop along the west coast, which could lead to Hydrilla spread there. Figure 4.1 and Figure 4.2 help us to see how boating facilitate the spread of Hydrilla. Figure 4.1 shows that after one year of time new spots of Hydrilla showcase in all marinas, although in a small amount. This is no longer the case by the end of the second year. The area with presence of Hydrilla has significantly grown larger and they have established themselves around the marinas. From there Hydrilla continues to spread across and essentially covers the entire north of Cayuga lake. We conclude that boating significantly conduces Hydrilla spread by introducing the plant to new locations where it could not reach in natural settings.

Apart from the direct results from the figures, a quantitative analysis of the simulation also help us better support our conclusions. We keep track of the number of units that reach the maximum density of 6000 tubers per square meters, which reflects the total area that has the highest density. This combines the growth rate of Hydrilla with the global spread speed and serve as a good indicator of the overall situation. As can be seen in Figure 5, with boating added to our model, the Hydrilla continuously grow and spread at an exponential speed. In comparison, the Hydrilla reach the maximum

capacity much slower when the boat is not present. An initial thought would be that the total number of Hydrilla should grow at an exponential speed regardless of the spread, but in reality Hydrilla would grow to the maximum local capacity and thus slow down the growth rate of the total population. Another interesting observation is that around 27 months of simulation, we see a stark decrease in the increase rate of the maximum density area in the case without boat. This well supports our conclusion that “the areas susceptible of high concentrations of Hydrilla after five years differs little from the areas susceptible of high concentrations of Hydrilla after two years.” From another point of view, we verify the existence of an upper limit of Hydrilla spread in the natural setting.

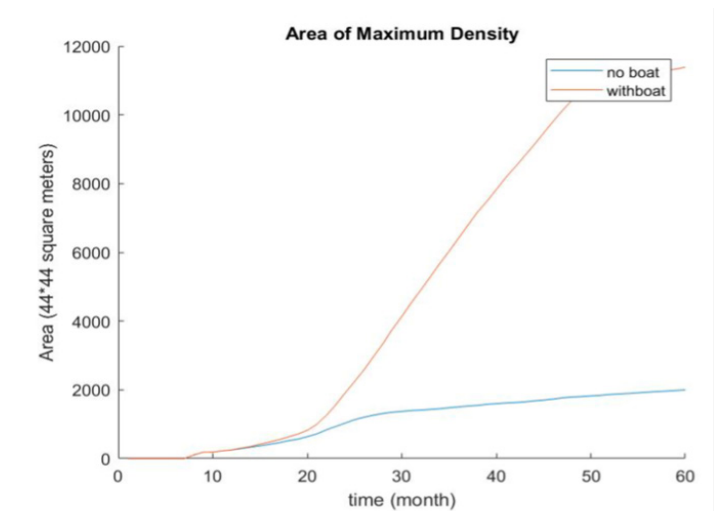


Figure 6: Area of Maximum Density.

## 4. Sampling

We have obtained the simulation model that predicts the future development of the plant. The question now is how do we determine the initial state of our model? The above simulations use available data in 2020, and clearly, the accuracy of such initial states would be crucial to good simulations. *Quantitative survey* provides a means to obtain accurate data for this purpose (Madsen, 1993). The current survey method at Cayuga Lake monitors previously treated sites by taking small samples of the sediment, called cores, and counting the number of tubers found in each core (CMCM 2021). The *sampling design* of the survey, such as the number of tubers to take, and the subsequent *statistical inference* of the survey results would then help generalize from local information of the samples to the overall situation

of Cayuga Lake (Madsen, 1993).

#### 4.1 Spencer's Logistic Regression

In 1994, Spencer D.F. published an important paper on subterranean propagules of submersed aquatic plants, including our most concerned *Hydrilla verticillata*. Spencer collected empirical data at Belle Haven Marina and environs, Potomac River, and Virginia, as well as historical records from Sutton and Portier (1985), Anderson and Dechoretz (1982), and Harlan, Davis, and Pesacreta (1985). The data summed up to 379 sample means and associated standard error from a total of 4942 cores (i.e. sample units). Using PROC REG in SAS (SAS Institute, 1988), Spencer claimed that the frequency distribution of Hydrilla follows not a normal distribution but a log normal distribution. Take  $\log(s^2)$  and  $\log(\bar{x})$  (all logs are in base 10) there exhibits a clear linear relationship between the two

$$\log s^2 = 1.7039 + 1.2668 \log \bar{x} \quad (8)$$

Here  $\bar{x}$  is the average number of tubers per square meters of the samples and  $s$  is the sample standard deviation.

#### 4.2 The Baseline Approach

The current sampling design at Cayuga Lake consists of taking 30 cores at each site, with each core in about 0.0187 square meters (CMCM, 2021). Suppose each core contains  $x_i$  ( $1 \leq i \leq 30$ ) tubers, then the 200 sample mean per square meters would be

$$\bar{x} = \frac{\sum x_i / 0.0187}{30} = \frac{\sum x_i}{0.561} \quad (9)$$

The standard deviation would thus be

$$s = \sqrt{\frac{\sum (x_i - \bar{x})^2}{30 - 1}} \quad (10)$$

Note that the frequency distribution of Hydrilla follows not a normal distribution, thus we cannot simply add or subtract multiples of standard deviations over the sample mean to get a confident range of the actual number of tubers. Then question naturally arises as to how confident we are in using our sample mean to reflect the real situation? A simple and intuitive validation is to see whether our sample mean fits the logistic regression. If the standard deviation calculated by the samples differs only a little from the standard deviation calculated by

the logistic regression, we are confident in our sample mean. Otherwise, we need to increase the sample number until the standard deviations match. In practice, however, it is often too troublesome to calculate the standard deviation from samples, especially when it is constantly changing. An alternative approach often used in the industry (Madsen, 1993; Spencer, 1994) assumes a fixed linear relationship between the standard error and the sample mean. Often, it is assumed that  $SE = 0.2\bar{x}$ . Plug in  $SE = s/\sqrt{N}$ , where  $N$  is number of samples (cores), and we have

$$s_1 = 0.2\bar{x}\sqrt{N} \quad (11)$$

Rewrite the logistic regression we have

$$s_2 = 10^{0.085195} \cdot \bar{x}^{0.6334} \approx 1.216\bar{x}^{0.6334} \quad (12)$$

Starting with  $N = 30$ , equation (11) becomes  $s = 1.095\bar{x}$  and monotonically increases as  $N$  increases. Meanwhile  $\bar{x}$  would stabilize around a constant according to the Law of Large Numbers. Thus  $s_1$  and  $s_2$  will eventually meet and the sampling process would terminate.

Finally, there is one last adjustment in the current approach. Given the sensitive nature of the issue, we want to be more conservative in our conclusion. Hence, when the sample data does not fit in the logistic regression, if  $\bar{x}$  is above the curve (given same  $s$  has higher  $\bar{x}$ ), we are more prone to believe this outlier actual exists and we should take immediate action to control the high concentration of Hydrilla. On the other hand, if  $\bar{x}$  is below the curve, we are more suspicious of our sample results and should take more samples to fit the curve. In practice, 42 tubers per square meter is often considered the benchmark for high concentration of Hydrilla. Thus during our sampling process, if  $\bar{x} \geq 42$  at any time, we cease the sampling and believe immediate action should be taken.

#### 4.3 An Adaptive Approach

To be even more efficient, we can calculate the minimum sample size  $N$  instead of the standard deviation. The idea is to assume that the theoretical standard deviation equals the sample standard deviation to get a formula of  $N$ . Combining equation (11)(12) we have

$$N = \frac{1}{0.04} \cdot 10^{1.7039} \cdot \bar{x}^{-0.7332} \quad (13)$$



If the calculated sample number is greater than the actual sample number, by some simple mathematics we know this implies that  $s_1 < s_2$ , and we need more samples to fit the curve. Instead of comparing standard deviation, we can now directly calculate the minimum sample size. Note that as  $\bar{x}$  changes as more samples are collected, according to equation (13), the minimum number of samples  $N$  also changes. Thus we come up with the following adaptive algorithm—

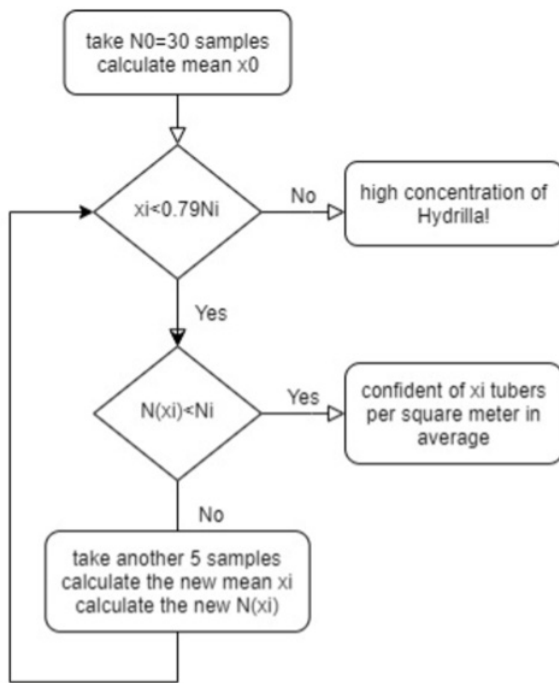


Figure 7: An Adaptive Algorithm for Sampling

Here  $x_i$  denotes the average number of tubers of all samples at iteration  $i$ ,  $N_i$  denotes the performed total number of sampling at iteration  $i$ , and  $N(x_i)$  denotes the minimum number of sampling to be confident of  $x_i$ . 0.79 is calculated from  $0.0187 * 42$ , following the same procedures at the beginning of section 5.1. If the sample average is greater or equal to the high concentration threshold, we exit the program and claim the area has a high concentration of Hydrilla. If the total sample number is greater or equal to the minimum sample size, we also exit the program and claim that there expect to be  $x_i$  tubers per square meter. If neither of these conditions is satisfied, however, we take another 5 samples and recalculate the sample mean and minimum sample size. Notice however that as the sample average goes to 0, the minimum sample size will go up to infinity. Thus in practice it is recommended to set also a upper bound of the sample size as 100.

## 5. Sensitivity Test

### 5.1 Simulation

In our current model we set  $s = 0.05$  based on the fact that Hydrilla's tubers are relatively immobile and in Auld's model the spread rate is set to 0.05 for mediocre mobility plants. A more direct statistics of Hydrilla spread would be much better but is hard to obtain. This leads us to double check the spread rate.

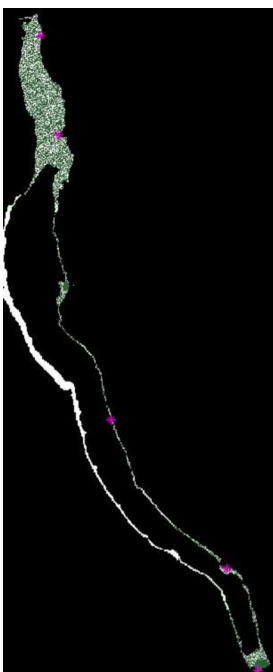


Figure 8:  $s = 0.01$



Figure 9:  $s = 0.05$

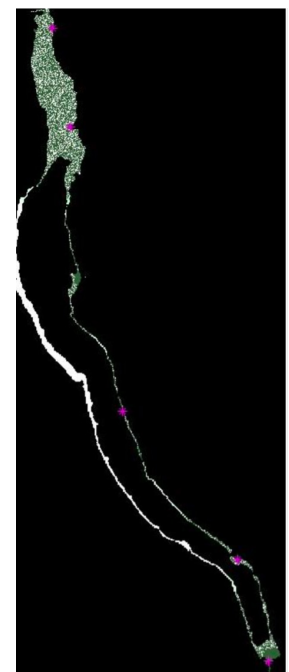


Figure 10:  $s = 0.1$

We test our model with different spread rate:  $s = 0.1$ ,  $s = 0.05$  and  $s = 0.01$  while keeping other parameters fixed. A closer look reveals that the dark green regions become sparse as  $s$  decreases, which means that less areas have a high density of Hydrilla and more areas have zero density with a lower spread rate. As spread rate increases, Hydrilla has a higher probability to spread from one area to others, and more areas would be affected. On the other hand, all of these three spread rates display the similar distribution pattern of the plant and only differs in the subtle density of the dark green. Thus choosing 0.05 as a middle ground value would not lead to severe inaccuracy in terms of the qualitative simulation result.

## 5.2 Sampling

Another important parameter that we need to test is the standard error of the sample mean. In either the baseline approach, the adaptive algorithm, or historical works, the standard error is set to be an arbitrary value of 0.2. Here we test how sensitive the minimum sample size is in our adaptive algorithm. We vary the standard error from 5% to 50% of  $\bar{x}$  and plot the number of samples needed versus this proportion in Figure 10. The conclusion from the figure is that if we are willing to tolerate higher variability in our samples, we can pull fewer cores to infer the overall picture.

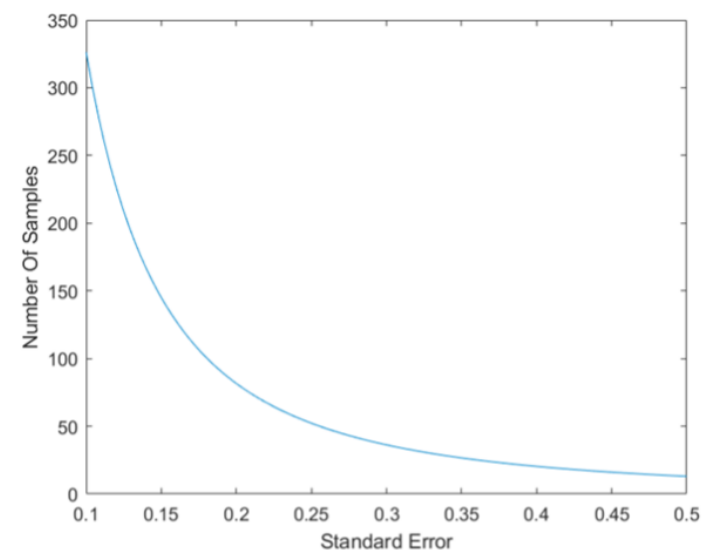


Figure 11: Minimum Sample Size in terms of SE

Often time in practice we want a rough estimate of the minimum sample size in terms of the current sample mean, and we want our rough estimate to not fluctuate too much so that the adaptive algorithm terminates faster. This leads us to vary the sample mean and see how the minimum sample size changes (Figure 12).

From Figure 12, the required number of samples decreases while the sample mean increases. Note that the minimum sample size varies greatly when the sample mean is low, which justifies why we should be more conservative of our conclusion when the sample mean is low.

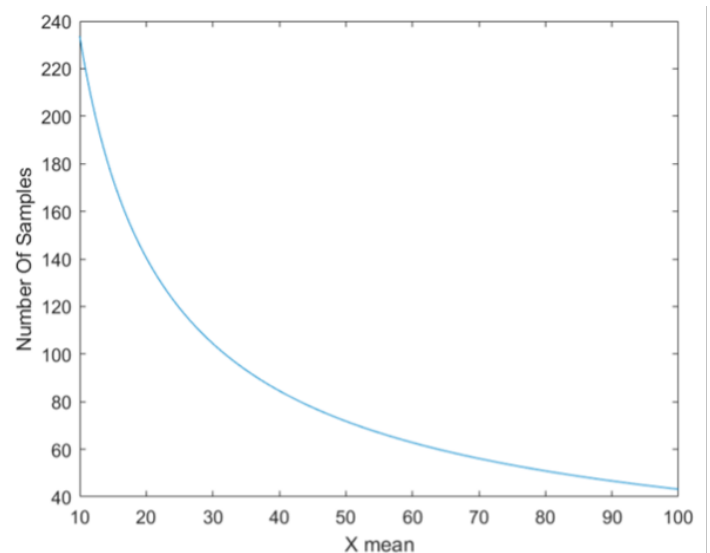


Figure 12: Minimum Sample Size in terms of Sample Mean

## 6. Discussions

Due to the distinctive nature of simulation of sampling, the simulation results and analysis and the reasoning of the statistical inference are discussed in detail separately in Section 3, 4. This section mainly elaborates on some of the possible future works after our study.

**Refine Model** So far, our model incorporates the natural growth of the plant, the dispersal of the plant, and boating as the main factor of the human spread of the species. One potential future work is to extend the current model to incorporate more human activities, such as cleaning the plant using fluridone. Environmental factors such as temperature, sunlight, wind, water level, etc., might also significantly influence the growth and spread of the plant. Also, in this paper, only the ten marinas alongside the Cayuga Lake are considered for boat activities for simplicity. One can include more details for boating activities by also considering boat ramp launch site and paddlecraft launch site.

**Other Species** Another direction is to modify the parameters to model other plant species with similar behaviors. For the spread simulation only the growth rate

$r$  and spread rate  $s$  follow directly from the features of Hydrilla. While in the sampling assessment, one can run linear regression on different species to get different equations between  $\sigma$  and  $\bar{x}$ , and the assessment method as well as the adaptive algorithm should still work.

**Update Data** For the sampling assessment, this paper directly uses Spencer's empirical results of Hydrilla in 1994. More accurate and relevant data can be obtained from direct surveys and historical data for Cayuga Lake protection. One might also seek more up-to-date data and reproduce Spencer's regression results.

**Practical Concerns** Our analysis mainly focuses on the quantitative and theoretical aspects of the simulation/samples. In practice, other than how many samples to take, there is also the concern of how to take those samples. Should the sample points be selected at regular intervals or completely random? What utilities better collect the samples? Discussion on these practical questions also has theoretical importance. For example, the actual error rate of our sample mean might depend on the method of sampling as mentioned above.

## 7. Concluding Remarks

Overall, this paper aims to provide a practical, quantitative, and real-time evaluation system that helps monitor and predict the population dynamics of the plant. The system includes two main parts: sampling and simulation. In Section 3, we discuss in detail our stochastic Monte Carlo simulation based on the enhanced *Invasive Plant Population Dynamic* (IPPD) model. Human activities, such as boating, are identified to greatly accelerate the spread of Hydrilla. In Section 4, we employ statistical methods to promote confidence in the sample results, which in turn guarantees more accurate simulation results. We provide an adaptive algorithm to calculate the minimum sample size in real time. Altogether, the authors reach the following conclusions: (1) if left unattended, a small population of Hydrilla could quickly establish itself and expand to nearby areas; (2) in natural settings Hydrilla could only cover limited areas of Cayuga Lake due to the geographical features of the lake; (3) boating significantly conduces Hydrilla spread by bringing Hydrilla to new locations that it could not reach in natural settings; (4) generally speaking, low

sample mean indicates not low density of Hydrilla, but that more samples are needed.

## References

- [1] Auld, B. A., & Coote, B. G. (1980). A Model of a Spreading Plant Population. *Oikos*, 34(3), 287. <https://doi.org/10.2307/3544288>
- [2] Blackburn, W. H., & Tueller, P. T. (1970). Pinyon and Juniper Invasion in Black Sagebrush Communities in East-Central Nevada. *Ecology*, 51(5), 841–848. <https://doi.org/10.2307/1933976>
- [3] Pennsylvania Sea Grant (2017). Hydrilla. <https://seagrant.psu.edu/sites/default/files/Hydrilla%202017.pdf>
- [4] Schuyler County Soil and Water Conservation District. Hydrilla. <http://www.schuylerswcd.com/Hydrilla.html>
- [5] Cayuga Lake Hydrilla Task Force (2021). Cayuga Lake Hydrilla Management Plan 2021–2026. Cornell Co operative Extension. [https://s3.amazonaws.com/assets.cce.cornell.edu/attachments/50128/Cayuga Lake Hydrilla Management Plan 2021 March 10 2021.pdf?1617048676](https://s3.amazonaws.com/assets.cce.cornell.edu/attachments/50128/CayugaLakeHydrillaManagementPlan2021March102021.pdf?1617048676)
- [6] Boughy (1973). *Ecology of Populations*. 2nd Ed.
- [7] WRC Education Committee of Tompkins County & Tompkins County Planning and Sustainability Department (2020). Clean boating combo map - Tompkins County NY. Tompkins County NY. [https://www2.tompkinscountyny.gov/files2/planning/committees/WRC/documents/clean-boating combo map brochure-2020-web.pdf](https://www2.tompkinscountyny.gov/files2/planning/committees/WRC/documents/clean-boating%20combo%20map%20brochure-2020-web.pdf)
- [8] Fall 2020 Community Conference Hydrilla focus 11.4.2020 (2020). Cayuga Lake Watershed Network. <https://www.youtube.com/watch?v=Qf3Xj21gslw&t=2473s>
- [9] Madsen & Bloomfield (1993). Aquatic Vegetation Quantification Symposium: An Overview. *Lake and Reservoir Management*, 7(2), 137–140. [https://doi.org/10.1016/0380-1330\(93\)90007-8](https://doi.org/10.1016/0380-1330(93)90007-8)

org/10.1080/07438149309354265

[10] Madsen, J. D. (1993). Biomass Techniques for Monitoring and Assessing Control of Aquatic Vegetation. *Lake and Reservoir Management*, 7(2), 141–154. <https://doi.org/10.1080/07438149309354266>

[11] Spencer, D. F., Ksander, G. G., & Whitehand, L. C. (1994). Estimating the abundance of subterranean propagules of submersed aquatic plants. *Freshwater Biology*, 31(2), 191–200. <https://doi.org/10.1111/j.1365-2427.1994.tb00853.x>

[12] Hydrilla – New York Invasive Species Information (2019). New York Invasive Species Information. Retrieved November 15, 2021, from <http://nyis.info/invasive-species/Hydrilla/>

[13] Downing, J. A., & Anderson, M. R. (1985). Estimating the Standing Biomass of Aquatic Macrophytes. *Canadian Journal of Fisheries and Aquatic Sciences*, 42(12), 1860–1869. <https://doi.org/10.1139/f85-234>

[14] Missouri Stream Team. Invasive Species Alert-Hydrilla. <http://mostreamteam.org/assets/factsheet26.pdf>

[15] Sutton D.L. & Portier K.M. (1985). Density of tubers and turions of Hydrilla in south Florida. *Journal of Aquatic Plant Management*, 23, 64-67.

[16] Cornell MCM (2021). Closer to Cayuga's Waters. [https://e.math.cornell.edu/sites/mcm/CMCM\\_2021\\_Cayuga\\_problem.pdf](https://e.math.cornell.edu/sites/mcm/CMCM_2021_Cayuga_problem.pdf)

## Appendix High Resolution Figures

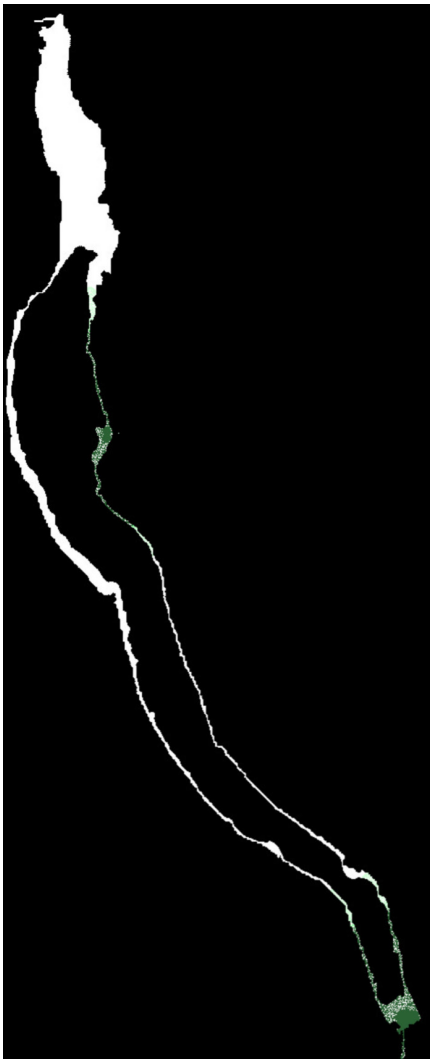


Figure 3: After 5 Years (No Boats).

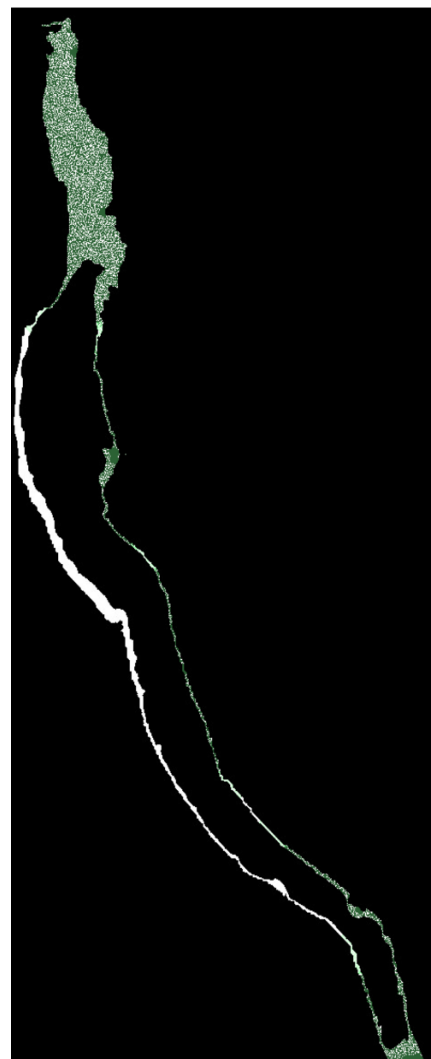


Figure 4: After 5 Years (with Boats).



# A Content Analysis on Fitspiration and Thinspiration Posts on TikTok

By Macy Hung

*Department of Communication, College of Agriculture and Life Sciences*

## Abstract

Anorexia nervosa and bulimia nervosa, two common eating disorders that affect young women, are becoming quite prevalent in recent years as social media gains popularity. Certain forms of content circulating on social media may be correlated to negative body image and eating disorders. Recent research has investigated forms of content referred to as fitspiration and thinspiration posts, as many of these posts promote specific body ideals typically involving a very thin body type. This exploratory study aims to investigate the relationship female adolescents have with TikTok in relation to body type, the development of negative body image, and eating disorders. The goal of this research is to further understand how social media influences these body image and disordered behavior among teenagers in America. A content analysis was conducted on a sample of 80 videos and 1,200 comments taken from TikTok under the hashtags of #fitspiration, #thinspo, and #kcaltok. The findings show that thinspiration content has the potential to induce negative body image disorder habits, as these types of posts had a heavier emphasis on unrealistic body ideals and sparked more conversations surrounding eating disorders. Fitspiration posts were found to have less of an emphasis on promoting skinniness, however, still induced comments surrounding negative body image and weight loss. Future research should continue to monitor and further investigate this content as well as understand the communities of users on other similar content types such as meanspiration, sweetspiration, and bonespiration.

## Introduction

In our increasingly digital age, much of the media we consume is coming from social networking sites. In more recent years, TikTok, a platform that allows users to share short video content, has become quite popular among users around the world. TikTok has gained a lot of traction due to its immersive platform design and personalized content which results in prolonged user stay (Montag et al., 2021). It has also been discovered that TikTok's audience consists of mostly young users and is more female dominated rather than male (Montag et al., 2021). More specifically, TikTok's U.S. demographic consists of 32.5% users who are 19 years old and younger (Sun et al., 2020). While many young teenagers rely on networking sites such as TikTok to keep up with their friends and find entertainment, it is important to take into consideration the types of content they are consuming and the effects they may have. For instance, many users are exposed to content on the app such as images or videos that visually promote excessively thin

or extremely toned and muscular female body types. These forms of content often referred to as thinspiration or fitspiration posts, are viewable on most types of social media platforms and may be correlated to eating disorders and weight loss (Talbot et al., 2017).

For this paper, anorexia nervosa and bulimia nervosa are the primary eating disorders that will be referred to. Researchers define anorexia nervosa as a psychiatric disorder that primarily affects young females and involves extreme overvaluation of shape and weight (Morris & Twaddle, 2007). On the other hand, bulimia nervosa is characterized by uncontrolled binge-eating episodes, an extreme preoccupation with weight, and other extreme measures to compensate for the fear of overeating (Hay & Claudino, 2010). It is also important to note that this study focuses on teenage girls around the ages of 13-19. This is due to the high prevalence of eating disorders in females that have developed during the end of the 20th century as female beauty standards shifted to a thin ideal portrayed in the media (Sharan & Sundar, 2015). Thus, the platform for TikTok was used

for this analysis due to its heavy teenage female audience as well as the lack of research performed specifically in this field and on this platform. Moreover, this topic is alarming because of the high mortality rates associated with these disorders. Those with eating disorders have a notably high mortality rate, and studies have shown that anorexia specifically has the highest rate (Arcelus et al., 2011). Thus, by analyzing fitspiration and thinspiration posts and their respective comments on TikTok, this study looks at the relationship between body type, the development of negative body image, and eating disorders.

## Literature Review

When looking into past literature, researchers have found correlations between body dissatisfaction and social networking sites. In an article by Richard Perloff, he touches on social comparison theory and how viewing social media posts involving thin female body types can trigger self-comparisons that result in negative body image when a user values thinness in body type (Perloff et al., 2014). This is important to keep in mind since self-comparison to those perceived as more attractive or more desirable than oneself can affect the way one views their own body, especially if the individual has low self-esteem or suffers from depression. Perloff's article really emphasizes this idea, as he discusses how those who already struggle with body image may find themselves spending more time online contemplating how they feel about their own bodies when exposed to this type of content which may thus lead to further body dissatisfaction (Sharan & Sundar, 2015).

Additionally, there has been some past research done on fitspiration and thinspiration posts where it was found that these types of content on Instagram, Twitter, and Tumblr focused heavily on physical appearance, sexually suggestive poses, and restrictive eating habits (Alberga et al., 2018). This is important to consider when thinking about how these posts shape the way in which teenagers perceive themselves. Researchers have also found that certain subsets of fitspiration content, as well as thinspiration posts, could potentially invoke disordered behavior and negative body image due to the wide acceptance and popularity of the idealization of thin body types (Talbot et al., 2017). There has also been mention of pro-eating disorder communities, or

groups of users who support and promote disordered behaviors and strive towards an idealized standard as an attempt to make themselves happier (Crowe & Watts, 2014). These findings suggest that when users are exposed to these types of content on social networking sites, there may be a correlation between the development of negative body image. This creates major concern, especially if users are viewing this type of content quite often. These studies are valuable when trying to understand the current environment of various social media platforms and how this specific content type can affect users.

## Methods

To analyze this topic, a content analysis of images and comments was conducted on TikTok. Multiple hashtags such as #fitspiration, #thinspiration, #thinspo, etc. were inputted in the TikTok search engine. When using these search terms, most hashtags relating to thinspiration content were blocked, as the algorithm appeared to be attempting to restrict users from viewing this type of content, and instead, the phone number for the National Eating Disorder Association showed up as the only result.

By using alternative spelling, thinspiration content was found under different hashtags. By clicking on other related hashtags that users would tag along with #thinspo, alternative tags such as #kcaltok appeared where the same community of users posting thinspiration content was discovered. Twenty posts were taken from the hashtags #fitspiration, #fitspo, #th1nspō, and #kcaltok. To ensure standardization, each video was required to have at least 300 likes, 10 comments, and been posted within July 2021-December 2021. The videos taken from the hashtags #fitspiration and #fitspo were analyzed and grouped together as fitspiration content, whereas #th1nspō and #kcaltok represented thinspiration content. A total of 80 videos and 1,200 comments were coded for. The amount of content under these hashtags were limited due to many videos not meeting the standard for engagement (likes and comments). TikTok also prioritizes the highest performing videos for each hashtag and displays them as the top results for a search. Across each of the four hashtags, only the top 20 videos met the engagement standard, thus, the sample size of 80 was chosen considering the limited

population of videos that were on the platform. Searches were conducted throughout the month of November and December 2021, and all the videos and comments coded for had been posted within a 6-month time frame.

While watching each TikTok video, the variables shown in the table below were coded for (Figure 1). The codebook shown below was adapted from previous research (i.e., themes of weight and specific body parts were included from an existing coding scheme), and new codes relating to disordered behavior were created to reflect categories most prevalent in comments (Alberga et al., 2018). The codes were separated by post and comments, to analyze both elements of the video separately. Posts were coded for physical features and body parts shown in videos as well as mention of eating disorders, where-

as comments were coded for message content relating to body image and disorder/body type praise. All variables were hand-coded for either yes or no, depending on whether each variable was present in the video or comment. For instance, under #fitspiration, thin body type was marked as present 3 times out of the 20 videos. Codes involved looking at body type, presence of body parts, weight loss, and eating disorders. When coding for comments, only the top 10 comments were analyzed, which also meant each video had to have a minimum of 10 comments. Due to space constraints, this paper focuses on the codes relating to the themes of body type, body image, and eating disorders. Lastly, codes were analyzed by performing a chi-square test on the pairs of variables (e.g., rib cage and midriff) sorted by category (e.g., body type).

Table 1. Codebook and the definitions of each code used in the content analysis divided by post and comments.

Post	Definition
Thin body type	Body that is presented as bony, minimal fat, with a small frame
Muscular body type	Body that is toned/bulky/presence of muscles
Rib cage	Rib cage is visible in picture
Weight	Post makes mention of the user's weight or weight loss
Midriff	Midriff/stomach area is shown in the picture
Eating disorder	Post makes mention of currently or previously having an eating disorder/ post makes mention of disordered behavior such as bingeing, purging, over-exercising, or restrictive eating
Comments	Definition
Weight loss	Comments are promoting unhealthy weight loss, mentioning their goal weight or current weight
Self-comparison	Comments mentioning the user wishes they had a certain body type/comparing themselves to a person, body type, or specific weight that is mentioned in the post
Skinny praise	Comments praising those who are skinny/ using skinniness as an indication of success
Disorder praise	Comments praising others or themselves for engaging in disordered habits such as bingeing, purging, over-exercising, or restrictive eating
Body positivity	Comments are praising body positivity and healthy eating/exercising habits
Eating disorder	Comments make mention of currently or previously having an eating disorder/ mentions disordered behavior such as bingeing, purging, over-exercising, or restrictive eating

# Results and Analysis

## Body Type

When looking at the difference in body types shown in thinspiration and fitspiration posts, there was quite a difference between the two content types. Of the entire sample, 43 videos were coded for thin body type. Of the content that presented a thin body type, 74.42% of the videos were from thinspiration posts, and 25.58% of videos were from fitspiration posts. 30 videos were coded for a muscular body type which consisted of 16.67% thinspiration posts and 83.33% of fitspiration posts. Based on a chi-square test that compared the frequency of thin body type and muscular body type, there was a significant relationship between these two variables,  $X^2(1, N = 73) = 23.6, p < .05$  (Figure 2). This finding shows a prominent difference between the two content types, which may have a correlation with thinspiration posts being slightly more impactful on developing a negative body image due to their emphasis on thin body ideals.

*The graph below shows posts that were coded for either thin body type or muscular body type on fitspiration and thinspiration posts.*

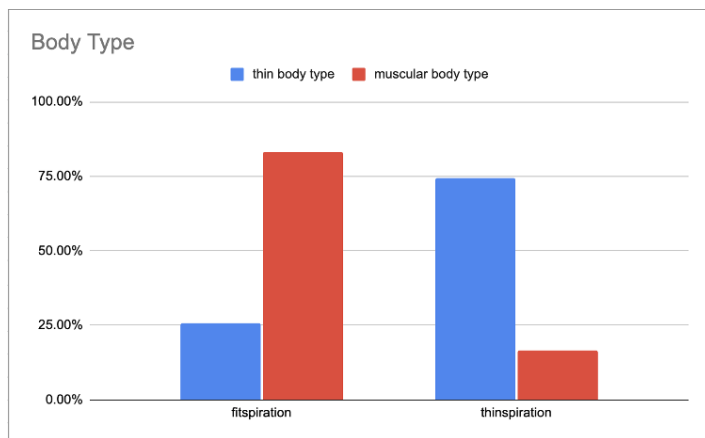


Figure 2. Thin and Muscular Body Type

On the other hand, when looking at body parts shown in the posts, both fitspiration and thinspiration posts had similar body parts shown in the videos analyzed. A chi-square test found that the coded variables for the presence of rib cage and midriff did not significantly differ between fitspiration and thinspiration posts,  $X^2(1, N = 75) = 0.05, p = .828382$  (Figure 3). Fitspiration content showed slightly more of both rib cage and midriff in comparison to thinspiration posts. From the total of 80 fitspiration and thinspiration posts, 23.75% of videos had a presence of rib cages and 70% of posts

had a presence of midriff. This indicates that both forms of content are revealing around the stomach and torso area, which may affect users' perception of their own body image especially if they are subject to having an eating disorder, as having a thinner waist is part of what is typically perceived as ideal when aiming to be skinny.

*The graph below shows posts that were coded for the presence of the rib cage and midriff in fitspiration and thinspiration content.*

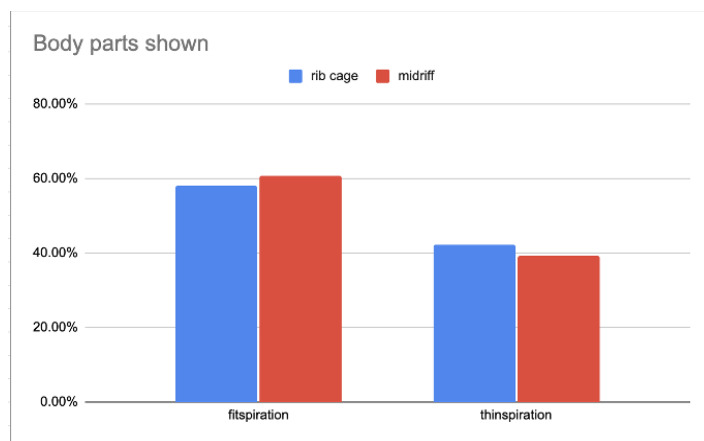


Figure 3. Body Parts Shown: Rib Cage and Midriff

## Body Image

When taking a closer look at the comments sections of these posts, we can see how this type of content was perceived by users. From the 80 fitspiration and thinspiration posts, 73.75% of posts had comments involving self-comparison and 75% of posts had comments related to weight loss. Based on a chi-square test, the presence of self-comparison and weight loss in comments were not significantly different between fitspiration and thinspiration posts,  $X^2(1, N = 116) = 0.08, p = .779507$  (Figure 6). This finding indicates that both forms of content provoked thoughts where users were comparing themselves to either the weight measurements discussed in the post or the body type of the person. Additionally, out of the 56 posts coded for self-comparison, 62.5% of posts were thinspiration videos whereas 37.5% were fitspiration videos. From the 60 posts that were coded for weight loss, 65% of posts consisted of thinspiration videos and 35% of posts were fitspiration videos. While fitspiration and thinspiration posts both have the potential to negatively impact body image, both self-comparison and weight loss were coded for less frequently in fitspiration posts, which may indicate that thinspiration posts are more likely to induce more negative thoughts



around body image. Some examples of comments that were coded for self-comparison or weight loss on thin-  
 spiration posts are shown below in Figure 4 and Figure 5. In one of the examples shown in Figure 5, a couple  
 of the comments on one of the fitspiration posts had thousands of likes which is quite alarming considering  
 this may be indicative that thousands of other viewers relate to having a negative body image and feeling terri-  
 ble about themselves after watching this type of content about weight loss.

Based on the way weight loss was defined in the code-  
 book, its high prominence indicates that many users are  
 discussing the actual weight they are currently at and/  
 or talking about how much weight they want to lose.  
 These comments can be triggering to others who view  
 them especially if they are talking about a particular-  
 ly extreme amount of weight the user is trying to lose.  
 Additionally, the notion of promoting weight loss espe-  
 cially seen in thin-  
 spiration posts may encourage a nega-  
 tive body image, since many of the users viewing this  
 type of content appear to be young girls who are already  
 at healthy weights and are attempting to lose weight to  
 achieve an unrealistic body standard to fit an aesthet-  
 ic. Many of the comments on thin-  
 spiration posts men-  
 tioned wanting to lose weight to look good while wear-  
 ing certain styles of clothing, or to gain validation from  
 their peers. A large majority of thin-  
 spiration posts were  
 uploaded by users posting videos of female Korean pop  
 music stars (celebrities who are typically extremely thin  
 and follow very restrictive diets) and stating that they  
 wished they looked like them. Some posts involved the  
 body measurements of the Korean celebrities, as well as  
 a breakdown of their diet which included their daily cal-  
 oric intake.

*The set of comments pictured below shows users compar-  
 ing themselves to the body and weight ideals defined in  
 two different thin-  
 spiration posts.*

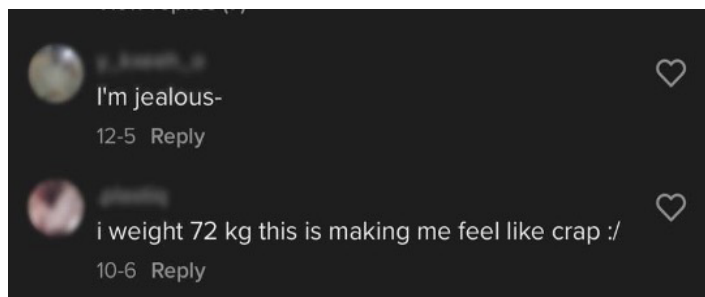
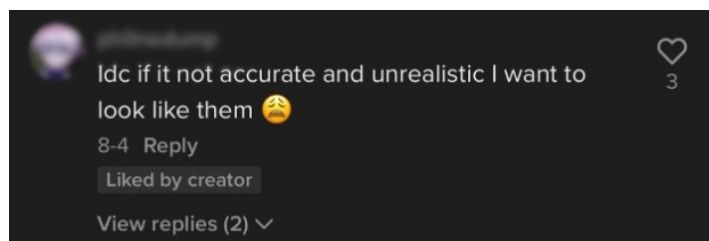


Figure 4. Example of Comments on Thin-  
 spiration Posts.

*The set of comments shown below also reflects users' self-comparison and discussion of weight loss in response to three different fitspiration posts.*



Figure 5. Example of Comments on Fitspiration Posts.



The graph below shows comments that were coded for self-comparison and weight loss on fitspiration and thinspiration content.

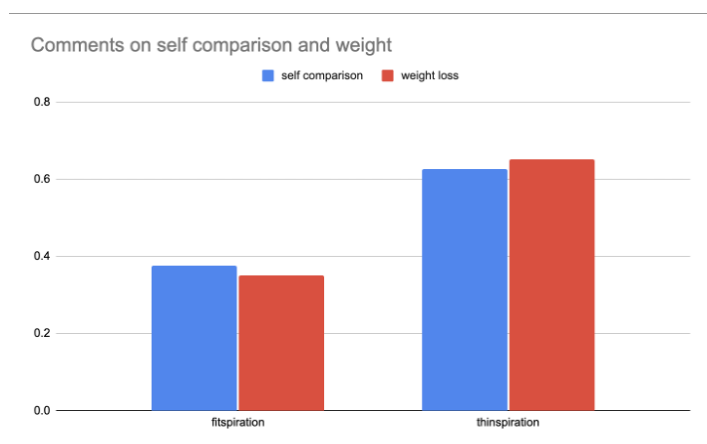


Figure 6. Self-Comparison and Weight Loss.

## Eating Disorders

Additionally, when looking at the comments in relation to disordered behavior and perceptions, thinspiration posts appear to induce greater conversations about eating disorders (Figure 7). Within the 30 posts that were coded for skinny praise, comments on thinspiration posts made up 93.33% of the content. In addition, 93.75% of the 16 videos coded for disorder praise was made up of comments on thinspiration posts as well. Examples of comments that were coded for skinny praise or disorder praise are shown in Figure 8 and Figure 9. These comments are quite alarming, as young girls are clearly viewing thinness as a measure of success, as well as disordered behavior to achieve those goals when having conversations on these posts.

On the 56 comment sections that were coded for self-comparison, only 6.66% came from fitspiration posts. Additionally, 6.25% of the 16 comment sections that were coded for disordered behavior made up of fitspiration posts. While this is a low number, there were still a portion of fitspiration content that made users think about eating disorders. Based on the findings it appears as though more users viewing thinspiration content already had eating disorders and were a part of a community of users who also had disorders, whereas users viewing fitspiration posts were preoccupied with losing weight to fit general societal body ideals that did not involve excessive thinness. Both types of content still seemed to stimulate users' thoughts of weight loss through unhappiness with their current body types

which may be perceived as unhealthy when thinking of the implications this could have on users' ability to develop an eating disorder if they did not already have one.

The graph below shows the comments coded for skinny praise and disorder praise on fitspiration and thinspiration content.

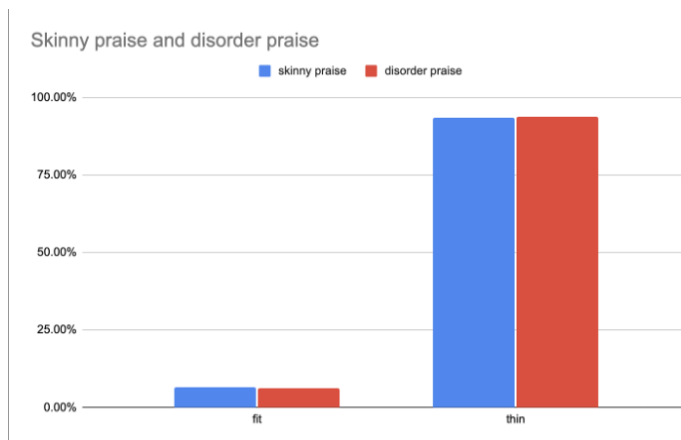


Figure 7. Skinny and Disorder Praise.

The set of comments shown below shows users idolizing a skinny body type and disordered behavior as a measure of success in two different thinspiration posts.

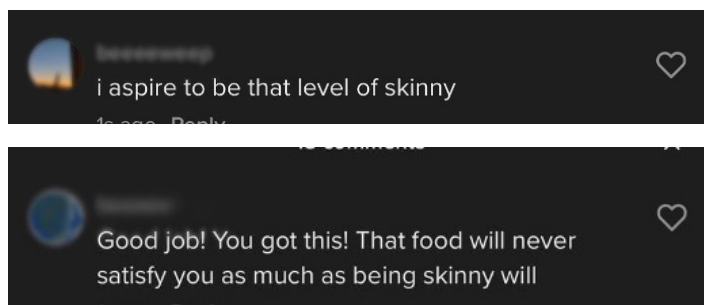


Figure 8. Examples of Comments on Thinspiration Posts.

The set of comments shown below reflects users idolizing and praising the skinny body type in two separate fitspiration posts.

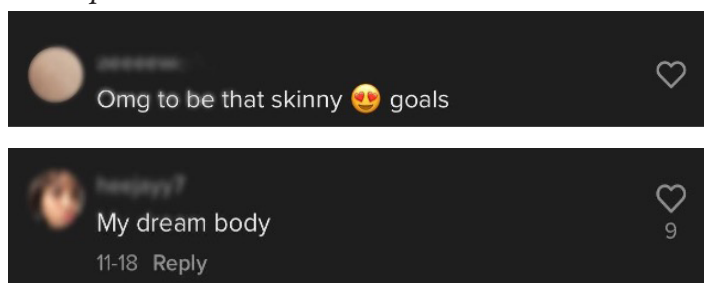


Figure 9. Example of Comments on Fitspiration Post.

# Results and Analysis

The findings in this study imply that fitspiration and thinspiration content differ when it comes to body type, however, the effects both content types have on users has a large impact on the development of negative body image. This research supports previous findings that thinspiration content and fitspiration content have many similarities particularly when it comes to weight loss and restrictive eating (Alberga et al., 2018). Thinspiration posts appear to be more impactful when it comes to triggering users' eating disorders as it promotes disordered behavior as well as unhealthy and unrealistic body ideals. This is similar to previous research that has compared the difference between fitspiration and thinspiration posts and have found that thinspiration posts may be perceived as an unhealthier type of content (Talbot et al., 2017). While fitspiration content does not appear to attract users who are already involved in the eating disorder community, thinspiration content seems to do so which brings up the concern of entirely removing this type of content on TikTok due to its ease of access. Despite the restrictions of hashtags TikTok has implemented, it is still quite easy for users to surpass this and create variations for these hashtags which defeats the purpose of the restrictions. Previous research has confirmed that these search constraints and alternative hashtags were also found on other social media platforms such as Instagram (Alberga et al., 2018). The high mortality rate of eating disorders makes this topic imperative to address, as there need to be better ways to encourage recovery, body positivity, and support for users on this app who need help.

Furthermore, there are some limitations to reflect on when interpreting the findings of this study. As stated previously, the total population of videos within this field on TikTok were rather limited, which restricted the total sample size the scope of this research could explore. It is also important to consider that each post had different amounts of engagement and viewership which could affect the types of comments on these posts, as the more traction a video receives, the more attention the comments will receive. Some of the fitspiration posts appeared to have more viewership, which is reflected in the high number of likes some of the comments received in Figure 4, whereas no other thinspiration post

received the same level of engagement. Additionally, only 2 different hashtags for fitspiration content and thinspiration content were analyzed, which did not account for other variations such as #fittok #fitsp0, #thin-sp0000, or #thintok.

Considering this study is one of the first to explore this constantly evolving topic, future research is necessary to understand more about the complexities of the eating disorder community. Other forms of content relating to motivational eating-disorder posts include bonespiration, meanspiration, and sweetspiration. Bonespiration involves idealizing thin body types with an emphasis on bone protrusions and is highly associated with the eating disorder community (Talbot et al., 2017). Meanspiration and sweetspiration, often referred to as meanspo and sweetspo on TikTok were mentioned quite frequently through the hashtags on thinspiration content. Meanspiration content involves promoting eating disorders through extreme criticism by encouraging disordered behaviors. On the other hand, sweetspiration content involves promoting eating disorders through reassurance and warmth.

Ultimately, the findings in this study on fitspiration and thinspiration posts imply that some users develop a negative relationship between body type, body image, and eating disorders when exposed to these types of content. While not all users experience a negative relationship, these forms of content should be monitored closely and the possibility of taking more in-depth action on restricting thinspiration posts should be considered.

## References

- Alberga, A. S., Withnell, S. J., & von Ranson, K. M. (2018). Fitspiration and thinspiration: a comparison across three social networking sites. *Journal of Eating Disorders*, 6(1). <https://doi.org/10.1186/s40337-018-0227-x>
- Arcelus, J., Mitchell, A. J., Wales, J., & Nielsen, S. (2011). Mortality rates in patients with anorexia nervosa and other eating disorders. *Archives of General Psychiatry*, 68(7), 724. <https://doi.org/10.1001/archgenpsychiatry.2011.74>

Crowe, N., & Watts, M. (2014). 'We're just like Gok, but in reverse': Ana Girls – empowerment and resistance in digital communities. *International Journal of Adolescence and Youth*, 21(3), 379–390. <https://doi.org/10.1080/02673843.2013.856802>

Hay, P. J., & Claudino, A. M. (2010). Bulimia nervosa. *BMJ clinical evidence*, 2010, 1009.

Montag, C., Yang, H., & Elhai, J. D. (2021). On the Psychology of TikTok Use: A First Glimpse From Empirical Findings. *Frontiers in Public Health*, 9. <https://doi.org/10.3389/fpubh.2021.641673>

Morris, J., & Twaddle, S. (2007). Anorexia nervosa. *BMJ*, 334(7599), 894–898. <https://doi.org/10.1136/bmj.39171.616840.be>

Perloff, R. M. (2014). Social Media Effects on Young Women's Body Image Concerns: Theoretical Perspectives and an Agenda for Research. *Sex Roles*, 71(11–12), 363–377. <https://doi.org/10.1007/s11199-014-0384-6>

Sharan, P., & Sundar, A. (2015). Eating disorders in women. *Indian Journal of Psychiatry*, 57(6), 286. <https://doi.org/10.4103/0019-5545.161493>

Sun, L., Zhang, H., Zhang, S., & Luo, J. (2020). Content-based analysis of the cultural differences between Tiktok and Douyin. *2020 IEEE International Conference on Big Data (Big Data)*. <https://doi.org/10.1109/bigdata50022.2020.9378032>

Talbot, C. V., Gavin, J., van Steen, T., & Morey, Y. (2017). A content analysis of thinspiration, fitspiration, and bonespiration imagery on social media. *Journal of Eating Disorders*, 5(1). <https://doi.org/10.1186/s40337-017-0170-2>



# The Male Fertilization Fantasy: Gendered Language in Biology Textbooks

By Grace Shan

*Department of Linguistics, College of Arts and Sciences*

## Abstract

This article explores the extent to which gender-biased language is used to describe fertilization in high school textbooks, akin to the stories with fairytale tropes that are heard during childhood about fertilization. After analyzing the relevant sections from four high school level biology textbooks by major publishers, three patterns were found: passive language used for the female reproductive system and active for the male, stereotypical male personification of sperm and the sole perspective of the sperm, and contrastive theta roles in the semantic and syntactic structure with the sperm as the agent and the female body as anything but. The four textbooks were then evaluated in these categories from least to most biased; one textbook was much more neutral than the other three. The conclusion is that there is still much improvement necessary to ensure the objectivity and accuracy of textbooks, which are often authoritative in a classroom; implicit sexist writing is harmful to both male and female students.

## Introduction

When children ask adults how babies are made, they are likely to hear a story about the race of millions of sperm, of which the strongest and most valiant becomes the one to enter and fertilize the awaiting egg, creating a zygote—the beginning of new life. However, it is just that—a story, or even a fairytale, with the egg often characterized as the “damsel in distress,” saved and courted by the sperm as “the knight in shining armor.”

Since gender norms are prevalent in how every part of society is understood, they must inevitably affect the way biology is understood and taught as well, even though biology is supposed to be a scientific field that is objective and uninfluenced by social constructs. Gender norms can draw focus to certain scientific topics, thereby excluding others, as well as cause scientists to interpret findings and observations in a biased manner.

Fertilization requires mutual, active participation by both gametes (egg and sperm), but portraying these equally important participants as aligning with dominant gender norms is dangerous, suggesting that even the biological process of reproduction provides evidence for the validity of these societal norms. Examining gender bias in human biology textbooks is insight-

ful because it requires description of both the male and female body and is an important process that carries on human existence. While simplified models for children to understand fertilization may be oversimplified and overflowing with gender stereotypes, this study investigates if high school textbooks also use gendered, misleading language to explain in vivo fertilization (fertilization that occurs inside the body). High school is the first-time children are exposed to advanced and detailed science since they are at an age where they can better grasp complex concepts. These higher-level explanations of natural processes can leave lasting impressions on their understanding of the world. Gender tropes would be even more uncalled for in these textbooks compared to simplified explanations for younger children. Determining the degree of objectivity and equality in writing meant to teach accurately and precisely is crucial. Since many adults still have this fairytale-like impression of fertilization even after learning about it in high school, the hypothesis is that these textbooks do contain problematic gendered language.

This topic was first explored over thirty years ago by Emily Martin in her groundbreaking 1991 article published in *Signs: Journal of Women in Culture and Society*, “The Egg and the Sperm: How Science Has Constructed a Romance Based on Stereotypical Male–Female Roles,”

where she found substantial gender stereotyping in biology textbooks on fertilization. In 2013, Lisa Campo-Engelstein and Nadia Johnson similarly examined biology textbooks of all levels in an article called “Revisiting ‘The fertilization fairytale:’ an analysis of gendered language used to describe fertilization in science textbooks from middle school to medical school,” in which they found some improvement since Martin’s work. We referenced both articles in order to be aware of previously detected biases while aiming to discover new ones. Since gender norms have been seriously questioned in recent years, particularly online, this study is an extension of the previous two to see if the new awareness of gender norms and feminism has flowed into scientific writing as well. Therefore, we suspect older textbooks use more gendered language than newer ones, which could be evidenced by further improvement since Campo-Engelstein and Johnson’s article.

## A Brief Overview: Human Fertilization

In order to evaluate the degree of bias within a textbook’s descriptions of fertilization, we will provide a brief description of the process, avoiding as much bias as possible through consulting and amalgamating information from multiple credible sources<sup>1</sup> and specifically searching for neutral language and the role of the egg. The description of human fertilization from “Revisiting ‘The fertilization fairytale:’ an analysis of gendered language used to describe fertilization in science textbooks from middle school to medical school” was used as a start-off point.

Fertilization is the union of two gametes, the female’s egg and the male’s sperm, both haploid, meaning they carry 23 chromosomes, into a new unique cell with the genetic material of both partners, called a zygote, which is diploid, containing 46 chromosomes. Cell division begins to form an embryo after fertilization. Many physiological and biochemical processes are involved in fertilization. Beforehand, an ovarian follicle releases a fully-grown egg into the fallopian tube.

---

<sup>1</sup> All sources consulted are included in the References. It was created through a combination of and confirmation from several sources, which complicates in-text citations.

For ejaculated sperm to be capable of fertilization, they must undergo capacitation, which includes protein modifications, hyperactivation of motility, and the acrosome reaction. When the egg and sperm meet in the fallopian tube, the sperm travels through the egg’s zona pellucida to bind with its plasma membrane, releasing a sperm-specific protein into the egg cytoplasm. In response to this protein, the egg releases calcium transients from internal stores and initiates the exocytosis of zinc. These metal fluxes cause egg activation, which prevents additional sperm from fusing with the egg’s plasma membrane that would be lethal to the zygote due to an abnormal number of chromosomes and initiates embryonic cell division.

## Methodology

We examined four American high school level biology textbooks—Human Physiology: An Integrated Approach (Edition 8, 2019) by Dee Unglaub Silverthorn, Principles of Human Physiology (Edition 6, 2017) by Cindy L. Stanfield, Biology: The Dynamics of Life by Alton Biggs et al. (2004), and Campbell Biology by Lisa A. Urry et al. (Edition 11, 2017). Campo-Engelstein and Johnson studied the first three of these textbooks (published in 2007, 2008, and 2007 respectively) in their paper, and found significant gender biased language. A decade later, we looked at much more recent editions of the first two textbooks listed to see if this problem was addressed since then, possibly resulting in a decrease of prominent sexist language. Campo-Engelstein and Johnson looked at a 2007 edition of the Biggs et al. textbook, and we looked at its very first edition, published in 2004, to determine if the section’s language was edited in the future edition. From personal anecdotal experience, the last textbook, by Urry et al., is prominently used in Advanced Placement Biology classes. The four texts were all published by major textbook companies like McGraw Hill and Pearson, so the likelihood of them being widely distributed to students is high, as well as their representativeness of U.S. high school biology textbooks’ use of gendered language in general. We examined the language in the sections on human reproduction, specifically fertilization, in each textbook, in order to determine how much gendered language was present and any patterns they followed. We paid attention to syntactical and lexical features and

the strategies used to explain the process, as well as any other substantial language components that were a sign of gender bias.

We found four patterns: passiveness vs activeness, personification/perspective, and theta roles<sup>2</sup>, which will be explored in the following section. After the analysis, we quantitatively scored the four textbooks based on the proportion of biased instances in their descriptions of fertilization, per category and then in total.

## Results

After analyzing the language on fertilization in each of the textbooks, we separated the gender-biased language into three main categories, which we will elaborate on and provide examples for individually: passiveness vs. activeness, personification/perspective, and theta roles. The associated tables provide pertinent examples which will be referenced in each section respectively.

### Passiveness vs. Activeness

Characterization of eggs as passive and sperm as active in both lexical and syntactical ways is a salient trend, as demonstrated in the passages in Table 1. All four textbooks use syntactic structures like “the sperm fertilizes the egg” or “the egg is fertilized by the sperm,” which implies that the sperm is the active participant acting upon the passive egg. This gives the sperm the credit of fertilizing and asserts that the egg is merely where the process takes place. The egg tends to be the object and the sperm the subject, and rarely the reverse, which indicates the same false notion of the sperm as the actor and the egg as the acted upon.

In addition, in Table 1, the authors describe sperm with verb phrases like “swim,” “deliver,” “penetrate,” and “break down [the barriers],” or terms like “self-propulsion,” indicating an independence and active physical effort to achieve the goal of fertilization. On the other hand, passive verb and adjective phrases like “receive,”

“are always sexually receptive,” “are present,” “has receptacles,” and “remain” are used for the female, conveying that the egg is resigned to the action of the male sperm and does not actively contribute to ensure the success of fertilization. Also, passive syntactical structure is used, such as “is swept,” where the object—the egg or the uterus—becomes the subject of the sentence but is still not active, only acted upon by another force. It is not difficult to convert these sentences into active ones with some rephrasing or additional information. For example, fertilization could be described as “the egg and sperm fuse.” Urry et al.’s Passage 2 of Table 1 could be rewritten as, “[...] often stores eggs in receptacles and delivers sperm to mature eggs.”

One of the only times the female body is said to do something active is when it “destroys” sperm due to its acidity and impedes fertilization in Biggs et al.’s passage 3 in Table 1 (Biggs et al., 2004). This relates to how the female reproductive system is often described as being a hindrance to fertilization, such as a “barrier” (Stanfield, 2017), even though these mechanisms are for protection and optimization. Also, while the vagina is said to be hostile due to its acidity, semen actually protects sperm from the male’s own acidic urinary tract as well, which is unmentioned, painting the female body in an unfair negative light. The favorable conditions of the cervix for sperm to survive hours and the many ways that the female body aids sperm transport—muscular contractions of the vagina, cervix, and uterus; ciliary movement; peristaltic activity; and fluid flow in the oviducts (Monroy, 2020)—are also less acknowledged.

In Silverthorn’s passage 5 and Stanfield’s passage 3 from Table 1, the authors do acknowledge the active and important role of the female reproductive system in fertilization and reproduction, but they are one-off occasions. Although Urry et al. also use the “the sperm fertilizes the egg” or “egg is fertilized by the sperm” constructions, they write the female and male reproductive system with more equal, active responsibility in fertilization, evidenced by the passages in Table 1.

---

<sup>2</sup> Theta roles are the formal device for representing syntactic argument structure, which is the number and type of noun phrases required syntactically by a particular verb and its meaning.

Table 1. Example passages from each textbook relevant to passive and active language to describe fertilization.

	Biggs et al.	Silverthorn	Stanfield	Urry et al.
active language for the male body/sperm	1. “delivery” (995) 2. “only one fertilizes the mature egg... survive... The surviving sperm swim up the vagina into the uterus... penetrate the egg” (1005).	1. “place sperm in the receptacle” (823). 2. “which enables the sperm to swim rapidly and fertilize an egg” (820). 3. “To fertilize the egg, a sperm must penetrate [...]” (827). 4. “destined” (807).	1. “produce sperm and deliver them into the female for fertilization” (668). 2. “producing sperm and delivering them to the female”(675). 3. “Sperm deposited in the vagina move by self-propulsion” (685) 4. “reach the oocyte and work together to break down the barriers to fertilization... penetrate the corona radiata, they bind to sperm-binding proteins” (685).	1. “fertilize eggs within the tract” (1020). 2. “delivers” (1021). 3. “First, sperm dissolve or penetrate any protective layer surrounding the egg to reach the plasma membrane. Next, molecules on the sperm surface bind to receptors on the egg surface, helping ensure that fertilization involves a sperm and egg of the same species”(1042). 4. “produce both sperm and reproductive hormones, accessory glands that secrete products essential to sperm movement, and ducts that carry the sperm and glandular secretions” (1023).*
active language for the female body/egg	1. “destroy most of the delicate sperm” (1005).	1. “Fluid movement created by the cilia and aided by muscular contractions transports an egg along the Fallopian tube toward the uterus” (818).*	1. “responsible not only for the production and transport of ova, but also for everything else that must occur to enable a new human being to be brought into the world” (675).*	1. “Molecules and events at the egg surface play a crucial role in each step of fertilization... Finally, changes at the surface of the egg prevent polyspermy, the entry of multiple sperm nuclei into the egg” (1042). 2. “produce eggs and reproductive hormones, and a system of ducts and chambers, which receive and carry gametes and house the embryo and fetus” (1024).*
passive language for the male body/sperm	No relevant instances	No relevant instances	No relevant instances	No relevant instances
passive language for female body/egg	1. “The egg is present” (1005).	1. “an internal receptacle for sperm” (823). 2. “Once an egg is released from the ruptured follicle, it is swept into the Fallopian tube by beating cilia” (820). 3. “Fertilization of an egg by a sperm” (827). 4. “women are always sexually receptive” (801).	1. “remain...fertilized by the arriving sperm” (665). 2. “fate” (681).	1. “has receptacles for storage and delivery of sperm to mature eggs” (1021).  <b>Note:</b> Asterisks indicate that the passage has low bias.



## Personification/Perspective

Table 2. Example passages from each textbook relevant to personification/perspective in language on fertilization.

	Biggs et al.	Silverthorn	Stanfield	Urry et al.
Perspective of the sperm	1. "Sperm enter the vagina of the female's reproductive system when strong, muscular contractions ejaculate semen from the male's penis. Between 300 and 500 million sperm are forced out of the male's penis and into the female's vagina during intercourse" (1005). 2. "The surviving sperm swim up the vagina into the uterus. Of the sperm that reach the uterus, only a few hundred pass into the two oviducts. The egg is present in one of them. The head of the sperm contains enzymes that help the sperm penetrate the egg" (1005).	1. "Now let's follow the path of sperm deposited in the vagina during intercourse" (815). 2. "To fertilize the egg, a sperm must penetrate both an outer layer of loosely connected granulosa cells (the corona radiata) and a protective glycoprotein coat called the zona pellucida. To get past these barriers, capacitated sperm release powerful enzymes from the acrosome in the sperm head, a process known as the acrosomal reaction. The enzymes dissolve cell junctions and the zona pellucida, allowing the sperm to wiggle their way toward the egg" (827).	1. "Sperm deposited in the vagina move by self-propulsion through the cervical canal into the uterus, where they move along the uterine wall and eventually enter the opening to the uterine tube. Sperm migration is also aided by vaginal and uterine contractions that occur during sexual arousal. Of the millions of sperm that are deposited, only a few hundred typically reach the uterine tube; the others die along the way" (685). 2. "During sperm migration, several sperm may reach the oocyte and work together to break down the barriers to fertilization—namely, the corona radiata and zona pellucida. Once sperm penetrate the corona radiata, they bind to sperm-binding proteins in the zona pellucida." (685).	No relevant instances
Personification of Sperm	"strong, muscular... surviving...penetrate" (1005).	"penetrate...wiggle" (827).	"die...work together...penetrate" (685).	No relevant instances

In the fertilization section, Biggs et al., Silverthorn, and Stanfield either explicitly or implicitly decide to focus on the path of the sperm for the process of fertilization, evidenced in Table 2. While writing through the perspective of sperm itself is not very problematic, the omission of the perspective of the egg from fertilization (except in separate designated sections on the female reproductive system) is. It implies that the sperm is the one that does the fertilizing and is therefore the more intriguing and important participant.

Whereas the textbooks portray egg release and transport as a passive and dull process, Biggs et al., Silverthorn, and Stanfield write the sperm's release and transport as an adventure, shown in Table 2, which gives agency to sperm and seems to subtly parallel the heroes of quest myths who travel to new lands, defeat enemies, marry the princess, and reform society.

The authors use the verb "penetrate" very often in their description of how the sperm enters the egg, which is

a parallel to how in heterosexual intercourse, the male penis is said to “penetrate” the female vagina, particularly during rape or aggressive sex. It is a personification of sperm during fertilization as the male himself during sex. In addition, “penetrate” has the semantic connotation of a violent, unwelcome intrusion when used to refer to biological or military contexts, which implies women are the weaker partner that can be dominated and abused. There are alternatives, such as Stanfield writing, “the first sperm to reach the oocyte binds to a receptor on the plasma membrane, which precipitates transport of the head of the sperm into the egg’s cytoplasm” (685), or using other verbs like “dissolve” or “enter” instead, but “penetrate” seems to be preferred in most instances. In addition, Biggs et al. write sperm are “forced from the man’s penis and into the woman’s vagina during intercourse” (1005), which suggests non-consensual sex by using the term “force,” as if the man is forcing sex onto the powerless woman and his semen into her for the sake of reproduction—an antiquated, unhealthy way of looking at sex.

Other words that usually describe people like “strong,” “muscular,” “powerful,” “wiggle,” “die,” “survive,” and “work together” also personify the sperm, making the sperm’s path in fertilization seem human. Given the context, “survive” anthropomorphizes the sperm by connoting that they are soldiers fighting for their lives and the prize, which is the chance to recreate with an objectified woman. Although these words are not exclusively used for people and are acceptable in scientific texts, they are used more often for sperm than for eggs. The same texts instead describe eggs with objective scientific words such as “intense” for “strong, muscular” and “disintegrate” or “degenerate” for “die” (Silverthorn, 2019), (Stanfield, 2017), and (Biggs et al., 2004).

Additionally, only the male orgasm is mentioned during fertilization. While female orgasm is not necessary like the male orgasm for fertilization to occur, the lack of information on it incorrectly suggests that the sole purpose of sexuality is biological reproduction and elevates the man’s sexual and reproductive importance.

### Theta Roles

Theta roles are the semantic relations of the syntactic arguments of a verb. The “agent” (intentionally) carries out the action of the verb; the “experiencer” undergoes

an emotion, a state of being, or a perception expressed by the verb; the “theme” directly receives the action of the verb or is the topic of the verb; the “source” is the direction from which the action originates; the “goal” is the direction towards which the action of the verb moves; and the “location” is where the action of the verb takes place. There is a trend (shown in Table 3), particularly in Biggs et al., Silverthorn, and Stanfield’s writing, where the male reproductive system and sperm have the theta role of agent in a sentence, while the female reproductive system and egg are the experiencer, theme, goal, or location. Urry et al.’s writing is the exception, where both the female and male reproductive systems are agents and both the sperm and egg are themes.

The sperm being coded as the agent conveys that it actively and purposely works toward the goal of fertilization. If the egg is the experiencer or theme, it experiences fertilization or undergoes the action of the sperm but does not act on its own. The uterus and egg are also frequently the source or location, which is not misleading in it of itself, as fertilization does take place in the uterus. However, the lack of the theta role “agent” for the egg and uterus makes them seem like merely the destination upon which fertilization takes place, instead of an active participant in the process.

## Discussion

The data show that it is common for the sperm to be described as the main actor and focus of fertilization in biology textbooks, with the egg as the backdrop for the process instead of an equal partner. Using the perspective of sperm in descriptions of fertilization leads to a lack of information on the female reproductive system, which implies that the biology of the male participant is more complex, interesting, or important. It conforms to traditional gender roles by giving the male body agency—conferring higher value to it than the female body—and by anthropomorphizing sperm with expected male traits and actions from fairy tales or harmful gender myths. All the textbooks use language like “the egg is fertilized by the sperm,” where the active, powerful sperm is responsible for fertilizing the passive egg (which has no movement or mission on its own and is merely the object in which fertilization takes place). Other contrasting verbs, adjectives, and syntactic struc-

Table 3. Example passages from each textbook relevant to theta roles in language on fertilization.

	Biggs et al.	Silverthorn	Stanfield	Urry et al.
Agent	1. "Sperm", "strong, muscular contractions" (1005). 2. "only one", "fluids secreted by the vagina are acidic and destroy most of the delicate sperm", "Yet, some sperm", "The surviving sperm", "The sperm" (1005).	1. "Sperm swimming upward through" (818). 2. beating cilia", "sperm deposited in", "the sperm" (826). 3. "a sperm", "capacitated sperm", "The enzymes", "the sperm" (827).	1. "the arriving sperm" (665). 2. "sperm deposited in the", "only a few hundred", "the others" (685). 3. "several sperm" (685). 4. "The first sperm to reach" (685).	1. "sperm deposited in or near" (1020). 2. "Molecules and events at the", "sperm", "molecules on the sperm surface", "changes at", (1042). 3. "gonads", "accessory glands", "ducts" (1023). 4. "gonads", "a system of ducts and chambers" (1024).*
Experiencer	1. "the mature egg" (1005).	1. "an egg" (826). 2. "the egg" (827).	1. "Ova" (665).	1. "eggs within" (1020).
Theme	1. "fluids secreted by the vagina... most of the delicate sperm", "The egg", "the egg" (1005).	1. "The Fallopian tubes" (818). 2. "an egg" (826). 3. "Fertilization of an egg" (827) 4. "an outer layer of loosely connected granulosa cells (the corona radiata) and a protective glycoprotein coat called the zona pellucida" (827).	1. "the barriers to fertilization—namely, the corona radiata and zona pellucida" (685).	1. "any protective layer surrounding the egg" (1042)* 2. "both sperm and reproductive hormone", "products essential to sperm movement", "the sperm and glandular secretions" (1023). 3. "eggs and reproductive hormones", "gametes", "the embryo and fetus" (1024).*
Goal	1. "the vagina of the female's reproductive system" (1005). 2. "the uterus" (1005).	1. "the egg" (827).	1. "the cervical canal into the uterus", "the opening to the uterine tube", "the uterine tube" (685). 2. "the oocyte" (685).	1. "the plasma membrane" (1042).*
Location	1. "the vagina" (1005)	1. "the uterus" (818). 2. "the female reproductive tract" (826)	1. "vagina", "uterine wall" (685)	1. "the female reproductive tract", "the tract" (1020). 2. "egg surface", "the surface of the egg" (1042).*
Source	No relevant instances	1. "its cavity" (818).	No relevant instances	No relevant instances

**Note:** Theta roles are not labeled for all arguments of each verb, only the relevant ones. In addition, noun phrases in adjuncts as well as arguments may receive a theta role, though by convention only arguments do. Asterisks indicate that the passage has low bias.

**Note:** Asterisks indicate that the passage has low bias.

tures for the male and female body fortify this notion as well. It aligns with the social norms of how men are supposed to act, and women react, and how historically men hold positions of power and decision-making while women stay home and accept male decisions. This should be substituted with equal language, like fertilization as “the union of sperm and egg” (Urry et al. 2017). While passive sentence structure is common in science, it becomes problematic when it is used unequally between two similar objects of scientific inquiry by creating a discrepancy in influence and sovereignty. The male body holding the theta role of agent while the female body is the experiencer, theme, source, or goal, makes the male the actor and the female the acted upon or the setting of fertilization, unrightfully disempowering the female partner.

After taking all of this into account, we scored the four

analyzed textbooks in their degree of bias, shown in Table 4 below. The calculations were rounded to the hundredth decimal point. Every violation as well as every sentence or instance of the phenomenon (biased or not) in Tables 1 through 3 were counted, and a ratio of the number of violations to the number of all examples was created to find a score for each category, per textbook.<sup>3</sup> Therefore, scores can range from 0 (0% violations) to 1 (100% violations). Then, the three category scores per textbook were averaged to create a final score for the textbook. Excerpts that had parallel structure to describe male and female roles—e.g. Stanfield’s passage 3 in Table 1, Urry et al.’s passages 3, 4 and 5 in Table 1, and Urry et al.’s passages 2-4 in Table 3—were considered neutral and counted only for the total number of instances. For example, active language for the male body would not be considered a violation if active language for the female body was used in a parallel fashion.

Table 4. *Category and Total Quantitative Scores for the Four Textbooks (regarding the amount of bias).*

	Passiveness vs. Activeness	Perspective/ Personification	Theta roles	Total Scores
<i>Biology: The Dynamics of Life</i> by Alton Biggs et al. (2004)	8/9 = 0.89	9/9 = 1.00	12/14 = 0.86	0.92
<i>Human Physiology: An Integrated Approach</i> (Edition 8, 2019) by Dee Unglaub Silverthorn	8/8 = 1.00	6/6 = 1.00	18/19 = 0.95	0.98
<i>Principles of Human Physiology</i> (Edition 6, 2017) by Cindy L. Stanfield	6/7 = 0.86	9/9 = 1.00	14/14 = 1.00	0.95
<i>Campbell Biology</i> by Lisa A. Urry et al. (Edition 11, 2017)	1/10 = 0.10	0	8/23 = 0.35	0.15

The higher the score, the more bias present. Table 4 indicates that *Biology: The Dynamics of Life* by Alton Biggs et al. (2004), *Human Physiology: An Integrated Approach* (Edition 8, 2019) by Dee Unglaub Silverthorn, and *Principles of Human Physiology* (Edition 6, 2017) by Cindy L. Stanfield have a similarly high proportion of biased instances, with scores in the 0.90s. However, *Campbell*

*Biology* by Lisa A. Urry et al. (Edition 11, 2017) stands out with by far the lowest proportion of biased instances—a score of 0.15. While the quantity of violations does not comprehensively determine the impression a textbook imparts, it gives a good idea of the amount of bias present.

There is not a clear correlation between publication year and amount of bias in the data as initially hypothesized: while one of the newer textbooks has the lowest bias, both old and new textbooks could have high bias scores. There was not an improvement in neutrality in newer editions of the textbooks Campo-Engelstein and Johnson examined either, nor differences compared to older editions, which points to stagnation or ignorance on this issue in textbooks that have already written, re-

<sup>3</sup> To specify, in Table 1, for each textbook, the number of sentences with active male and passive female language was divided by the total number of sentences. In Table 2, the number of instances of male personification and sentences with male perspective were divided by the total number of instances of personification plus the total number of sentences. In table 3, the number of instances of the male body being an agent and a female body having any other theta role was divided by the number of total relevant instances of theta roles.



ardless of edition updates.

Further evidence beyond language in fertilization was also discovered to support gender bias in biology textbooks. In all four, the section on the male reproductive system was before the one on the female reproductive system. While it might seem like a coincidence, it is likely a reflection of a patriarchal society if it is such a consistent pattern, implying the male is primary and standard, and the female is secondary or an afterthought, even if these beliefs are unconsciously held by the authors. Furthermore, Silverthorn included a section on male sexuality (Silverthorn, 2019), where she mentions male libido, without one on female sexuality, propagating the myth that men innately have high libido and women minimal libido. This misconception could be used to absolve men from blame for their sexual aggression towards women or minimize the prioritization of female pleasure.

## Implications

The results show that recent textbook publications from 2017 (*Principles of Human Physiology* by Stanfield) and 2019 (*Human Physiology: An Integrated Approach* by Silverthorn) can still endorse societal gender norms in their language on fertilization, while other recent textbooks can be relatively unbiased as well, such as *Campbell Biology* by Urry et al. from 2017. As society questions and rejects social gender roles in modern times, scientific writing should also reflect this. Authors must reevaluate their past work, be cognizant of their own biases, and then be careful not to reflect them in their writing. Some textbooks clearly need revision to remove implicit perpetuation of the supposed superiority of the male and prejudice and discrimination towards the female. In sections on fertilization, there must be equal agency for and information and focus on the female body and its contributions, compared to the male body.

Though these patterns of gender inequality within language may be subtle to readers, there is a powerful adverse effect from repeated exposure to gender bias, particularly in educational biology writing, which should strive to be as objective and informative as possible and is therefore assumed to be. Unfortunately, human partiality is always a possibility. Sexism in writing on biology is especially dangerous because these so-called comprehensive facts can then be used to prove that gen-

der norms agree with biology, being valid and innate in humans, and should therefore continue to be perpetuated and used to determine societal structure, hierarchy, expectations, and views. They are detrimental and restrictive to both male and female students and undermine the ability of the teachers using these textbooks to teach accurately and impartially themselves.

## Limitations and Future Research

Since there was no systematic random sampling of the most popular textbooks, it is uncertain if this is a representative sample of all high school biology textbooks in America, which would require further research, from sales data or surveys for example.

While this study focused on the text itself and took into consideration the date of publication (of the edition), a deeper analysis of the textbook authors and editors' backgrounds, the dates of initial publication, and details of textbook usage and circulation could provide deeper insight into the results.

It is important to note for future research that making progress on this issue should involve several intersecting disciplines, such as anthropology, linguistics, biology, science and technology studies, gender studies, sociology, pedagogy, etc.

## Conclusion

Presenting science with a gendered narrative in educational institutions may create pressure for young people to conform to these norms. Boys may feel the need to have high agency and dominance, while girls feel that they should be demure and submissive, which according to their biology textbooks, their own bodies encourage. The notion that boys should assertively act and girls should compliantly react limits both in their potential for self-expression and their future roles and careers in life. It may even dissuade girls from enjoying and pursuing careers in science.

Textbooks are an authoritative source of information for students, so they rarely question them nor are asked to do so by teachers, which makes this bias so problematic.

These textbooks can undermine the ability and worth of the egg and female reproductive system, while over-emphasizing the potency and agency of the male sperm and semen during fertilization. However, not all hope is lost with faulty textbooks. Teachers may actually point out the bias present in the text and use it to teach about sexism and gender norms, as well as ask students to reflect on their dangers. Only then will students notice them in the textbook and then think of examples of similar prejudices that they have witnessed. In addition, textbooks like *Campbell Biology* by Lisa A. Urry et al. (Edition 11, 2017) demonstrate that it is possible to write with neutrality and accuracy in reproductive biology without sacrificing clarity, information, or understandability.

This article has shown that normalized gendered language still exists in very recent editions of biology textbooks by big publishers that would be used in classrooms today, and how it can sustain gender stereotypes in our minds and in our society. There seems to have been an improvement from decades ago when Martin wrote her pioneering article on this topic in 1991, but the degree of bias in these findings seems similar to those of Campo-Engelstein and Johnson's from 2013. Clearly, almost a decade later, there is currently still a long way to go, also evidenced by the fact that most people still remember and think about fertilization in this story-like, gender-biased way. Impartial language is imperative in science, especially in reproductive biology, which easily falls into gender tropes. Only then can we further dismantle sexism and its prevalent prescriptive, heteronormative, feminine and masculine expectations that are toxic and restrictive for all parties involved.

## References

- Biggs, A. L., Hagins, W. C., Kapicka, C., Lundgren, L., Rillero, P., Tallman, K. G., & Zike, D. (2004). Reproduction and Development. In *Biology: The Dynamics of Life* (pp. 994–1022). essay, The McGraw-Hill Companies, Inc.
- Bowen, R. A. (2000, April 1). *Fertilization*. Colorado State University - VIVO. Retrieved December 7, 2021, from <http://www.vivo.colostate.edu/hbooks/pathphys/reprod/fert/fert.html>
- Campo-Engelstein, L., & Johnson, N. L. (2013). Revisiting “The fertilization fairytale:” An analysis of gendered language used to describe fertilization in science textbooks from middle school to medical school. *Cultural Studies of Science Education*, 9(1), 201–220. <https://doi.org/10.1007/s11422-013-9494-7>
- Gharghoury, J. (2020, December 9). *The history of subjective diction in sex ed textbooks*. History Daily. Retrieved December 7, 2021, from <https://historydaily.org/history-of-subjective-diction-sex-ed-textbooks>
- Gunderson, G. (2004). 1. *Fertilization*. Columbia University. Retrieved December 7, 2021, from <http://www.columbia.edu/itc/hs/medical/humandev/2004/Chapt1-Fertilization.pdf>
- Martin, E. (1991). The egg and the sperm: How science has constructed a romance based on stereotypical male-female roles. *Signs: Journal of Women in Culture and Society*, 16(3), 485–501. <https://doi.org/10.1086/494680>
- Martin, R. D. (2018, August 23). *The macho sperm myth*. Aeon. Retrieved December 7, 2021, from <https://aeon.co/essays/the-idea-that-sperm-race-to-the-egg-is-just-another-macho-myth>
- Meyerhoff, M. (2019). *Introducing Sociolinguistics* (3rd ed.). Routledge.
- Monroy, A. (2020, February 18). *Fertilization*. Encyclopædia Britannica. Retrieved December 7, 2021, from <https://www.britannica.com/science/fertilization-reproduction>
- Nanda, S. (2020). *Evaluation and management of high-risk pregnancies: Emerging research and opportunities*. IGI Global.
- Silverthorn, D. U. (2019). Chapter 26: Reproduction and Development. In *Human Physiology: An Integrated Approach* (8th ed., pp. 800–833). essay, Pearson Education, Inc.
- Stanfield, C. L. (2017). 22: The Reproductive System. In *Principles of Human Physiology* (6th ed., pp. 661–696). essay, Pearson Education Limited.

Urry, L. A., Cain, M. L., Wasserman, S. A., Minorsky, P. V., & Reece, J. B. (2017). *Campbell Biology* (11th ed.). Pearson.

# 2D Microwave Simulation Using Finite Differences

By Brandon Li

*Department of Physics and Math, College of Arts and Sciences at Cornell University*

---

## Abstract

We derive a finite difference scheme to numerically simulate the propagation of microwaves in a 2D domain with reflective obstacles. An analysis of the consistency and stability of this method is performed, leading to a rigorous justification of its convergence. Following this, we discuss the boundary conditions and derive the mathematical form for energy flux. Finally, the numerical approximation is compared against prior experimental results. The simulation was found to have been able to predict the distribution of interference maxima and minima with some accuracy, but it was seen to be less effective in predicting average intensities. The advantages and disadvantages of these techniques are then discussed along with possible avenues for improvement.

---

## Introduction

This paper aims to contextualize an experiment conducted for the semester-long PHYS 2210 lab course (Fine et al., 2021) by developing a numerical method to model the propagation of microwaves in the system under study. This model has allowed for an informed experimental design process and has given us a better way to interpret our results. The experiment itself was motivated by the concept of wave protection arrangements. The idea behind wave protection is that there are situations in which the goal is to reduce the force of waves that propagate from one region to another. Therefore, an effective wave protection arrangement will minimize the transmitted energy while also minimizing the amount of material used (this objective results from economical concerns). One example of an application is in shoreline protection, where the goal is to prevent erosion of the coast by incoming ocean waves (Smith et al., 2020). In this experiment, we chose to study microwave protection arrangements, partly due to the selection of lab equipment available, and also because we thought microwaves would be a good proxy for general wave phenomena. The experiment consists of a rectangular region, in which cylindrical metal obstacles may be placed, bound by two metal walls on the sides (Figure 1). The experiment consisted of arranging the obstacles in

certain patterns and then measuring the microwave energy transmitted from one end to the other. Microwaves were sent through the obstacle arrangement by a transmitter and were measured with a movable detector on the other side. This allowed the quantification of exactly how much microwave energy was able to pass through the obstacles, with the rest being either reflected or absorbed by the physical obstacles (Fine et al., 2021). Several trials were conducted with a different spatial arrangement of obstacles each time. It became apparent that a more reliable method of designing wave protection arrangements was needed than just relying on intuition. Because it is not possible to see or interact with microwaves directly, the idea was to instead numerically model their behavior on a computer. The goal of this paper is to mathematically justify the development of this model and explain how exactly the electromagnetic wave equation was simulated in our system. We start by setting the domain to be a rectangular area corresponding to a 2D horizontal slice of the experiment region with two of the sides representing the metal walls. This is the same area as depicted on the left side of Figure 1. There are two good reasons to assume that the 2D slice will approximate the entire 3D system reasonably well. Firstly, the microwave generator produces waves polarized in the  $z$  direction only, and secondly, the whole experiment was designed to have approximate translational sym-



metry in the vertical (z) direction. This dramatically reduces the number of degrees of freedom, while simplifying the equations and reducing the overall computational load. With this simplification in place, the next task is to derive the physical equations that govern microwave propagation (section 3).

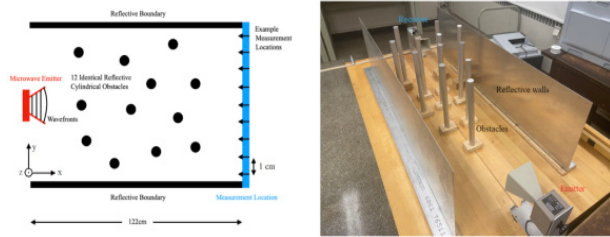


Figure 1: Diagram and Photograph (Fine et al., 2021). On the left is a top-down diagrammatic depiction of the setup, and on the right is a photograph from a standing perspective with the emitter on the near side. Note that the z-axis points up out of the horizontal plane.

## Experiment Details

The two aluminum walls were both 122 cm long and they were separated by 50 cm of distance. A total of 12 cylindrical metal obstacles were manufactured, each with a diameter of 2.5 cm, and all were set on wooden bases (Fine et al., 2021). Wood was chosen for both the bases and the table material since it would interfere relatively little with microwave propagation. A standard 10.5 GHz microwave transmitter was placed at one end of the setup in order to generate vertically polarized microwaves, and a Gunn diode receiver was placed at the other end to measure the intensity pattern. The receiver's sensitivity was set to a fixed value for each experiment and a total of 41 data points were taken each time. The receiver was moved 1 cm horizontally between each reading. Finally, a total of seven configurations (including the control) had their intensity patterns measured and the analysis of these results can be found in sections 8-9.

### Derivation of electromagnetic wave equation

We begin this section by deriving the wave equation starting from Maxwell's equations. To describe how microwaves propagate in air, we observe that there are no free charges in this system and both the per-

mittivity and permeability are close to that of the vacuum:  $\frac{\mu}{\mu_0} \approx \frac{\epsilon}{\epsilon_0} \approx 1$ . Maxwell's equations therefore state

$$\nabla \cdot \vec{E} = 0, \quad \nabla \cdot \vec{B} = 0, \quad \nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}, \quad \nabla \times \vec{B} = \frac{1}{c^2} \frac{\partial \vec{E}}{\partial t}. \quad \#(1.1-4)$$

Taking the curl of Faraday's law (1.3) gives

$$\nabla \times \nabla \times \vec{E} = -\nabla \times \frac{\partial \vec{B}}{\partial t} \Rightarrow \nabla(\nabla \cdot \vec{E}) - \nabla^2 \vec{E} = -\frac{\partial \nabla \times \vec{B}}{\partial t} \Rightarrow \nabla^2 \vec{E} = \frac{1}{c^2} \frac{\partial^2 \vec{E}}{\partial t^2}. \quad \#(2.1-2)$$

After substituting in Gauss's law (1.1) and the Ampere-Maxwell law (1.4), followed by exchanging partial derivatives, the result is the vector form of the wave equation. Now, since our transmitter emits vertically polarized microwaves and we are taking a 2D slice of the system, we may make the assumption that

$$\vec{E} = u(x, y, t) \hat{z} \quad \#(3)$$

where the E-field is invariant along the z-axis and is always directed vertically. Substituting this into (2.2) leads to the scalar wave equation for u:

$$\frac{1}{c^2} u_{tt} = \nabla^2 u + f. \quad \#(4)$$

To this equation, we have also added a forcing term  $f=f(x,y,t)$  that varies sinusoidally over time to account for the generation of waves at the emitter's location. This term is equal to zero everywhere else in space.

## Finite difference method

### Introduction to general technique

To solve the wave equation numerically, we must restrict the domain to a finite region of space. Let  $\Omega = [x_1, x_2] \times [y_1, y_2]$  be the rectangular region bounded by the metal walls along the x-direction. Letting  $u(x,y)$  be the true solution of the wave equation, we may represent it with a set of values  $U(x_i, y_j, t_k)$  that approximate  $u$  at a finite set of points  $(x_i, y_j, t_k)$  in space and time. These points are laid out on a grid with spacings of  $\Delta x$ ,  $\Delta y$ , and  $\Delta t$  respectively along the x, y, and t dimensions.

### Finite differences

Rewriting the EM wave equation in terms of

partial derivatives, we get

$$u_{tt} = c^2(u_{xx} + u_{yy}) + f. \quad \#(5)$$

Let  $u$  be the solution to the wave equation and  $U$  be its finite difference approximation. Assume  $u$  is sufficiently smooth enough that the third derivatives  $u_{xxx}, u_{yyy}, u_{ttt}$  are all bounded by some constant  $M$ . By Lagrange's remainder theorem,

$$u(x + \Delta x, y, t) = u(x, y, t) + u_x(x, y, t)\Delta x + \frac{1}{2}u_{xx}(x, y, t)\Delta x^2 + \frac{1}{6}u_{xxx}(x, y, \xi)\Delta x^3, \quad (8)$$

$$u(x - \Delta x, y, t) = u(x, y, t) - u_x(x, y, t)\Delta x + \frac{1}{2}u_{xx}(x, y, t)\Delta x^2 - \frac{1}{6}u_{xxx}(x, y, \xi')\Delta x^3 \quad (9)$$

for some  $\xi \in [t, t + \Delta t]$  and  $\xi' \in [t - \Delta t, t]$ . Adding the two equations together and observing that  $\frac{1}{6}u_{xxx}(x, y, \xi)\Delta x^3 - \frac{1}{6}u_{xxx}(x, y, \xi')\Delta x^3 \leq \frac{M}{3}\Delta x^3 = O(\Delta x^3)$ , we obtain the expression for the finite difference approximation with error term:

$$u_{xx}(x, y, t) = \frac{u(x + \Delta x, y, t) - 2u(x, y, t) + u(x - \Delta x, y, t)}{\Delta x^2} + O(\Delta x^2). \quad (10)$$

Similarly, we may calculate the expressions for the other partial derivatives as follows:

$$u_{yy}(x, y, t) = \frac{u(x, y + \Delta y, t) - 2u(x, y, t) + u(x, y - \Delta y, t)}{\Delta y^2} + O(\Delta y^2), \quad u_{tt}(x, y, t) = \frac{u(x, y, t + \Delta t) - 2u(x, y, t) + u(x, y, t - \Delta t)}{\Delta t^2} + O(\Delta t^2). \quad \#(8.1-2)$$

Then, after substituting equations (7), (8.1), and (8.2) into the wave equation (5) and solving for  $u(x, y, t + \Delta t)$ , we find that

$$\begin{aligned} u(x, y, t + \Delta t) &= c^2 \frac{\Delta t^2}{\Delta x^2} [u(x + \Delta x, y, t) - 2u(x, y, t) + u(x - \Delta x, y, t)] \\ &\quad + c^2 \frac{\Delta t^2}{\Delta y^2} [u(x, y + \Delta y, t) - 2u(x, y, t) + u(x, y - \Delta y, t)] + 2u(x, y, t) \\ &\quad - u(x, y, t - \Delta t) + \Delta t^2 f(x, y, t) + O(\Delta x \Delta t^2) + O(\Delta y \Delta t^2) + O(\Delta t^3). \end{aligned} \quad \#(9)$$

Now we can simplify things if we choose an equal grid spacing for the  $x$  and  $y$  axis and set  $\Delta x = \Delta y \equiv \Delta s$ . Along with defining  $\sigma^2 = c^2 \frac{\Delta t^2}{\Delta s^2}$ , the equation becomes

$$\begin{aligned} u(x, y, t + \Delta t) &= \sigma^2 [u(x + \Delta s, y, t) + u(x - \Delta s, y, t) + u(x, y + \Delta s, t) + u(x, y - \Delta s, t)] \\ &\quad + (2 - 4\sigma^2)u(x, y, t) - u(x, y, t - \Delta t) + \Delta t^2 f(x, y, t) + O(\Delta s \Delta t^2) \\ &\quad + O(\Delta y \Delta t^2) + O(\Delta t^3). \end{aligned} \quad \#(10)$$

This suggests that we update the grid according to the finite difference scheme

$$\begin{aligned} U(x, y, t + \Delta t) &= \sigma^2 [U(x + \Delta s, y, t) + U(x - \Delta s, y, t) + U(x, y + \Delta s, t) + U(x, y - \Delta s, t)] \\ &\quad + (2 - 4\sigma^2)U(x, y, t) - U(x, y, t - \Delta t) + \Delta t^2 f(x, y, t). \end{aligned} \quad \#(11)$$

Therefore, if the approximate solution is known at  $t$  and  $t - \Delta t$ , then the approximate form at  $t + \Delta t$  can be computed by plugging the equation in. Since this

is a second order method and we have two linearly independent initial conditions, then to initialize the method we must provide the values of both  $U(x, y, 0)$  and  $U(x, y, 0 + \Delta t)$ . Based on the assumption that there are no electromagnetic waves to start at  $t = 0$ , we set  $U(x, y, 0) = u(x, y, 0) = 0$  and

$$u_t(x, y, 0) \approx \frac{U(x, y, \Delta t) - U(x, y, 0)}{\Delta t} = 0 \Rightarrow U(x, y, 0 + \Delta t) = 0$$

## Convergence analysis

The convergence analysis is a mathematical proof that the numerical method can approximate the true solution over a fixed time interval with an arbitrary degree of accuracy provided that the mesh size is taken sufficiently small. This information is necessary to know, but not relevant for the implementation itself besides giving a stability condition for the time step size.

## Consistency

We may write the equation (11) in the form of a linear equation  $\varphi_{\Delta s, \Delta t} U = 0$  where  $\varphi_{\Delta s, \Delta t} U(x, y, z) = \sigma^2 [U(x + \Delta s, y, t) + \dots + U(x, y, t - \Delta t)]$ . The definition of consistency is that as  $\Delta s, \Delta t \rightarrow 0$  then  $\varphi_{\Delta s, \Delta t} u \rightarrow 0$  where  $u$  is the true solution. We can see that

this is true since equation (10) states that  $\varphi_{\Delta s, \Delta t} u = O(\Delta s \Delta t^2) + O(\Delta y \Delta t^2) + O(\Delta t^3)$  which goes to zero.

## Stability

A necessary condition for any numerical scheme to be useful is that it needs to be stable, meaning small errors should not blow up exponentially over time. To see that this method is indeed stable, let us suppose that at times  $t - \Delta t$  and  $t$ ,  $U$  takes on the form of a complex plane wave with wavevector  $k_x x + k_y y$ , along with some scaling constant relating the two time slices:

$$U(x, y, t - \Delta t) = e^{i\vec{k} \cdot \vec{r}} = e^{i(k_x x + k_y y)}, U(x, y, t) = \lambda e^{i\vec{k} \cdot \vec{r}} = \lambda e^{i(k_x x + k_y y)}, \quad \#(12.1-2)$$

Note that according to Fourier analysis, any function can be linearly decomposed into plane

waves. Therefore, if we prove that the magnitude of each plane wave stays bounded, then as a consequence, arbitrary combinations of plane waves will not experience numerical blow-up. We can check this is true by computing the state of the system at  $t+\Delta t$ , denoted  $U(x,y,t+\Delta t)$ . This is done by plugging in (12.1) and (12.2) into equation (11):

$$\begin{aligned} U(x,y,t+\Delta t) &= \sigma^2 \left[ \lambda e^{i(k_x(x+\Delta x)+k_y y)} + \lambda e^{i(k_x(x-\Delta x)+k_y y)} + \lambda e^{i(k_x x+k_y(y+\Delta y))} \right. \\ &\quad \left. + \lambda e^{i(k_x x+k_y(y-\Delta y))} \right] + (2-4\sigma^2) \lambda e^{i(k_x x+k_y y)} - e^{i(k_x x+k_y y)} \\ &= (\lambda \sigma^2 [e^{ik_x \Delta x} + e^{-ik_x \Delta x} + e^{ik_y \Delta y} + e^{-ik_y \Delta y} - 4] + 2\lambda - 1) e^{i(k_x x+k_y y)} \\ &= (\lambda \sigma^2 [2\cos(k_x \Delta x) - 2 + 2\cos(k_y \Delta y) - 2] + 2\lambda - 1) e^{i(k_x x+k_y y)} \\ &= \left( -4\lambda \sigma^2 \left[ \sin^2\left(\frac{k_x \Delta x}{2}\right) + \sin^2\left(\frac{k_y \Delta y}{2}\right) \right] + 2\lambda - 1 \right) e^{i(k_x x+k_y y)} \\ &= (2\alpha\lambda - 1) \end{aligned} \quad \#(13)$$

where we define  $\alpha = 1 - 2\sigma^2 \left[ \sin^2\left(\frac{k_x \Delta x}{2}\right) + \sin^2\left(\frac{k_y \Delta y}{2}\right) \right]$ . If we now want this plane wave to be an eigenvector, then we require  $|\lambda|^2 = \alpha\lambda - 1 \Rightarrow \lambda = \alpha \pm \sqrt{\alpha^2 - 1}$ . This shows that there are two possible plane wave eigenmodes for each wavevector with correspondingly different eigenvalues. Finally, both of the eigenvalues need to have magnitude less than one in order for the waves not to grow exponentially. First, we observe that  $\alpha \in [1 - 4\sigma^2, 1]$ . If  $1 - 4\sigma^2 < -1$  then  $\alpha < -1 \Rightarrow \alpha = -\sqrt{\alpha^2 - 1} < -1$  which is not allowed. If  $1 - 4\sigma^2 \geq -1$  then the imaginary component is non-zero and  $|\lambda|^2 = \alpha^2 + (1 - \alpha^2) = 1$ , which means the waves are stable. Therefore, we must require that

$$1 - 4\sigma^2 \geq -1 \Rightarrow \sigma^2 \leq \frac{1}{2} \Rightarrow \sigma \leq \frac{1}{\sqrt{2}} \quad \#(14)$$

for stability. From this follows the restriction that  $\Delta t \leq \frac{1}{\sqrt{2}c} \Delta s$  is required for stability, and this bound is known as the CFL condition for the 2D wave equation. In practice, this means the time step cannot be too large, otherwise the simulation “blows up” numerically. (Olver, 2013). Experimentally, if  $\Delta t$  is increased to even a slight amount larger than the theoretical limit, the output shows extreme numerical instability. If  $\Delta t$  is slightly below this limit then there are no issues.

## Convergence

Finally, the Lax-Richtmyer Equivalence Theorem states that since our method is both consistent and stable, then it converges numerically. Therefore, fixing a time interval  $0, T$ , the finite difference approximation approximates the true solution to an arbitrarily high accuracy as  $\Delta s, \Delta t \rightarrow 0$ .

## Boundary conditions

Since the simulation domain is finite, we must consider what kind of behavior occurs at the edges. There are actually two types of boundary conditions that are relevant to our model.

### Reflecting boundary

The first boundary condition arises at the interfaces between conductors and the surrounding free space. The laws of physics dictate that the E-field near a perfect conductor must have no component parallel to its surface. What this means in our case is that on the boundary of the conductor,  $u(\partial \text{conductor}) = 0$

. This can be accomplished by setting  $U=0$  at each grid point that overlaps the location of a conductor. The reflecting boundary is required to model both the metal walls and the obstacles.

### Absorbing boundary

The other boundary condition is more difficult. We need the waves to disappear from the front and back of our domain, and the way to accomplish this is through absorbing boundary conditions. The differential form of these boundary conditions has been derived already with various levels of approximations based on successive Taylor approximations (Engquist & Majda, 1977). The second-order approximation will be used in accordance with the rest of the method. For a boundary at  $x=0$  where waves

disappear off to the left, the equation is

$$cu_{xt} - u_{tt} + \frac{1}{2}c^2 u_{yy} = 0. \quad \#(15)$$

We will use the standard finite difference approximation for  $u_{tt}$  and  $u_{yy}$ . However, for  $u_{xt}$ , we will derive the approximation starting with the second order Taylor expansion around  $u(x,y,t)$ ,

$$\begin{aligned} u(x+\Delta s, y, t+\Delta t) &= u(x, y, t) + u_x(x, y, t)\Delta s + u_t(x, y, t)\Delta t \\ &\quad + \frac{1}{2}u_{xx}(x, y, t)\Delta s^2 + u_{xt}(x, y, t)\Delta s\Delta t + \frac{1}{2}u_{tt}(x, y, t)\Delta t^2 + E, \end{aligned}$$

which gives us the update rule

for nodes along the left wall. By symmetry, one can also deduce the rule for the right wall.

## Energy

In order to make predictions about the efficiency of obstacle arrangements, formulas for electromagnetic energy and energy flux must be derived. This flux is given by the Poynting vector,

$$\vec{S}, \text{ defined as } \vec{S} = \frac{1}{\mu_0} \vec{E} \times \vec{B}. \#(20)$$

This vector field represents the flow of electromagnetic energy at each point in space. To compute this for our system, we start with the definition of  $E$  and substitute it in to Faraday's law (2) to get the magnetic field at any given time.

$$\vec{E} = u\vec{z} \Rightarrow \nabla \times \vec{E} = \frac{\partial u}{\partial y} \hat{x} - \frac{\partial u}{\partial x} \hat{y} = -\frac{\partial B}{\partial t} \hat{x} - \frac{\partial B}{\partial t} \hat{y}, \Rightarrow B_x = -\int_0^t u_y dt, \quad B_y = \int_0^t u_x dt. \#(21)$$

We may then calculate the Poynting vector as follows:

$$\vec{S} = \frac{1}{\mu_0} (u\vec{z}) \times (B_x \hat{x} + B_y \hat{y}) = \frac{1}{\mu_0} [-uB_y \hat{x} + uB_x \hat{y}] = -\frac{1}{\mu_0} \left[ u \int_0^t u_y dt \hat{x} + u \int_0^t u_x dt \hat{y} \right]. \#(22)$$

Now, let the electromagnetic energy be denoted . We may calculate the rate of energy change as

$$-\nabla \cdot \vec{S} = \frac{\partial \theta}{\partial t} = \frac{1}{\mu_0} \left[ u \int_0^t u_x + u \int_0^t u_{xx} + u \int_0^t u_y + u \int_0^t u_{yy} \right] \left[ \frac{1}{\mu_0} \left[ u \int_0^t u_x + u \int_0^t u_y + \frac{1}{c^2} u \int_0^t u_{tt} \right] \right]. \#(23)$$

Taking the definition of electromagnetic energy as

$$\theta = \frac{1}{2} \left( \epsilon_0 \vec{E} \cdot \vec{E} + \frac{1}{\mu_0} \vec{B} \cdot \vec{B} \right) = \frac{\epsilon_0}{2} u^2 + \frac{1}{2\mu_0} \left( \int_0^t u_y dt \right)^2 + \frac{1}{2\mu_0} \left( \int_0^t u_x dt \right)^2, \#(24)$$

This matches the result obtained above, showing that the definition of electromagnetic energy is consistent with the Poynting vector and the conservation law  $-\nabla \cdot \vec{S} = \frac{\partial \theta}{\partial t}$  is obeyed. We may calculate the energy and energy flux by integrating

$u_x$  and  $u_y$  numerically to get  $B_x$  and  $B_y$ , which yields the Poynting vector when plugged into equation (22). One concern is whether computation of  $B_x$  and  $B_y$  using a running sum can lead to uncorrected drift over time. This is mitigated by the

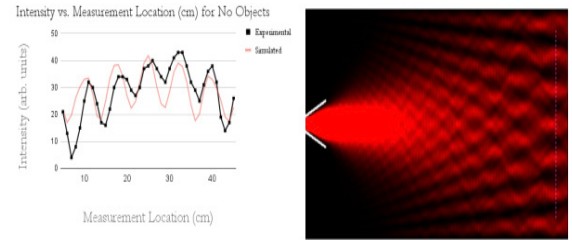
fact that keeping the total time interval consistent while increasing the spatial/temporal resolution will allow the  $E$  field to converge to its true value as its integral converges along with it.

## Results

### Experimental results vs. Prediction

For the purposes of the experiment, the numerical method was implemented in java as an interactive GUI application. The domain was set

to the rectangular region  $[-8, 122] \times [0, 50]$  with  $c=30$ ,  $\Delta s=0.1$ , and  $\Delta t=0.002$ , all chosen to satisfy the CFL condition (units are  $L=\text{cm}$ ,  $T=\text{ns}$ ). Figure 2 shows the comparison between experiment and simulation on the left and a visualization of the energy density on the right in the case of no objects. Subjectively, this seems to be the case in which the two curves correspond the most.



**Figure 2: Control comparison** (Fine et al., 2021). In the control case without obstacles, the simulation seems to match physical reality quite well. On the left is a comparison between the expected measurements along the back wall, versus the real data (scaled so that the averages match). On the right is the time-averaged electromagnetic energy density plotted over space where brighter regions contain more energy.

Besides this, six other configurations were tested and all of the graphs corresponding to these setups are located in the appendix. The first non-trivial configuration was created by placing the obstacles into a rectangular grid with three rows and four obstacles in each row (Figure 6). The next pattern was a triangular grid where neighboring obstacles were arranged in equilateral triangles (Figure 7). The reasoning behind this design had to do with the hypothesis that the triangular grid would provide many opportunities for the incoming waves to scatter back. Next, there were three randomly



generated configurations (Figures 8-10). The purpose of these was to test the accuracy of the simulation as well as to determine the effectiveness of purely random configurations. By the nature of random systems, this required more than one trial, so three separate random configurations were generated using an algorithm. The last design was a V-shaped grid, and in this case, we believed it would maximize the head on surface area and provide many opportunities for waves to bounce off the rods (Figure 11). After all the data was collected, the readings were added up and divided by the total number of data points taken to get the average intensity across the back wall for each configuration. These values were then plotted against the predicted average intensities as shown in Figure 3.

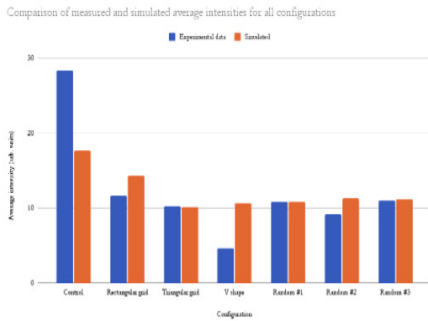


Figure 3: Comparison between measured and predicted average intensities (Fine et al., 2021). The predictions were normalized so that the average intensity over all the configurations matched the average for the experimental data.

One observation is that the predicted average intensities show much less variation in magnitude than the experimental measurements. In addition, we see a large deviation between predicted and measured values in the control case and the V-shaped grid. Some possible reasons for these discrepancies are discussed in section 9.

## Numerical evidence for convergence

The mathematical proof that this method converges is quite important, however, it does not give the exact rate at which convergence occurs. It is necessary to know this information if we wish to create reasonably accurate physical models. This information was determined by running the simulation with a range of

grid resolutions ( $4\Delta s_0$ ,  $3\Delta s_0$ ,  $2\Delta s_0$ ,  $1.5\Delta s_0$ ,  $1\Delta s_0$ , and  $0.5\Delta s_0$ , where  $\Delta s_0=0.1$ ) and then outputting the resulting intensity pattern predictions. In this case, the triangle grid was arbitrarily chosen as the test scenario and  $\Delta t$  was held proportional to  $\Delta s$  to ensure the CFL condition was met. Ideally, these predictions should be compared against the true solution as  $\Delta s \rightarrow 0$ , but since there is no analytical solution for such a complex arrangement of obstacles, each output was compared against the output from the finest resolution grid,  $\Delta s=0.5\Delta s_0$ . The numerical error was then calculated by taking the  $L^2$  norm of the difference between the patterns. As can be seen in Figure 4, making the grid finer will decrease the error by roughly the same amount. In addition to this, several of the intensity patterns were also plotted graphically. Figure 5 shows visually what happens as the resolution is increased. As spacing is decreased from  $4\Delta s_0$  to  $2\Delta s_0$ , the pattern changes dramatically, indicating that the method is not close to converging. As the spacing decreases to  $s_0$ , the pattern starts to stabilize. Finally, when the spacing goes from  $s_0$  to  $0.5\Delta s_0$ , the pattern stays mostly the same. This indicates that the simulation is converging rapidly around this point, and we consider these results stable enough to generate a useful prediction.

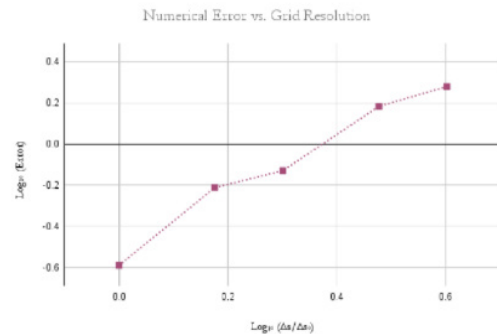
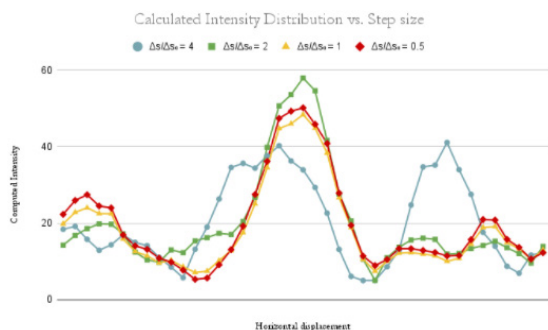


Figure 4: Effect of grid resolution on error. The plot shows a rate of convergence that is slightly greater than linear.



**Figure 5: Calculated intensity distribution vs. Step size.** Figure graphically depicts the convergence of predicted intensity as grid spacing is decreased.

## Discussion

Despite the inability of the simulation to predict average intensities, the energy density diagrams may still provide valuable information on why certain setups are more effective in practice than others. For example, the energy density diagram in Figure 11 shows the energy flux being deflected off to the sides which provides a possible explanation for the low energy transmittance observed. The reason for a greater observed transmittance in the rectangular grid setup may have to do with the fact that the geometry provides a clear path for energy to flow directly to the right (Figure 6). Additionally, in many instances, the shape of the simulated intensity curve generally corresponds to the shape of the experimental curve. In particular, the number, relative amplitudes, and locations of the peaks correspond somewhat to the experimental measurements in most cases. One possible cause of the discrepancy between the curves may be caused by the chaotic nature of certain configurations. This can be seen by approximating the wave as a series of wavefronts and considering the movement of one small section of a particular wavefront. Initially, this section can be thought of as having a certain amount of uncertainty in its position and direction of motion. After bouncing off a convex surface like a cylinder, one can show that the uncertainty in its angle is multiplied by some constant greater than one. This is why the overall uncertainty in the trajectory increases exponentially with the number of bounces as each successive reflection multiplies the uncertainty by the same factor (Datseris et al., 2019). Correspondingly, the most chaotic systems

in our experiment were generally the ones that had the most obstacles in contact with the wavefronts. To partially remedy this, the numerical accuracy of the simulation may be taken with smaller step sizes to reduce the truncation errors, although this has diminishing returns. The more important issue is that there is also a non-negligible uncertainty in the placements of the obstacles during the experimental trials. Due to the design of the experiment and the fact that the obstacles were placed by hand, there were unavoidable errors of at least 1-2mm in the positions of the obstacles. The exponentially growing uncertainties imply that above a certain arrangement complexity, it would not be possible to predict the intensity distribution at all, assuming obstacles are placed by hand. It remains to be seen if this hypothesis is accurate and further research along these lines will be needed to determine exactly how chaotic this system is. This can be quantified by measuring the system's sensitivity to changes in initial and boundary conditions. The other failure mode is that the average predicted intensities do not match all that well with the experimental average intensities. We believe this is because the simulation does not account for reflective losses that occur every time a wave bounces off metal walls or obstacles, or the loss of intensity due to energy leaking away in the z-axis. The reasoning behind the reflective losses is that every time a wave bounces off of a non-ideal conductor, some energy is lost due to resistive heating in the metal. Therefore, the final energy is diminished by a constant percentage of the starting energy after reflection. The implication of this is that the energy of the wave decreases exponentially with the number of bounces, so for complex obstacle arrangements, the amount of energy transmission would be far lower in reality compared to the amount predicted. This matches quite well with what we see in Figure 3. We now provide a way to account for resistive energy losses by including the electrical current term in Maxwell's Equations and modifying the derivation in section 3. After adding the current term to Ampere's law,

$$\nabla \times \vec{B} = \mu_0 \vec{J} + \frac{1}{c^2} \frac{\partial \vec{E}}{\partial t}, \quad \#(26)$$

and taking the same steps as before, we get

$$\nabla \times \nabla \times \vec{E} = \nabla(\nabla \cdot \vec{E}) - \nabla^2 \vec{E} = -\frac{\partial \nabla \times \vec{B}}{\partial t} \Rightarrow \nabla^2 \vec{E} = \frac{1}{c^2} \frac{\partial^2 \vec{E}}{\partial t^2} + \mu_0 \frac{\partial \vec{j}}{\partial t}. \#(27)$$

In the case of a metallic conductor, the relation between electric field and current is given by  $\vec{E} = \vec{J} / \sigma$  where  $\sigma = \sigma(x, y, z)$  gives the electrical conductivity at every point in space. Substituting in Ohm's law, we arrive at the equation

$$\frac{1}{c^2} \frac{\partial^2 \vec{E}}{\partial t^2} = \nabla^2 \vec{E} - \mu_0 \sigma \frac{\partial \vec{E}}{\partial t} \quad \left( \Leftrightarrow \frac{1}{c^2} \frac{\partial^2 u}{\partial t^2} = \nabla^2 u - \mu_0 \sigma \frac{\partial u}{\partial t} \right) \#(28)$$

which accounts for the effect of non-perfect electrical conductors (and note how it resembles the damped wave equation). Converting this equation into the finite difference form for  $u$  is not too difficult, but care must be taken when choosing the finite difference form for  $\frac{\partial u}{\partial t}$  to prevent numerical instability.

The final loss of intensity comes from the diffraction of waves away from the  $xy$ -plane into the  $z$ -axis, and like the previous sources of error, depends on the number of bounces as well as the total distance the wave travels. To mitigate these inaccuracies, ideally, a 3D simulation would be used, the main disadvantage being a dramatic worsening of speed and memory usage. To account for the extra spatial dimensions and loss of symmetry, the fields would have to be defined at every point in 3D space and all three components of the electric and magnetic field would have to be specified. The standard way of computing Maxwell's equations in their full complexity is through the use of a technique called Yee's method. In this approach, the  $E$  and  $B$  fields are encoded in a lattice that staggers the two fields in space. Furthermore, the time evolution of the fields is simulated directly as a pair of coupled first-order PDEs that update one after another, in a leapfrogging manner. The advantage of this approach is that the geometry of the grid allows the usage of the simplest possible finite difference form for all the important differential operators (partial derivatives, divergence, curl, and gradient) while maintaining second-order accuracy (Chew, 2020). This contributes to the overall stability and performance of the technique. One benefit of the 2D finite difference method as well as Yee's method is that they are both extremely parallelizable

and thus can be adapted to run very well on systems with many processing cores.

In conclusion, the simulation is good for predicting the overall shape of the intensity pattern in most cases but must be used with caution as there are a few ways in which our model diverges from reality. Some areas for further investigation include quantifying how chaotic the system is, implementing the damped wave equation for non-ideal conductors, or developing a full 3D simulation based on Yee's method. It might also be interesting to try the same experiment with water waves where the effects of dispersion would have to be taken into account.

## Acknowledgements

I would like to thank my team members Anthony Fine and Frank Verdi for helping to design and carry out the physical experiment that this paper is based on. I would also like to thank Neti Bhatt for giving us advice and direction throughout the duration of the course, Mark Lory-Moran for suggesting we use microwaves in the first place and assisting us in acquiring all the important materials and parts, and finally Nam-Jung Kim for supervising the course and providing feedback on this paper.

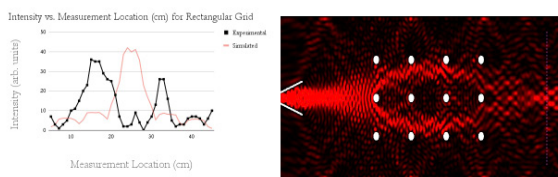
## References

- Chew, W. C. (2020). Lectures on electromagnetic field theory: Lecture 37, finite difference method, yee algorithm. Purdue University. Retrieved from <https://engineering.purdue.edu/wc-chew/ece604s20/Lecture\%20Notes/Lect37.pdf>
- Datseris, G., Hupe, L., & Fleischmann, R. (2019). Estimating lyapunov exponents in billiards. *Chaos: An Interdisciplinary Journal of Nonlinear Science*, 29(9), 093115. Retrieved from <https://doi.org/10.1063/1.5099446>
- Engquist, B., & Majda, A. (1977). Absorbing boundary conditions for numerical simulation of waves. *Proceedings of the National Academy of Sciences*, 74(5), 1765–1766. Retrieved from <https://doi.org/10.1073/pnas.74.5.1765>
- Fine, A., Li, B., & Verdi, F. (2021). Microwave protection arrangement. (Team project in the lab course PHYS 2210 (Fall 2021) in-

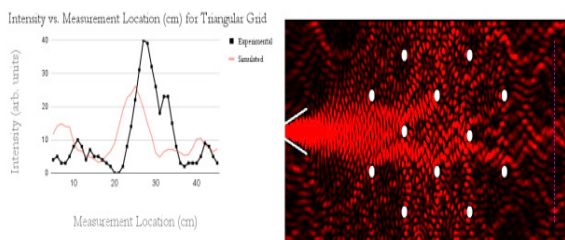


structed by faculty (Nam-Jung Kim, Ph.D.), Lab TA (Neti Bhatt), and Teaching lab manager (Mark Lory-Moran)) Olver, P. J. (2013). Introduction to partial differential equations. Springer International Publishing. Retrieved from <https://books.google.com/books?id=aQ8JAgAAQBAJ> Smith, C. S., Rudd, M. E., Gittman, R. K., Melvin, E. C., Patterson, V. S., Renzi, J. J., Wellman, E. H., & Silliman, B. R. (2020). Coming to terms with living shorelines: A scoping review of novel restoration strategies for shoreline protection. *Frontiers in Marine Science*, 7. Retrieved from <https://doi.org/10.3389/fmars.2020.00434>

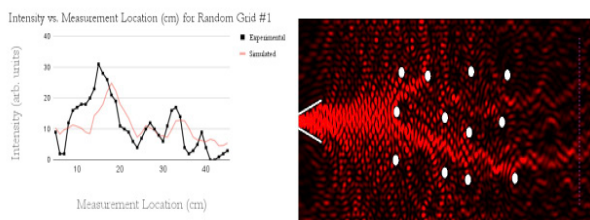
## Appendix



**Figure 6:** Rectangular grid comparison (left) and time-averaged energy density (right) (Fine et al., 2021). Interestingly, the largest measured peak is in a completely different location than the prediction suggests.

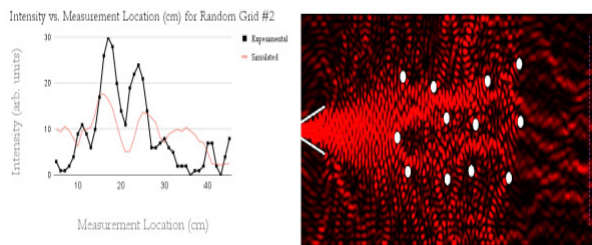


**Figure 7:** Triangular grid comparison (left) and time-averaged energy density (right) (Fine et al., 2021).

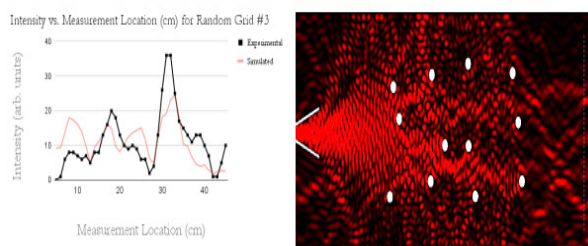


**Figure 8:** Random grid #1 comparison (left)

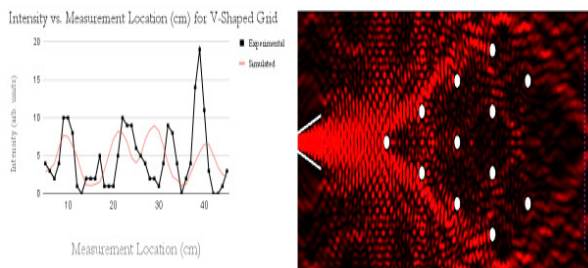
and time-averaged energy density (right) (Fine et al., 2021). There is a close correspondence between the two curves.



**Figure 9:** Random grid #2 comparison (left) and time-averaged energy density (right) (Fine et al., 2021).



**Figure 10:** Random grid #3 comparison (left) and time-averaged energy density (right) (Fine et al., 2021).



**Figure 11:** V-shaped grid comparison (left) and time-averaged energy density (right) (Fine et al., 2021).



# Authors' Biographies



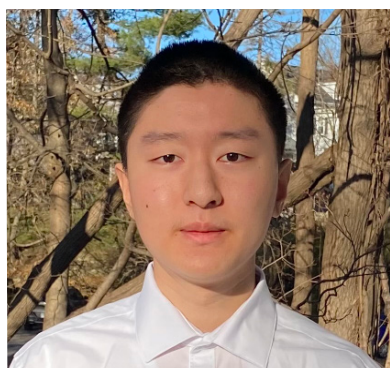
James Campbell is a junior studying physics with minors in computer science and cognitive science. He is a member of the Computational Connectomics Lab, where he is using machine learning to better understand how information is encoded in the brain. In addition, he hopes to pursue a PhD focused on biological and artificial intelligence and to build an exciting future shared by the two. James hails from Long Island and can be found on the basketball court or jogging around Ithaca when he is not studying, often in an intense, caffeine-fueled manner.



Macy Hung is a senior in CALS majoring in communication. She is passionate about social media and digital marketing, and is looking to pursue a career in the marketing and advertising industry. She is originally from Orange County, California where she attended Saddleback Community College before transferring to Cornell. For fun, she loves being outdoors, as she enjoys relaxing on the beach and going on hikes. As a former athlete, she also loves staying active, as she has always enjoyed distance running and going to the gym.



Mia Krishnamurthy is a final-year Sociology major in the College of Arts and Sciences at Cornell University. Her focus is on the Sociology of Organizations, Networks, and Businesses. She is interested in high-technology regions, start-up culture, entrepreneurship, and venture capital.



Brandon Li is a sophomore in the College of Arts & Sciences majoring in physics and mathematics with plans to attend physics graduate school. He is interested in computational and condensed matter physics, with a special interest in how computers can be used to understand nonintuitive physical phenomena. He is currently working in the Arias group and investigating the applications of variational perturbation theory to density-functional calculations there. In his spare time, he enjoys playing piano, video gaming, hiking, and attending classical concerts at Cornell. His favorite food is spicy Thai basil fried rice.

# Authors' Biographies



Marah Selim is a recent graduate who studied Biology and Society with a concentration in Neurobiology and Society. She is now looking into PhD programs in Clinical Psychology to pursue her interest in Psychology research and fulfill her passion for helping others. She has worked in a wide cast of research areas, including Epidemiology, Ophthalmology, and mostly recently, Psychology. It was her time at Cornell that allowed her to discover her passion for the field and pursue related opportunities. In her second, third, and fourth years, she worked in Dr. David Pizarro's lab, studying moral judgment and political alignment. Most recently, she worked under the supervision of Dr. Shimon Edelman, researching the association between social class and mental health. Marah looks forward to a long career in clinical practice and academia.



Grace Shan is a sophomore from New York studying linguistics in the College of Arts & Sciences. She grew up in an English/Mandarin bilingual household, later learned Spanish, and is working on speaking more languages. After her undergraduate degree, she intends to obtain a PhD researching multilingualism through a social and cognitive lens, which is crucial in an increasingly culturally intersecting world. Additionally, she will be studying abroad at Cambridge University for her junior year. Alongside her education, she has been dancing since age six and is in several dance crews at Cornell. She is also passionate



Melanie Valencia recently graduated from Cornell in December with a degree in Human Biology, Health and Society. While at Cornell she performed research in orthopedics, nutrition, and education. Since graduating, she has begun clinical research at Emory University. Throughout all the fields she has explored she has focused on identifying and addressing inequities in society. The next steps in Melanie's career include starting medical school at Mercer University this fall.

# Authors' Biographies



Zichen Wang is a sophomore student at Cornell University majoring in math and cs. He finds his interest in the abstraction of the real world into pure math as well as the application of theories back into reality. A good model, as he believes, makes sense of the massive data by identifying key properties of the modeled subject. Geometry and topology would then be the ideal medium to uncover the hidden structure of the data.



Raquel Zohar is a junior studying Industrial & Labor Relations with minors in Business, Inequality Studies, and Law & Society. On campus, she is involved with Chabad of Cornell, Cornellians for Israel, Phi Alpha Delta, Sigma Delta Tau, and the Undergraduate Law & Society Review. Raquel is from Miami, Florida where she was raised in a Modern Orthodox Jewish household and attended Jewish day school at the Hebrew Academy. During the Summer of 2021, Raquel served as a Cornell ILR High Road Fellow at the Buffalo Jewish Federation's Jewish Community Relations Council where she worked on her report *State of Hate in Greater Buffalo: A Community Perspective*.



CORNELL UNDERGRADUATE RESEARCH JOURNAL

[www.curj.org](http://www.curj.org)