Laridae

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In a Dream, A Thousand Years Ago

Sunny A.L. Krause

(Featured on the cover and to the right)

FACULTY MENTOR: Jinchul Kim

ABSTRACT

In a Dream, A Thousand Years Ago is a 24-by-18-inch oil on canvas painting. This quadratic self-portrait explores the cyclical nature of time and how contemporary art connects all the way back to ancient spaces and practices. Inspired by concepts of Greek myth and history, this piece questions the relationship of internal and external parts of the mind through physical representation and perception of that space.

The connection between past and contemporary is echoed through techniques drawn from historical works of art. The beginning layers of the portrait are made quickly, leaving texture visible in brushstrokes. This is similarly seen in expressionist and impressionist techniques from late nineteenth century paintings. As the painting is refined, the artist draws techniques from earlier Baroque artists. Artists like Michelangelo Merisi da Caravaggio and Artemisia Gentileschi frequently employed an oil technique called glazing. The artist uses a medium (in this contemporary case, Liquin) to dilute pigments to brush lightly over the composition. This lends refined air to the colors of the piece. By employing a combination of these techniques, a unique sense of personality, expression, and thought is evoked in this portrait.

Atop the central self-portrait, three figures emerge. This triangular composition reflects mythical figures like Hecate. She is frequently represented in three bodies as a physical representation of crossroads and pathways.

The central figure of this trifecta faces the viewer head on. Open-handed and open-minded, she holds a sword in her outstretched palms. Does one take the initiative, dance along the narrow edge of the blade, and accept ownership and control of one's own fate? She is action and indecision folded into one. Her gaze is confident, yet slightly suspicious of the viewer. She is flanked by double figures, each representing inner and outer perception. The left figure represents inner insight. Unconcerned with challenging or maintaining contact with the environment around her, she gazes contemplatively into the distance. She is protected by her pendant, an apotropaic silver Medusa charm. On the right-hand side, outer perception is represented. This figure is concerned with observing herself and her physicality through someone else's lens. The forward arm extends, depicting repeating versions of the self seen through varied perspectives. By mirroring a portrait in different forms, visual tension is created through expressions and pose, reflecting the inner thoughts of the creator.

This combines with the background figures, a direct representation of the Greek myth of the Birth of Athena from the head of Zeus and apotheosis of Hephaestus. By representing these ideas diametrically, the painting invites the viewer to look internally; to consider that rebirth is continuous, not static. Self-concepts ebb and flow, like the death and rebirth of gods and animals amidst myth and reality. The viewer and the painting enter a dreamlike state together. This invites one to consider that the past may not be so distant after all. Rather, these distinct timelines loop back on one another in cyclical patterns, at once familiar and alien.



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Letter from the Editor-in-Chief

On the heels of Salisbury University's Centennial, we at *Laridae* decided to launch our own website for the journal's eighth edition, an important milestone in cementing itself as a distinct campus entity. As with anything new, the journey of creating the eighth edition of *Laridae* while navigating our new website, submission process, and timeline was a learning curve and came with its own set of challenges. However, in Sea Gull spirit, the *Laridae* team met these challenges head-on to deliver a truly wonderful eighth edition.

Totaling 10 works, this year's selection of articles was heavily art-lead, from a piece comparing procrastination to a fish trapped in a bowl, to one that explores the psychological toll body dissatisfaction can have on oneself, all the way to a three-part artwork analyzing the experiences and expressions of LGBTQ+ individuals. In a time where it is easy to see the bleakness of the world, we hope the vibrant contributions of this edition will highlight the beauty and color of humans and of undergraduate education.

This edition is the product of the extensive teamwork and combined effort of the editorial staff and faculty reviewers who diligently worked for months to bring this to life. We also extend our sincerest thanks to our advisors and directors at the Office of Undergraduate Research and Creative Activity, Dr. Sherry Maykrantz, and Dr. Timothy Werner, whose unwavering support throughout the entire process made the publication of this journal possible. Thank you to every member of this team and to every reader; your contributions keep the intellectual and creative spirit of undergraduate research alive, which is more necessary than ever.

ALBI FREDA
Editor-in-Chief

Whiplash

Raegan Tucker

FACULTY MENTOR: Jinchul Kim

ABSTRACT

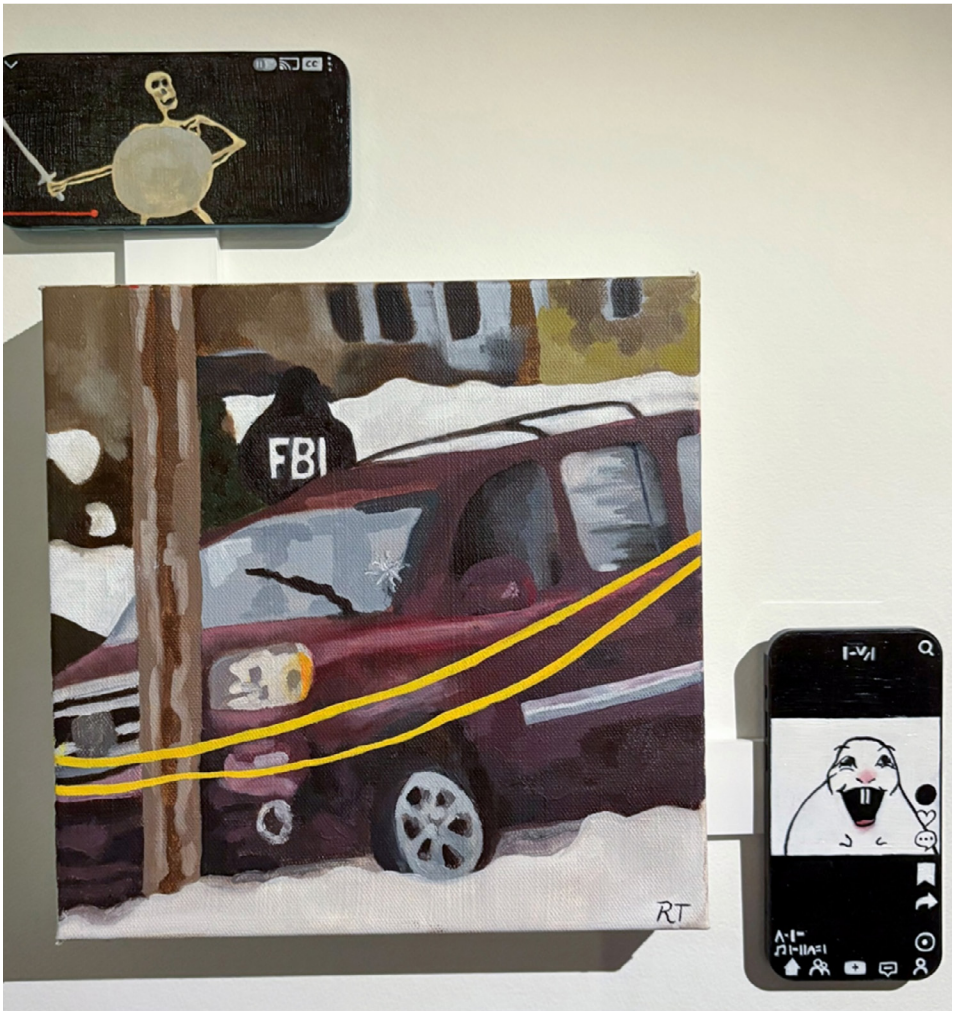
Whiplash is a mixed-media painting that applies fragmentation as a key strategy in contemporary art, expanding the pictorial field beyond a singular, solid surface. The work comprises a 10 × 10-inch oil painting accompanied by two attached 3 × 6-inch painted panels, whose proportions and compositional logic evoke the visual likeness of smartphone screens. These appended elements disrupt the integrity of the central image, invoking the fractured, multi-screen experience of digital spectatorship and complicating the boundaries between discrete and continuous forms.

Dull colors used throughout the piece create an impression of severity, further emphasized by the use of bright yellow for the caution tape in the foreground of the central image. The coloring is a tool to further elicit the concept of fragmentation. Short and blocky brushstrokes show the rigidity of the subject matter and serve as a way to disassociate from the reference scene itself. Directly in the center of this canvas is the bullet hole on the windshield, further insinuating the true grimness in the concept. The bordering canvases provide an intentional distraction to the viewer with their familiarity in shape and interface; they create their own appeal through a similar sense of draw to social media.

The imagery presents two markedly distinct images, further calling upon the idea of fragmentation in a metaphysical form. Bigger than the others, the central canvas renders an image from the shooting of Renee Good in January of 2026. This size differentiation marks the dissemination of this particular kind of content into all aspects of the internet. Real-world tragedies are being broadcast alongside blasé content, such as the memes depicted on the flanking canvases.

Algorithmic strategies on social media prioritize engagement and prolonged usage. When puissant emotions are activated, it encourages these behaviors; the algorithm strives to push human emotions to the extreme. Oftentimes, it seems as if the inhuman algorithms being fed to us rely on human emotions to continue scrolling. As Akane Kanai explains in *The New Politics of Online Feminism*, people go on social media to feel soothed or inspired, but they feel guilty upon leaving when they get overwhelmed with real-world tragedy (Kanai, 2026). There is shame when you choose to look away.

Unfavorable sentiments are reinforced when the previous ones were especially positive. Scrolling from tragedy to meme and so on strains the brain and creates a sense of "emotional whiplash." There is a desire to disconnect from social media, but it seems like we keep getting pulled into a world outside of one's own where suffering and stress run rampant, and looking away is a privilege (Kanai, 2026).



Keywords: social media, current events, fragmentation, algorithm, tragedy, meme, emotional whiplash, contemporary art

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Trapped in My Own Mind

Caroline Hyder

FACULTY MENTOR: Jinchul Kim

ABSTRACT

Trapped in My Own Mind is a 20" x 24" oil painting on canvas that explores the artist's experience with anxiety, with particular focus on the intensification of symptoms in recent years. As her anxiety worsened, the artist recognized the need to seek help, yet found the process daunting and, at times, inaccessible. The paradox of needing support for anxiety while feeling too anxious to pursue it became central to the work. Although the artist has found support through different management strategies, anxiety remains an ongoing and unresolved condition, which this painting seeks to confront and communicate.



The painting depicts a self-portrait of the artist in a contorted pose within a cramped box. The figure is stuck in an uncomfortable position to represent the pressing sensation of repetitive, cyclical thoughts that make one feel trapped within their own mind. The artist's anxiety causes her to become so consumed by intrusive thoughts that she loses awareness of her surroundings. The composition reflects the notion of being so focused on one's anxiety that one overcomplicates the situation with irrational worries. In the painting, the person is seemingly stuck pressing all four limbs against the edges of the box; but from the viewer's perspective, the rigid orthogonal framing of the box suggests the figure could theoretically crawl forward and escape. From the perspective of the calm observer, the solution seems simple, but for the subject, anxiety has begun to cloud their vision and impair their decision-making. The person also makes direct eye contact with the viewer, as if to ask for help but is too panicked and stuck in place to do more.

To symbolize the juxtaposition of inner and outer awareness induced by anxiety, the artist chose a vibrant color palette and geometric, simplified paint strokes. The colors present in the painting are oversaturated to coincide with the vivid and active nature of a constantly worrisome mind. In contrast, the subject and background are reduced to simplified shapes to portray the experience of a person whose surroundings are dulled because they are not present in the moment. Inspiration for the intense color palette and brushwork comes from the work of Xenia Hausner, specifically, *Aborigines* and *On Fire*. Hausner uses vibrant colors throughout her portraits and thick, bold brush strokes, which create an angular quality to her works. The artist wished to emulate the intensity of the colors and brushwork in Hausner's paintings to parallel the assertiveness of her own anxiety.

While rooted in personal experience, anxiety is also widely prevalent, as this disorder affects nearly one-third of the U.S. population (Esala and Del Rosso, 2020). Therefore, the artist positions the painting as a physical representation of her own anxiety and an opportunity for the viewer to see their anxiety reflected. The artist has learned that anxiety and learning to cope are not a linear path. She hopes to share the peaks, valleys, and cycle of emotions through the tangled limbs and cowering posture present in *Trapped in My Own Mind*.

Keywords: anxiety, self-portrait, trapped, mental health, geometric, full-body portrait, oil painting

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Comfortable Harm

Isabel Grochmal

FACULTY MENTOR: Jinchul Kim

ABSTRACT

Comfortable Harm is a 20 x 16-inch oil painting that represents procrastination as a form of self-imprisonment and self-sabotage. People often have the potential to succeed, yet they choose to confine themselves within what feels comfortable. Escape may be obvious, but often avoided, and over time, this avoidance can lead to harm. Procrastination can feel easier than taking action, but without change, individuals risk remaining stuck in a cycle of comfortable harm. This piece suggests that mental prisons can be just as strong as, or even stronger than, physical ones.

The composition features a fish inside a glass bowl, placed in the middle of the ocean. This creates an ironic situation, as the fish is surrounded by open water and could leave the bowl at any time. Instead, it remains within its enclosure, putting itself at risk. Beneath the bowl is an arrangement of various weapons, representing the danger the fish is choosing to ignore. As the bowl slowly sinks, the fish is brought closer to these threats, increasing the sense of urgency.

The fish contrasts strongly with its surroundings. Its vibrancy suggests that it has the qualities needed for success, yet it continues to remain confined. Fluid brushstrokes and the use of contrasting blue and orange tones help the fish stand out, reinforcing its significance within the composition. The fishbowl acts as a kind of invisible prison – not defined by physical barriers, but by comfort and hesitation rather than force.

Bubbles rise from the fish toward the surface, indicating an opening at the top of the bowl and emphasizing how accessible escape truly is. The weapons at the bottom of the ocean appear aged and worn, incorporating elements from different time periods. Their muted green, blue, and brown tones help create the effect of depth and submersion. The gradient in the background, shifting from light to dark, highlights the fish's two choices: to rise toward the surface or continue sinking toward danger.

This piece uses fragmentation by bringing together objects that would not normally coexist and arranging them to tell a story. The surreal setting creates a sense of irony while maintaining elements of realism. Although the scene itself is unlikely, its meaning reflects a familiar experience, capturing the tension and consequences of self-sabotage through procrastination.



Keywords: procrastination, self-sabotage, mental prison, avoidance, irony, fragmentation, potential

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Reflection

Samantha Minner

FACULTY MENTOR: Jinchul Kim

ABSTRACT

Reflection is oil on 18" x 24" canvas, and it explores the psychological strain of body-image dissatisfaction and its relation to mental health. The work visualizes the crushing feeling of wanting to "claw out of your own skin," reflecting an experience shared by many people who struggle with body image. While I do not experience clinical body dysmorphia, I engage with similar patterns of self-scrutiny, often hyper fixating on everything "wrong" with my appearance.



Many people, especially women my age, struggle with mental health in relation to the way they see themselves. "Freshman 15," school workload, lack of time, and natural development of our bodies all contribute. These concerns affect numerous women with different body types, not just those who are medically overweight. There have even been studies that proved that these issues exist no matter the age, weight, or fitness groups. These issues are not rational, they can affect anyone, whether the parts they stress over actually exist or not.

Social media is the leading motivator for these emotions. A recent viral TikTok suggested that there was a "body trend" that favored women who are thin. The woman in the video then went on to hypothesize that the next trend will be larger breasts. The fact that there are "body trends" at all is unacceptable and demeaning toward those affected. Bodies are not like clothing, they cannot be taken off and traded out for another, they are the forms that humans were born with. These trends and the rhetoric that surround them create unstable environments for young girls who see one body type placed on a pedestal while the others are treated as less than.

Another pressure that ultimately stems from social media is familial and self-pressure. It can be hard for you and those who know you to reconcile with changes in appearance. I personally struggle with this, looking at old pictures and comparing myself with how I used to look. Going from being one of the smallest in your family to the largest, sticking out in photos. This can create an enormous amount of stress and low self-worth on someone, especially if those around them bring it up as well.

These feelings are represented through different aspects in my painting, as seen above. The blue tints, the fingers ripping through flesh, the lone figure looking at herself, all depict loneliness, desperation, and self-loathing. This piece isn't depicting hope, it doesn't show that there is beauty on the inside, it is simply meant to depict the way it feels in the moment. To make other women feel seen, that others feel the same way as well and to bring attention to it.

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I thank Professor Jinchul Kim, my faculty advisor. He aided me both in the process of creating this piece as well as the writing and submission to the *Laridae* journal. I couldn't have done this without him.

Expression and Visibility of the LGBTQ+ Community

Kayla Knopp

FACULTY MENTOR: Viktoria Basham

ABSTRACT

Art has the power to prompt and facilitate conversations on topics of social significance. This project explores how art can facilitate conversations about identity, visibility, and self-expression within the LGBTQ+ community. Building upon previous research conducted on LGBTQ+ visibility and representation, this work combines scholarly inquiry with artistic practice to investigate how visual art can communicate personal experiences and encourage dialogue. Through the creation of three original artworks – *VULNERABILITY, Being Visible*, and *Fly Free* – the project examines themes of emotional exposure, societal perception, fear of visibility, and freedom of expression. The three works represent the artist's perspective on obstacles, anxieties, hopes, and desires that members of the LGBTQ+ community face: a nude work tackles self-expression through body dysmorphia, emotional vulnerability, and visibility; an arched canvas with neon eyes stares you down embodying both the fear of visibility and the desire to be seen; and a rainbow colored 3D wing reminds of the importance of the flight and freedom of expression. Together, these works demonstrate how artistic processes and visual symbolism can communicate personal and collective experiences while fostering meaningful conversations about LGBTQ+ visibility. The project highlights art's ability to serve as both a form of self-expression and a catalyst for dialogue, while also laying the foundation for future artistic exploration through an expanded body of work and potential exhibition.

Keywords: art, LGBTQ+, belonging, visibility, vulnerability, fear, freedom

FIGURE 1. *VULNERABILITY*



The first artwork created was *VULNERABILITY* (**Figure 1**), which is a self-portrait fragmentation piece. This piece engages the concept of fragmentation by sectioning and dividing parts of the body. To emphasize this idea even further, the bones and heart are shown, essentially peeling away the skin and revealing what is underneath. The heart is red while everything else is blue and white, allowing the heart to stand out and capture attention. By allowing the viewer to see what is hidden "underneath," this piece becomes a powerful representation of human vulnerability. In addition, the piece focuses on self-expression by unveiling body dysmorphia which the artist sometimes experiences. The work highlights the nuances of emotional vulnerability and visibility and brings attention to how AFAB (assigned female at birth) bodies can be misperceived.

FIGURE 2. *Being Visible*



FIGURE 3. *Fly Free*



The second artwork was *Being Visible* (**Figure 2**); the work represents both the fear of visibility and the desire to be seen. This piece was created after an inspiring conversation with a friend of the artist who is a part of the LGBTQ+ community. This conversation helped the artist understand how their friend fears "being seen" because of the harmful stereotypes and dangers associated with widespread misconceptions that the LGBTQ+ community faces. This piece was created with a double meaning in mind because over time people and their desires change, they may have a change of heart or identity, or they might even discover something new about themselves. The artist used chalk and chalk markers intentionally and strategically. Chalk and chalk markers were chosen because of the vibrancy of the colors and because of the control of the material they allow for while making the piece. In addition, the chalk markers dried quickly, giving the artist the ability to layer more drawings on top without waiting and without the danger of the drawings mixing up. The markers also allowed for semi-transparency, letting the viewer see the sketches underneath creating a metaphor for seeing one's multi-layered complex identities that might remain hidden to a surface-level look.

The third and last artwork is *Fly Free* (**Figure 3**), symbolizing the flight and freedom of expression. The artist has associated the idea of freedom with wings and birds, and specifically with how birds have been gifted with the capability to fly. The piece was crafted with modeling paste and a pallet knife to create the 3D effect of the feathers. This technique allows for a textile piece and adds much needed depth and multidimensional highlights and shadows to the work, which embodies the complexity of its theme. After first painting the piece a solid brown color, the artist added the colors of the rainbow through the use of dry brushing, slowly decreasing the vibrancy of the colors as they went through the rainbow. By combining the artists own interpretation of freedom as birds and flight with the colors of the rainbow, which is a universal symbol of the LGBTQ+ community, the artist brings attention to the lack of safe spaces and communities where the members of the LGBTQ+ community can freely be themselves, have the freedom of expression, and truly belong.

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From Pathophysiology to Precision Medicine: Molecular Drivers, Current Therapies, and Novel Treatments for Alzheimer's Disease

Sean Richard Zupnik

FACULTY MENTOR: Dr. Tim Werner

INTRODUCTION

Alzheimer's Disease (AD) is an irreversible neurodegenerative condition defined by reductions in cognitive function, memory, mobility, speech, and other factors affecting a patient's ability to perform activities of daily living (ADLs). The condition is diagnosed by assessing a combination of clinical and family history, including mental health changes, cognitive testing, imaging, and lab tests, which examine cerebrospinal fluid for amyloidbeta (National Institute on Aging [NIA], 2022). Almost 30% of adults older than 65 years of age will be diagnosed with AD, and the risk of diagnosis increases by almost 50% every 10 years after the age of 60 (Eratne et al., 2018). While Alzheimer's Disease is incurable, it is often managed using a combination of N-Methyl D-Aspartate (NMDA) receptor antagonists, cholinesterase inhibitors, along with diet and exercise interventions. However, the state of treatment is swiftly evolving. Emerging research into disease-modifying therapies (DMTs) – including novel immunotherapies like donanemab and lecanemab, allogeneic mesenchymal stem cell therapy, and repetitive transcranial magnetic stimulation (rTMS) – aims to move beyond symptom management toward inhibiting the underlying biological progression of the disease.

PATHOPHYSIOLOGY

In a healthy brain, Amyloid Precursor Protein (APP), which aids in synapse formation and maintenance, neurite outgrowth, axon guidance, synaptic plasticity, neural protection and repair, is processed by the enzymes α-secretase and γ-secretase to ensure proper protein turnover. However, in Alzheimer's disease, APP can accumulate and block synapses due to multiple factors. Firstly, the retromer complex, responsible for shuttling APP between endosomes, trans-Golgi network, or plasma membrane, fails due to obstructions, dynein motor protein breakdown, defective motor-cargo attachment, or microtubule instability. Without the ability to move the protein, it accumulates in the cell's endosomes. Likewise, kinesin motor protein causes APP to accumulate in axonal swellings due to damage and cellular stress (Cai et al., 2025; Mecozzi et al., 2014).

Additionally, lysosomes, which digest waste and assist in protein turnover, become less acidic as they age. As a result, they struggle to degrade APP, allowing undigested fragments to accumulate. Risk factors such as age, a history of traumatic brain injury, hypertension, obesity, and diabetes create cellular conditions which cause the APP to interact with β-secretase, an enzyme found in endosomes, due to the retromer complex, dysregulated Rab GTPase enzymes, and the Endosomal Sorting Complex Required for Transport (ESCRT) proteins, failing to properly sort proteins and enzymes (Crotti et al., 2019; Hunter-Chang et al., 2024). When APP is broken down by β-secretase, the result is Amyloid Beta (Aβ), a precursor to extracellular plaque formation (Eratne et al., 2018). The same factors are known to cause tau, a structural protein that reinforces the neuron's microtubules, to become hyperphosphorylated. A higher-than-normal number of phosphates become bound to the tau proteins, due to kinase overactivation, which causes them to become tangled and further impede signaling (Eratne et al., 2018).

Less commonly discussed, but still incredibly important to consider, are the concepts of brain iron dysregulation and exosomes. Proteins called Iron Response Proteins are also disrupted by the mechanisms behind Alzheimer's disease and, as the condition progresses, patients' abilities to regulate levels of iron in the brain deteriorate. As iron accumulates, it can block the Electron Transport Chain, which leads to the creation of Reactive Oxygen Species (ROS), further damaging tissues over time (Onukwufor et al., 2022). Exosomes, extracellular vesicles that can transport proteins, have potentially positive and negative effects associated with Alzheimer's Disease. For example, exosomes contain the enzymes insulin-degrading enzyme (IDE) and neprilysin (NEP), which break down Amyloid Beta (Aβ) (Zhang et al., 2021). However, in the case of Alzheimer's Disease, evidence also suggests that exosomes can transport tau around the brain as well. A 2019 study examined post-mortem cerebrospinal fluid samples from patients with AD and found substantial amounts of tau in exosomes present in the fluid (Crotti et al., 2019). Furthermore, the researchers also noted a higher-than-normal amount of Bridging Integrator 1 (BIN1) protein within the fluid. BIN1's role in AD is still disputed, but researchers believe that BIN1 over-expression induces the release of tau from exosomes (Crotti et al., 2019). While the exact mechanism of this process is far less clear than other previously mentioned pathways, this correlation points to a possible link between exosomes and the onset of Alzheimer's Disease.

Ultimately, these stresses lead to the creation of axonal spheroids. Axons undergo apoptosis due to either the lack of a trophic factor or activation of Sterile Alpha and Toll-Interleukin Receptor Motif-Containing 1 (SARM1), the Neuron's "self-destruct" enzyme, which is inactive during healthy physiology (Hunter-Chang, 2024). This leads to the breakdown of Nicotinamide adenine dinucleotide (NAD+) before it can be reduced to NADH in the synthesis of Adenosine Triphosphate (ATP).

As a result, calcium rushes into the cell (Hunter-Chang et al., 2024). This increases the osmotic gradient and draws water into the cell, causing cyst-like bumps, or spheroids, to form on the axon (Hunter-Chang et al., 2024). Spheroids further weaken neurons until they rupture, spreading fragments of damaged organelles, proteins, and other pro-inflammatory material throughout the brain (Hunter-Chang et al., 2024).

A 2025 study published by Yale University examined the proteins involved in axonal spheroids. In healthy physiology, the Phosphatidylinositol 3-Kinase/Protein Kinase B/Mammalian Target of Rapamycin (PI3K/AKT/mTOR) pathway is an important regulator of cell

growth and protein synthesis and degradation (Cai et al., 2025; Paplomata & O'Regan, 2014). PI3K converts the phospholipid phosphatidylinositol 4,5-bisphosphate (PIP2) into Phosphatidylinositol (3,4,5)-triphosphate (PIP3), which activates AKT and causes it to activate mTOR to control cell growth (Paplomata & O'Regan, 2014). The Yale University researchers discovered that this pathway is overactive in axonal spheroids, inhibiting the cell from both breaking down and removing defective components (Cai et al., 2025). This is the result of neuroinflammation, which induces overactivity as a stress response.

Ultimately, the result is further dysfunction as even more axonal spheroids form, cell membranes are weakened, and further inflammatory material is spread through the brain. While Alzheimer's Disease is not directly fatal to affected patients, neurodegeneration can lead to losses in mobility, swallowing, and continence, and can increase a patient's risk for falls or infections due to the aspiration of food, or sores caused when individuals are unable or unwilling to move from chairs and beds (Eratne et al., 2018). As the condition progresses, patients will require full-time care from professionals and loved ones.

EXERCISE PRESCRIPTION AND TESTING

As previously discussed, certain risk factors associated with a lack of exercise, such as hypertension, obesity, and diabetes, are also linked to Alzheimer's Disease. Therefore, one could argue that chronic exercise decreases the risk of developing AD. In healthy individuals, exercise has been proven to heighten cognitive function by increasing levels of Nerve Growth Factors, such as Brain-Derived Neurotrophic Factor (BDNF), which stimulate synaptogenesis (Sleiman et al., 2016). In addition to helping regulate blood glucose and blood pressure, exercise can reduce such risks by stimulating and regulating the secretion of certain neurotransmitters, such as monoamines, which are associated with adaptations in the nervous system (Lin & Kuo, 2013).

In AD patients, exercise has been shown to improve cognitive metrics as well. A 2021 meta-analysis examined 28 studies with a total of 1,337 participants aged 79-90 years on average to assess the association between physical activity and improvements in cognitive and physical function, functional independence, and neuropsychiatric symptoms (López-Ortiz et al., 2021). These were assessed using the Barthel Index, six-minute walk test (6MWT), Neuropsychiatric Inventory (NPI), and Mini-Mental State Examination (MMSE). Each study featured a combination of both aerobic and anaerobic training (López-Ortiz et al., 2021). The groups that were prescribed exercise saw an improvement of 8.36 points on the Barthel Index, indicating improvements in completing activities of daily living (ADLs), an improvement of 84 meters in the 6MWT, indicating increases in cardiovascular endurance, and a decrease of 4.4 points in the NPI, denoting a reduction in neuropsychiatric symptoms.

Interestingly, only aerobic exercisers improved on the MMSE, a measure of cognitive function that assesses a patient's orientation, memory, attention, calculation, recall, language, and praxis, from 10 points (moderate dementia) to 26 points (mild cognitive impairment). This was a difference of 2.31 points, indicating a sizable cognitive improvement and underscoring the merits of prescribing aerobic training for patients with Alzheimer's Disease (López-Ortiz et al., 2021).

The American College of Sports Medicine (ACSM) recommends that individuals with Alzheimer's Disease complete at least 150 minutes of light to moderate-intensity aerobic training per week and resistance training 2-3 times per week to maintain general health. This is the same recommendation for healthy adults and helps protect the patient from the onset of further pathologies, ultimately helping them maintain their quality of life and ability to perform ADLs (Bushman & Pullen, 2021). An example of an exercise prescription plan, based on ACSM guidelines, that could be prescribed to a patient with Alzheimer's Disease may include aerobic training three days per week, resistance training two to three days per week, and flexibility training anywhere from two to seven days per week (Bushman & Pullen, 2021). The intensity that is appropriate for each individual patient is based on their experience level and the severity of their case. The ACSM guidelines specify starting patients with more severe AD at a lower intensity (30%-39% VO2R or HRR) and increasing it to moderate (40%-59% VO2R or HRR) based on their tolerance to exercise training (Bushman & Pullen, 2021). Additionally, novice resistance trainers should begin training with only about 40% to 50% of their one-repetition maximum (1RM), the maximum weight they could lift with proper technique one time. This should increase to around 60% to 70% of their 1RM as they become more experienced at resistance training. Exercise duration is also highly variable, as severe patients may begin aerobic training for as little as 10 minutes per session but may progress over time to as long as one hour per day (Bushman & Pullen, 2021). During resistance training, patients should perform at least one set of each exercise for 8 to 12 repetitions. Novice lifters using a smaller percentage of their 1RM should instead opt for 10-15 repetitions per set (Bushman & Pullen, 2021). Lastly, proper stretching duration is between two to four repetitions, held for 10 to 30 seconds each (Bushman & Pullen, 2021). When considering which type of exercise to administer, the ACSM specifies the use of large muscle groups (quads, hamstrings, etc.) in a repetitive or rhythmic fashion; swimming or walking are common examples. Free weights are not suggested for resistance training with Alzheimer's Disease patients due to their increased risk of falls. Instead, focus on bands, bodyweight exercises, and resistance-training machines (Bushman & Pullen, 2021).

A major factor in developing an exercise testing protocol for a patient with Alzheimer's Disease is safety. Cognitive challenges may compromise a patient's ability to remember the testing protocol, and deteriorating mobility and balance may interfere with their ability to safely run or ride a cycle ergometer. With that said, accurately tracking metrics such as mobility, endurance, balance, and strength is critical when designing an appropriate training program. A meta-analysis by the University Medical Center Groningen and Vrije Universiteit Amsterdam examined 89 randomized controlled trials to determine which of the most popular exercise tests for patients with AD are the most reliable. The researchers noted 10 commonly used physical tests: the Six-Minute Walk Test, Two-Minute Step Test, Five Times Sit-to-Stand Test, 30-Second Chair Stand, Tinetti Balance Scale, Abnormal One-Leg Balance, Berg Balance Scale, Timed Up and Go Test, Six-Meter Walk Test, and Functional Reach Test. These are methods of assessing endurance, strength, balance, and flexibility (Bossers et al., 2012). Each test was evaluated using the Physiotherapy Evidence Database (PEDro) scale, a rating system for physical testing protocols which takes into account issues regarding selection bias (PEDro, 1999). The purpose of this was to assess the validity of each study included in the meta-analysis, ensuring that the data for each exercise test were as accurate as possible. Ultimately, the meta-analysis examined test-retest reliability and determined that the most reliable and accurate exercise tests for mobility were the Timed Up and Go and Six-Meter Walk tests. The Timed Up and Go test evaluates a patient's ability to stand from a seated position, walk 3 meters, and return to the starting position. If this journey takes longer than 14 seconds, sufficient evidence exists of mobility deficiencies and an increased risk of falls (Bossers et al., 2012). The Six-Meter Walk

test simply asks participants to walk 6 meters at a comfortable speed; any pace slower than 0.8 meters per second suggests a mobility limitation (Bossers et al., 2012). The most reliable endurance test examined was the Six-Minute Walk Test (6MWT): patients are prompted to walk for six minutes, and their total distance covered is noted. If the patient is unable to walk more than 300 meters, this suggests low functional mobility (Physiopedia, 2011). The Tinetti Balance Scale, the most highly rated balance test according to the meta-analysis, measures a patient's ability to maintain balance while seated, standing from a chair, maintaining balance soon after rising from a seated position, being lightly nudged with eyes open and closed, making a 360-degree standing rotation, and returning to a seated position (Tinetti Gait and Balance Assessment Tool, n.d.). The tester then examines the patient's gait, analyzing their ability to walk, step length and height, step symmetry and continuity, gait path, trunk movement, and walking stance. Each metric is scored on a scale of 0 (maximal assistance required) to 2 (no assistance necessary), and a total score below 19 indicates severe mobility deficiencies (Tinetti Gait and Balance Assessment Tool, n.d.). Lastly, the researchers noted that the best assessment of strength is the Five Times Sit-to-Stand Test. Here, patients are instructed to sit in a chair and assume a completely relaxed posture with their arms folded across their chest; testers then measure the patient's time to stand completely and return to the chair five times. Any duration longer than 11.4 seconds for ages 60-69, 12.6 seconds for ages 70-79, and 14.8 seconds for ages 80-89 is considered abnormal and suggests weakness (Physiopedia, n.d.). These tests are championed by researchers at the University Medical Center Groningen and Vrije Universiteit Amsterdam for their combination of reliability and the ability to detect changes induced by exercise interventions. Unfortunately, this must be approached with a degree of skepticism, primarily due to the surprising lack of research on factors such as feasibility (Bossers et al., 2012). For now, this remains the most extensive analysis of exercise testing protocols used in Alzheimer's Disease treatment; however, a full understanding can only truly be achieved through more vigorous research.

Interestingly, a 2025 study conducted by the Chinese University of Hong Kong assessed 456 adults aged 60-80 with mild cognitive impairment to determine whether nurse-led physical exercise and cognitive training could improve cognition (Xu et al., 2025). Participants were randomized into three groups: a multi-component intervention group, which included one hour of targeted cognitive exercises, 30 minutes of physical activity – most notably tri-weekly Tai Chi for three months – and quarterly and semiannual meetings with nurses and primary care physicians, respectively; a risk factor modification group, which involved only quarterly and semiannual meetings with nurses and primary care physicians aimed at identifying and addressing Alzheimer's disease risk factors such as hypertension and diabetes; and a control group, in which participants received a health information pamphlet but no provider meetings, exercise, or cognitive training (Xu et al., 2025). Ultimately, the researchers found no clinically significant differences in ADAS-Cog scores, a measure of cognitive decline used in Alzheimer's Disease treatment that assesses language, praxis, and memory, among the three groups. However, they noted that participants in the multi-component intervention group who also suffered from hypertension or depression demonstrated modest cognitive improvement at the six-month follow-up compared with the control group (Xu et al., 2025).

CURRENT TREATMENTS TO MANAGE ALZHEIMER'S DISEASE

A common method to manage the symptoms of Alzheimer's Disease is Cholinesterase Inhibitors (ChEIs), medications that prevent the breakdown of acetylcholine. This increases the overall concentration of the neurotransmitter in the brain, which aids communication between neurons. Three popular ChEIs to be discussed later in the section are Rivastigmine, Donepezil, and Galantamine. ChEIs are known to improve Mini-Mental State Examination (MMSE) scores. Unfortunately, little evidence exists to show any significant effect on the progression of mild Alzheimer's Disease itself (NIH, 2024). Additionally, common side effects include nausea, vomiting, and diarrhea (Szeto & Lewis, 2016).

Approved by the United States Food and Drug Administration in the year 2000, the aforementioned Rivastigmine is a common ChEI. It's most effective when administered in 6-12 mg doses daily; however, it's also effective when administered via a transdermal patch at a rate of 9.5 mg per day. This is shown to limit gastrointestinal (GI) discomfort, as the transdermal route allows for a longer, steadier release into the bloodstream, which can be less harsh (Szeto & Lewis, 2016). Additionally, patients prescribed transdermal Rivastigmine can expect roughly 11% less vomiting and roughly 16% less nausea than those treated orally (Szeto & Lewis, 2016; Kueper et al., 2018). Both routes offer comparable improvements of about 2 points on the ADAS-Cog (Szeto & Lewis, 2 016).

Donepezil also aims to improve ADAS-Cog and MMSE scores in patients with mild to moderate Alzheimer's Disease (Szeto & Lewis, 2016). Significantly, a 104-week, double-blind, 994-participant study by Kingshill Research Centre, CHU Hospital Guy de Chauliac, McGill University, Ospedale Civile Maggiore, and Novartis Pharmaceuticals compared the effects of Rivastigmine and Donepezil on Alzheimer's Disease. Both medications induced similar gastrointestinal side effects (nausea and vomiting) and similar cognitive improvements (Bullock et al., 2005). Crucially, patients younger than 75 with possible symptoms such as bradykinesia, tremors, and confusion, with Lewy Body Dementia, and full gene expression of the enzyme butyrylcholinesterase – which can hydrolyze acetylcholine in the brain – saw an improvement in their ability to perform activities of daily living (ADLs). However, the majority of patients who met these criteria and experienced a significant improvement were also part of an Intent-to-Treat with Last Observation Carried Forward (ITT-LOCF) subpopulation within the study. As Non-ITT-LOCF patients did not see similar effects, the differences between Rivastigmine and Donepezil are not considered significant (Bullock et al., 2005).

A third common medication to manage Alzheimer's Disease symptoms is Galantamine. It's a Cholinesterase Inhibitor, similar to Rivastigmine and Donepezil, but also binds to the allosteric site of the acetylcholine receptors, changing their shape and making them more sensitive to the neurotransmitter (Szeto & Lewis, 2016). Limited research compares the effects of Galantamine with the effects of Rivastigmine and Donepezil, and the benefits of one medication over the other two are, at this point, unclear (Szeto & Lewis, 2016). All seem to provide a similar level of cognitive improvement but also induce similar gastrointestinal-related side effects.

Besides Cholinesterase Inhibitors, N-Methyl D-Aspartate (NMDA) Receptor Antagonists have been approved for patients with moderate to severe Alzheimer's Disease. NMDA Receptor Antagonists such as Memantine, a commonly prescribed example, work by blocking the neurons' glutamate receptors (Olivares et al., 2012). Glutamate is a highly potent neurotransmitter that, when unregulated as a result of damaged "leaky" neurons, causes excessive neuron excitation, which disrupts effective communication between neurons

(Olivares et al., 2012).

In healthy physiology, the brain's Astrocytes would clear excess Glutamate. However, plaque formation blocks their Excitatory Amino Acid Transporters (EAATs), which are integral to the uptake of the Neurotransmitter (Zhang et al., 2021). This overexcitation stimulates a constant uptake of calcium, triggering kinases to hyperphosphorylate tau proteins (Cai et al., 2025).

When the medicinal effects of Memantine on Alzheimer's Disease symptoms were examined in a 2019 University of Oxford meta-analysis, the drug was found to improve cognitive function by 3.11 points on the Severe Impairment Battery (SIB), a scale used to assess orientation, attention, memory, language, visuospatial function, and praxis in patients with severe AD (McShane et al., 2019). Likewise, patients' abilities to perform ADLs improved by 1.09 points on the ADL19 scale, a measure of daily task performance (McShane et al., 2019). Additionally, behavior and mood scores also improved by 1.84 points according to the NPI, a measure of psychiatric symptoms such as depression and mood swings (McShane et al., 2019). However, when the researchers shifted their focus from moderate to severe Alzheimer's Disease to mild Alzheimer's Disease, they observed conflicting results as Memantine had virtually no effect on the same metrics (McShane et al., 2019).

Coupled with exercise and medication, diet is also an important factor to consider when treating AD patients. Maintaining balanced nutrition by reducing refined sugar, saturated fat, cholesterol, and sodium while encouraging vegetables, fruit, lean protein, whole grains, and low-fat dairy products is considered key to preserving overall health and preventing Alzheimer's Disease symptoms from worsening (Alzheimer's Association, 2019). As previously discussed, metabolic conditions such as diabetes and obesity are risk factors for Alzheimer's Disease. Therefore, implementing lifestyle modifications to reduce the risk of metabolic disease will also decrease one's risk of AD. Three nutritional strategies in particular are routinely prescribed to maintain health among the Alzheimer's Disease population. These include the Diet Approach to Stop Hypertension (DASH), the Mediterranean Diet, and the Mediterranean-DASH Intervention for Neurodegenerative Delay (MIND) (Bushman & Pullen, 2021). Each is designed to reduce blood pressure, thereby protecting brain arteries from microvascular injury, which increases inflammation and ultimately leads to further dysfunction (Bushman & Pullen, 2021).

In 2024, the U.S. Food and Drug Administration approved donanemab-azbt, marketed under the brand name Kisunla, for the treatment of early-stage Alzheimer's disease in adults with mild dementia (FDA, 2024). Kisunla is an intravenous monoclonal antibody administered once every four weeks. It is engineered to target and remove amyloid plaques by binding to N-terminal 3rd amino acid pyroglutamate-modified amyloid-β (N3pG) and signaling the body's immune system to facilitate their clearance. N3pG is found only in mature plaques and isn't typically present at healthy levels like other types of plaque (Gueorguieva et al., 2025). Treatment is discontinued once brain imaging demonstrates sufficient reduction in amyloid levels (FDA, 2024).

The drug's efficacy was evaluated in a double-blind, placebo-controlled trial involving 1,736 participants with mild cognitive impairment or mild dementia, with amyloid plaque confirmed by brain imaging (Gueorguieva et al., 2025). Participants received either Kisunla or a placebo for up to 72 weeks. Compared with the placebo group, patients treated with Kisunla experienced a slower decline in daily functioning and cognition, as measured by the Integrated Alzheimer's Disease Rating Scale (iADRS), Alzheimer's Disease Assessment Scale–Cognitive Subscale (ADAS-Cog13), Alzheimer's Disease Cooperative Study – Instrumental Activities of Daily Living scale (ADCS-iADL), and Clinical Dementia Rating – Sum of Boxes (CDR-SB) (Gueorguieva et al., 2025).

While these outcomes are notable, a common concern with anti-amyloid "plaque-attack" therapies is the risk of amyloid-related imaging abnormalities (ARIA). Although ARIA is often asymptomatic, it can lead to cerebral edema or microbleeding, which may progress to hemorrhage and become life-threatening (Gueorguieva et al., 2025). Additionally, individuals who carry two copies of the apolipoprotein E ε4 allele (APOE ε4) are at a higher risk for developing ARIA (Eli Lilly and Company, 2024). Other reported adverse effects include nausea, vomiting, blood pressure abnormalities, flu-like symptoms, headaches, and anaphylactic or angioedematous allergic reactions (FDA, 2024). Despite these risks, the FDA granted accelerated approval to donanemab as a breakthrough therapy due to its potential to provide meaningful clinical benefit in an area of substantial unmet need in Alzheimer's disease treatment (FDA, 2024).

Given the known risk of ARIA, researchers at Eli Lilly – the manufacturer of donanemab – sought to determine whether modifying the drug's original titration schedule to allow for slower dose escalation could reduce ARIA risk while preserving its demonstrated efficacy (Eli Lilly and Company, 2024).

A total of 843 participants aged 60-85 with mild cognitive impairment or dementia and amyloid-positive Positron Emission Tomography (PET) scans were randomized into four dosing groups. Group one received the standard titration regimen: 700 mg once monthly for three months, followed by a maintenance dose of 1,400 mg once monthly for the remainder of treatment. Group two received a modified titration, beginning with a 350 mg dose, increasing by 350 mg each month for four months until the 1,400 mg maintenance dose was reached, affording a more gradual dose escalation. Group three received a single 700 mg dose, followed by two months of once-monthly placebo doses, then progressed to a 1,400 mg dose in the fourth month and continued through the maintenance phase. Finally, group four received 350 mg biweekly doses for three months, followed by a monthly 1,400 mg dose thereafter (Eli Lilly and Company, 2024).

Notably, the modified titration approach resulted in approximately a 40% reduction in ARIA-E (edema and brain swelling), with a lower severity than in the standard titration group (Eli Lilly and Company, 2024). Among participants carrying the APOE ε4 allele, the incidence of ARIA-E decreased from 57% in the standard titration group to 19% in the modified titration group (Eli Lilly and Company, 2024). In contrast, differences in microbleeding and hemorrhage (ARIA-H) between the standard and modified groups were minimal, with only a 5% reduction – from 25.1% to 20.3% – at 24 weeks (Eli Lilly and Company, 2024). Across measures of amyloid plaque reduction, the biomarker plasma p-tau217, and total drug exposure, results were not significantly different. These results indicate that reducing ARIA risk through slower dose escalation does not compromise amyloid clearance, supporting modified titration as a safer but equally effective treatment strategy (Eli Lilly and Company, 2024).

Another anti-amyloid therapy approved in 2025 was lecanemab, marketed under the brand name Leqembi. Similar to donanemab, lecanemab is a monoclonal antibody; however, it differs in that it specifically targets amyloid beta protofibrils, immature, soluble plaques that float in the brain's extracellular fluids and interfere with synapse function (Van Dyck et al., 2025).

In a randomized, double-blind study with an open-label extension following an initial 18-month "core" phase, 1,795 participants aged 50–90 with mild cognitive impairment or mild dementia and amyloid pathology confirmed by PET imaging or cerebrospinal fluid analysis were randomized to either a lecanemab group or a placebo group (Van Dyck et al., 2025). During

the subsequent 18-month extension period, participants in the lecanemab group received biweekly intravenous infusions of 10 mg/kg.

Notably, individuals who received lecanemab from the beginning of the core phase demonstrated approximately a 30% delay in disease progression compared with those who initiated treatment later, illustrating the importance of early intervention (Van Dyck et al., 2025).

An additional consideration in lecanemab therapy is the FDA's approval of subcutaneous maintenance dosing. Previously, patients receiving lecanemab were required to undergo regular intravenous infusions administered by healthcare providers. In 2025, weekly subcutaneous self-injections using an autoinjector were introduced as an alternative maintenance option (Alzheimer's Association, 2025). Before transitioning to self-administration, patients or their caregivers must complete an initial treatment phase consisting of biweekly intravenous infusions in a hospital or infusion center over an 18-month period. Provided this phase is well tolerated, patients may proceed to weekly subcutaneous injections using the Leqembi IQLIK autoinjector, an option considered more convenient "in the real world" because it reduces travel to doctor's appointments and the associated scheduling concerns (Alzheimer's Association, 2025).

Given the risk of ARIA, the 18-month intravenous phase allows for close monitoring and ensures that amyloid plaque levels are reduced to an acceptable threshold, as determined by the Centiloid Scale, a standardized measure of amyloid buildup scored from 0 to 100 (Van Dyck et al., 2025). While individuals with Alzheimer's disease typically exhibit amyloid levels around 100 centiloids and cognitively healthy individuals measure near 0 centiloids, neurologists generally use a cutoff of approximately 20-25 centiloids to designate "amyloid-negative" status. At this level, radioactive tracers used in PET imaging no longer bind in patterns characteristic of Alzheimer's disease (Van Dyck et al., 2025). Once lecanemab is no longer actively removing large volumes of amyloid, the risk of ARIA is substantially reduced, and subcutaneous self-injection provides an adequate maintenance dose.

NOVEL TREATMENTS

Most treatments currently in the research phase fall into three main categories: Disease-Modifying Therapies (DMTs), Symptomatic Cognitive Enhancers (Rivastigmine, Donepezil, and Galantamine are current examples), and Behavioral and Psychological Symptoms of Dementia (BPSD) medications. DMTs are the most widely researched of the three classifications. They work to inhibit the progression of AD by attacking amyloid-beta (Aβ) plaques, tangled tau strands, or inflammation. Symptomatic cognitive enhancers are designed to improve measures of cognitive function, whereas BPSD medications are used to control disease symptoms and have no effect on disease progression (Atri, 2019).

Current research on DMTs, such as γ-secretase inhibitors (GSIs) and β-secretase inhibitors (BACEi), has revealed potential toxicity concerns, but also some encouraging benefits that will be discussed later. GSIs work by inhibiting the binding of γ-secretase, which ultimately blocks amyloid-beta (Aβ). Critically, however, GSIs also disrupt the Notch signaling pathway, an important communication system between cells that helps maintain homeostasis. Understandably, interrupting this system will lead to dysfunction, commonly in the gastrointestinal and immune systems (Atri, 2019). Taking this into account, these shortcomings are believed to outweigh any clinically significant benefits. β-secretase inhibitors (BACEi), on the other hand, bind to the active site of the βsecretase enzyme (BACE1), preventing the formation of Beta-Carboxyl-Terminal Fragment (β-CTF, also called C99). This fragment is further processed via additional ε (epsilon), ζ (zeta), and γ (gamma) cuts by γ-secretase into amyloid beta (Mecozzi et al., 2014).

While BACEi don't interfere with the Notch signaling pathway and therefore don't induce GI and immune system dysfunction as GSIs do, challenges still exist. Since BACE1 is highly important for synaptic plasticity, myelination, and neuronal signaling, over-inhibiting BACE1 can lead to reductions in synaptic density, accelerated brain atrophy, and neuronal hyperexcitability (Mecozzi et al., 2014). Current research is migrating from complete inhibition of BACE1 and into pharmacological chaperone treatments. These treatments do not bind to APP; instead, they bind to the retromer complex at the interface between the Vps35 and Vps29 proteins. By stabilizing this "weak link" in the retromer, the treatment enhances the trafficking of APP out of the endosome, thereby reducing its exposure to BACE1 and limiting its processing into pathogenic fragments (Mecozzi et al., 2014).

Ultimately, matters of pharmacokinetics and delivery remain a challenge. Molecules must cross the blood-brain barrier (BBB), and "sneak" past the Multidrug resistance (MDR) efflux pumps, the transport proteins located in the plasma membranes of cells that identify and expel foreign substances, all without inadvertently stimulating a severe immune response (Zhang et al., 2021). Additionally, these molecules must bind with and stabilize the Vps35-Vps29 interface without interfering with natural protein turnover. Current "proof of concept" tests using computer models show promise; however, human testing is required to demonstrate true effectiveness (Mecozzi et al., 2014).

Another novel treatment option is agonistic antibodies targeting Triggering Receptor Expressed on Myeloid Cells 2 (TREM2). TREM2 is a glycoprotein in microglia, the brain's resident immune cells, that helps inhibit the accumulation of amyloid-beta (Aβ) plaques and the activity of proinflammatory cytokines (Li et al., 2023). Early studies in mice have shown that TREM2 overexpression is associated with reduced microglia-mediated inflammation and decreased tau protein hyperphosphorylation, the process that causes tau proteins to tangle (Li et al., 2023). Additionally, TREM2 enhances phagocytosis of Aβ plaques. Conversely, mice with lower TREM2 levels exhibited increased plaque accumulation (Li et al., 2023). It is believed that proteolytic enzymes, such as the A Disintegrin and Metalloproteinase (ADAM) family–specifically ADAM10 and ADAM17–strip TREM2 from microglia, preventing it from carrying out its protective effects (Li et al., 2023). Current research is focused on TREM2 agonistic antibodies that block this cleavage, allowing TREM2 to remain attached to microglia and continue its protective role. If effective, this treatment could inhibit the development of Alzheimer's disease by reducing neuroinflammation, tau hyperphosphorylation, and Aβ plaque accumulation. However, a major challenge remains: developing a reliable method to transport these antibodies across the blood-brain barrier (BBB) (Li et al., 2023).

The United States Food and Drug Administration's (FDA) rapid approval of aducanumab marked a pivotal leap in Alzheimer's disease treatment and research; however, its developer, Biogen, ultimately discontinued the product in 2024 (Alzheimer's Association, 2024). The drug was the first monoclonal antibody treatment approved by the FDA and worked by selectively binding to soluble amyloid oligomers and insoluble amyloid fibrils rather than monomers (Sevigny et al., 2016). The antibody's Fragment crystallizable (Fc) region then signals microglia to phagocytize the plaques via Fc receptors (FDA, 2021). Though Biogen's early PRIME, EMERGE, and ENGAGE trials illustrated the technology's promising ability to reduce amyloid plaques, the project

lost momentum owing to a combination of lackluster support from insurance companies and medical providers based on an uncertainty regarding clinical benefits, and a subsequent loss of investment in their then-ongoing ENVISION Phase 4 confirmatory study (Budd Haeberlein et al., 2022; Cummings et al., 2021). Consequently, Biogen has shifted its efforts to its current product, lecanemab, which has yielded stronger clinical results, greater medical support, and is currently prescribed (Biogen, 2024).

Another novel treatment under investigation is gantenerumab, a monoclonal antibody administered via subcutaneous injection. Unlike donanemab and lecanemab, gantenerumab targets mature collections of amyloid protofibrils called fibrillar amyloid plaques and initiates Fc receptor–mediated phagocytosis (Bateman et al., 2025). While Washington University School of Medicine's GRADUATE trials on gantenerumab were originally discontinued due to a lack of statistically significant evidence that its originally intended dose of 225mg every four weeks was effective in the general Alzheimer's disease population. However, this mechanism prompted questions regarding whether anti-amyloid therapies could be administered prophylactically in individuals who carry Alzheimer's disease-associated genes but are otherwise cognitively healthy. In a subsequent study conducted by Washington University School of Medicine, which compared gantenerumab with an amyloid monomer-attacking anti-amyloid medicationcalled solanezumab, 73 carriers of the dominantly inherited Alzheimer's disease (DIAD) gene – 48 of whom were cognitively healthy and 25 of whom exhibited mild Alzheimer's disease symptoms – were initially treated with either 225 mg of gantenerumab every four weeks, 400 mg of the intravenous medication solanezumab every four weeks, or a saline placebo (Bateman et al., 2025). While solanezumab aimed to target soluble amyloid beta monomers, its developer, Eli Lilly, discontinued the project after a study dubbed EXPEDITION found that its intended strategy for plaque clearance was insufficient (Honig et al., 2018).

Concurrently, Roche's, at the time ongoing SCarlet RoAD and Marguerite RoAD trials, along with Eli Lilly's EXPEDITION study, provided evidence that the doses used in the Washington University study were insufficient for efficacy and that higher doses of antiamyloid therapies were safer than first anticipated (Bateman et al., 2025). Consequently, in 2016, researchers amended the protocol to include a stepwise dose escalation of gantenerumab over eight weeks, culminating in a maintenance dose of 1,200 mg administered once every four weeks (Bateman et al., 2025). This approach was later replicated in 2017 with solanezumab, with doses increased to a maximum of 1,600 mg every four weeks (Bateman et al., 2025). Ultimately, neither drug demonstrated an ability to slow cognitive decline, although gantenerumab did produce a statistically significant reduction in amyloid plaque burden (Bateman et al., 2025). Ultimately, due to repeated clinical failures and an inability to clear existing brain plaques, solanezumab never reached the market (Eli Lilly and Company, 2023).

Building on these outcomes, researchers initiated an open-label extension (OLE) study in 2020 to evaluate the long-term effects of gantenerumab over three years. During this time, higher doses were shown to more effectively clear amyloid plaques, and evidence suggested that anti-amyloid therapies are possibly more effective as prophylactic interventions than as treatments for established plaque accumulation. Participants who were cognitively healthy and had remained in the study since 2012 experienced an approximately 47% reduction in cognitive decline over the three-year OLE period, denoting a delay in the onset of more severe symptoms compared with participants who entered during the OLE phase (Bateman et al., 2025). This evidence supported the authors' "Threshold Theory," which proposes that anti-amyloid therapies are not truly effective until an "amyloid-negative" state is achieved (Bateman et al., 2025). However, it is important to note that only 13 participants remained in the study from its conception in 2012 through the entire three-year OLE period. Ultimately, larger sample sizes are needed to draw definitive conclusions.

Researchers have also explored whether leveraging the brain's innate immune system may yield a practical strategy for treating Alzheimer's disease. A considerable challenge in this approach is the blood–brain barrier (BBB), a selectively permeable membrane that permits essential nutrients to enter the brain while restricting pathogens and many therapeutic agents (Rhea & Banks, 2024). Trontinemab, a monoclonal antibody developed by Roche and its subsidiary Genentech, employs the company's Brainshuttle technology, which uses antibody fragments to facilitate transport of therapeutic molecules across the BBB and achieve deeper, more uniform brain distribution (Roche, n.d.).

Trontinemab binds to transferrin receptor 1 (TfR1), which normally mediates iron transport into the brain, allowing the antibody to undergo receptor-mediated transcytosis across the BBB (Roche, 2025). Once inside the brain, the antibody's Fab regions bind amyloid-beta (Aβ), while the Fc region interacts with microglial Fc gamma receptors to stimulate phagocytosis of Aβ (Roche, 2025). Compared with gantenerumab, early preclinical studies in non-human primates demonstrated that trontinemab achieved deeper and more uniform cortical and subcortical brain exposure. This was confirmed using radiolabeled tracers and positron emission tomography (PET) imaging, which revealed broader distribution relative to conventional antibodies (Roche, 2025). Based on pharmacokinetic modeling, researchers estimate that trontinemab could achieve approximately a 20% reduction in amyloid-beta levels in humans, supporting progression to clinical trials (Roche, 2025).

Attempting to forge a completely new path, the biotechnology research company Longeveron investigated the safety and potential efficacy of allogeneic mesenchymal stem cell therapy as a further treatment for Alzheimer's disease. This approach, termed laromestrocel and marketed as Lomecel-B, involves harvesting mesenchymal stem cells from the bone marrow of healthy donors aged 18-45 years. These cells can differentiate into multiple cell types, including osteocytes, adipocytes, and neurons, and possess immunomodulatory properties and the ability to secrete growth factors that promote tissue regeneration and repair (Pittenger et al., 2019).

While most existing and emerging Alzheimer's disease treatments focus on clearing amyloid plaque accumulation, stem cell therapy may target other critical but often underemphasized disease mechanisms, including severe neuroinflammation and neural tissue atrophy (Longe et al., 2025). In a Phase 2a clinical trial, 49 patients with mild Alzheimer's disease were randomized into four groups: a placebo group receiving four monthly intravenous saline infusions; a low-dose group (Group 2) receiving a single intravenous infusion of 25 million cells followed by saline placebo infusions for the subsequent three months; a second low-dose group (Group 3) receiving four monthly intravenous infusions of 25 million cells; and a high-dose group receiving four monthly intravenous infusions of 100 million cells (Longe et al., 2025).

Researchers monitored the incidence of adverse and serious adverse events, chiefly within four weeks of each infusion, and assessed safety through regular physical examinations, electrocardiograms, blood tests, and urinalysis. Blood samples were specifically analyzed for soluble Tyrosine Kinase with Immunoglobulin-like and EGF-like domains 2 (sTIE2), the shed

form of the endothelial cell protein TIE2, which helps reduce inflammation and protect the integrity of the blood–brain barrier (BBB) (Longe et al., 2025). In Alzheimer's disease, metalloproteases that normally degrade TIE2 to promote proper protein turnover are upregulated, leading to elevated circulating sTIE2 levels and heightened vulnerability of cerebral blood vessels to inflammation (Longe et al., 2025).

Cerebrospinal fluid samples were also analyzed for glial fibrillary acidic protein (CSF GFAP), a biomarker of astrocyte activation and neuroinflammation, and neurofilament light chain (CSF NfL), a marker of neuroaxonal injury (Longe et al., 2025). In addition, MRI was used to monitor ARIA and brain volume changes. Diffusion tensor imaging (DTI), an advanced MRI technique, assessed axonal organization and neuroinflammatory processes (Longe et al., 2025).

To assess clinical progression, the researchers developed the Composite Alzheimer's Disease Score (CADS), which integrates outcomes from four measures: the Alzheimer's Disease Cooperative Study – Activities of Daily Living scale (ADCS-ADL), which evaluates a patient's ability to perform activities of daily living (ADLs); the Clinical Dementia Rating – Sum of Boxes (CDR-SB); the Alzheimer's Disease Assessment Scale – Cognitive Subscale (ADAS-Cog-13), which assesses domains including word recall, object naming, ability to follow multistep instructions, constructional and ideational praxis, orientation, word recognition, retention of test instructions, spoken language ability, word-finding difficulty, comprehension, delayed recall, and concentration; and magnetic resonance imaging (MRI) data. In this study, CADS specifically incorporated measurements of left hippocampal volume, a region critical for memory function, scored on a normalized scale from 0 to 1 (Longe et al., 2025).

Ultimately, only one participant across Groups 2, 3, and 4 reported adverse effects, which included headache and chills. Given the low incidence and nonspecific nature of these events, a causal relationship with laromestrocel treatment could not be definitively established. Notably, no cases of ARIA were reported. CADS results exhibited a 0.38-point improvement in Group 2 compared with placebo at week 39 and a 0.44-point improvement in Group 4 at the same time point. Although Group 3's CADS results were not reported independently, they contributed to the overall treatment effect, which included a 48.4% slowing of total brain tissue atrophy, a 61.9% slowing of left hippocampal atrophy, and an approximately 37% reduction in ventricular enlargement, reflecting decreased expansion of intracranial cerebrospinal fluid space associated with brain shrinkage (Longe et al., 2025). Improvements in cognitive performance, ability to perform ADLs, and overall quality of life were also observed, alongside reductions in sTIE2, cerebrospinal fluid glial fibrillary acidic protein (CSF GFAP), and cerebrospinal fluid neurofilament light chain (CSF NfL), suggesting decreased neuroinflammation following allogeneic mesenchymal stem cell therapy (Longe et al., 2025). Nevertheless, the study's small sample size warrants caution, and larger trials are needed to draw definitive conclusions about treatment efficacy.

Researchers also wonder whether vaccination may provide sufficient protection against the onset of Alzheimer's Disease. The vaccine ACI-24 represents a novel approach to hindering AD progression through active immunotherapy. An interesting consideration is that patients with Down Syndrome (DS) possess the greatest genetic risk for developing AD since they are born with an extra copy of the APP gene, which is located on chromosome 21. Despite this, DS patients were historically excluded from AD clinical trials. ACI-24 contains the Aβ1–15 N-terminal sequence, which is highly immunogenic. Using only this small, synthetic segment of the Amyloid Beta antibody prevents excessive T-cell activation and an inflammatory response, reducing the risk of meningoencephalitis. This was the downfall of many early immunotherapy attempts in AD research (Rafii et al., 2022). In the ACI-24 vaccine, these fragments are bound to microscopic lipid vesicles called liposomes and also contain a molecule called monophosphoryl lipid A (MPLA), which signals the activation of dendritic cells, presents the antigen to B cells, and stimulates antibody production (Rafii et al., 2022). These antibodies circulate in the bloodstream and can cross the blood-brain barrier (BBB), where they bind to amyloid plaques and mark them for destruction. A 2022 study by the University of California, San Diego (UCSD), Massachusetts General Hospital (MGH), and Barrow Neurological Institute investigated safety, immune response, and feasibility of immunotherapy in adults with Down syndrome (Rafii et al., 2022). The initial phase one, randomized, double-blind, placebo-controlled trial included 16 adult participants with Down syndrome aged 25 to 45, with six receiving a 300 μg dose, six receiving a 1,000 μg dose, and four receiving a placebo. Ultimately, each participant received seven injections over 48 weeks, followed by a 48-week monitoring period (Rafii et al., 2022). In this early trial, there were no ARIA symptoms or other adverse events or deaths, indicating that the strategy avoided stimulating an excessive inflammatory response. Additionally, four of the six individuals in the 1,000 μg dose group developed detectable amyloid-beta antibodies. This result, although promising, only functions as a proof of concept due to the small sample size. Subsequently, the attention shifted to a larger sample size and to modifying the vaccine to specifically target pyroglutamate-Aβ (pGlu-Aβ), a particularly "sticky" and neurotoxic form of amyloid formed through a multi-step process beginning with the aforementioned cleavage of the amyloid precursor protein (APP) by beta and gamma secretases into amyloid-beta. Subsequently, aminopeptidases trim the N-terminus from the amyloid-beta, exposing glutamate residues, which are converted to pyroglutamate by glutaminyl cyclase (QC) (Schilling et al., 2008). This optimized form of ACI-24, called ACI-24.060, can elicit a stronger immune response by triggering B cells to attack targets, specifically pyroglutamate or amyloid-beta, and phagocytose them. With ACI-24.060, these B cells will then present antigens from a common pathogen, such as tetanus. Since most individuals are vaccinated against tetanus, the helper cells are already "trained" to respond to those antigens, supporting B cells in producing potent antibodies without triggering excessive neuroinflammation (Rafii et al., 2022). The ABATE trial, currently underway, is expected to conclude in 2026 and aims to recruit roughly 140 DS and early AD patients without DS. So far, results are promising, with no ARIA cases in Down syndrome cohorts, stronger and more consistent antibody responses than those observed with the original vaccine, and a Fast Track designation from the U.S. FDA recognizing the urgent need for treatments in this population (Rafii et al., 2022).

Another developing immunotherapy is UB-311. It uses the same basic principles as ACI-24 to protect against AD, but B cells specifically target the $A\beta_{1-14}$ fragment of the amyloid-β protein (Yu et al., 2023). Since the B-cell epitope is not strong enough to trigger a sufficient immune response alone, UB-311 contains UBITh® peptides, which assist by linking both of its T-cell peptide epitopes to amyloid beta. From there, T cells recognize the target and signal B cells to produce antibodies against amyloid beta (Yu et al., 2023). As UB-311 triggers the Th2 immune response, its focus is rapid antibody production, which enables the elimination of Aβ without stimulating an excessive T-cell response and neuroinflammation

(Yu et al., 2023). The resultant antibodies are also highly selective, preferentially binding to amyloid-β fibrils and oligomers (Yu et al., 2023). In a 78-week, randomized, double-blind, placebo-controlled study by Taipei Veterans General Hospital (TVGH), National Taiwan University Hospital (NTUH), Linkou Chang Gung Memorial Hospital (LK-CGMH), and Kaohsiung Chang Gung Memorial Hospital (KS-CGMH), 43 patients, between 60 and 90 years of age, with AD and associated amyloid pathology, confirmed by PET imaging and MMSE scores between 20 and 26, were randomized into three groups. This consisted of a quarterly dosing group that received seven doses, a biannual dosing group that received five doses and two placebos, and a placebo group (Yu et al., 2023). Each dose was a 300 μg intramuscular (IM) injection in a 0.5 mL solution containing 150 μg of each of the two synthetic helper T-cell peptides (Yu et al., 2023). All participants in the active groups received initial doses at weeks 0, 4, and 12, serving as a priming phase. Subsequently, each patient was randomly assigned to different booster schedules. In the quarterly dosing group, booster injections were administered every three months at Weeks 24, 36, 48, and 60. The biannual group received booster injections at Weeks 36 and 60. Finally, the placebo group received IM injections at weeks 24 and 48 that contained no active peptides (Yu et al., 2023). Ultimately, the results were promising, with no participants terminating treatment due to drug-related adverse events, including ARIA-E. However, 14% of patients experienced asymptomatic amyloid-related imaging abnormalities with microhemorrhages (ARIA-H), 16% experienced injection-site pain, and 12% experienced diarrhea. UB-311 elicited a 97% antibody responder rate across both treatment groups, which remained stable throughout the study, with 93% of patients maintaining detectable antibody levels at 78 weeks (Yu et al., 2023). While future testing with a larger sample size is required, these results show promise that UB-311 can be safe and effective.

Two additional experimental vaccines, ACI-35.030 and JACI-35.054, were examined for safety and effectiveness in a 2025 double-blind, randomized, placebo-controlled Phase 1b/2a clinical trial. While it operates similarly to the aforementioned ACI-24, both utilizing liposomes (called SupraAntigen® in ACI-35) to target antigens, ACI-35.030 targets phosphorylated tau (pTau), specifically the Tau393–408 peptide sequence, to generate antibodies (Rafii et al., 2022).

Tension is applied to the pTau peptide when it binds to a liposome along its curvature. This forces them to mimic the "twisted" appearance of diseased Tau so B-cells make antibodies for it instead of healthy tau. These "twisted" fragments are called enriched paired helical filaments (ePHF) (Schlepckow et al., 2023).

In contrast, JACI-35.054 utilizes a more traditional carrier-protein conjugate vaccine approach. Here, phosphorylated tau is chemically bound to an inactive, genetically modified form of diphtheria known as CRM197. Similar to the use of Tetanus in ACI-24, CRM197 is utilized to provoke a stronger immune response than is generated by tau protein fragments alone. The immune system often fails to recognize peptides, diseased or not, as pathogens (Zhang et al., 2021).

Ultimately, antigen-presenting cells consume the conjugate CRM197 protein, cleave it into smaller fragments, and display them on major histocompatibility complex (MHC) molecules to activate helper T-cells. These in turn stimulate B-cells to produce antibodies which specifically target CRM197 and the tau peptide it's attached to (Li et al., 2023). Unfortunately, as CRM197 is large and highly immunogenic, the immune system tends to fixate on it rather than its associated tau peptide. The result is that these antibodies don't necessarily target the phosphorylated tau specifically; rather, they target pTau and healthy Tau used to maintain the neuron's structure (Schlepckow et al., 2023).

Lastly, this method also stimulates an immune response more gradually and can require an onslaught of booster injections to reach adequately strong antibody levels. The 2025 study examined both immunotherapies, initially with 34 participants divided into an 18-participant ACI-35.030 group and a 16-participant JACI-35.054 group. These were again divided into dosage groups. The ACI-35.030 group consisted of six participants receiving a 300 μg dose, six receiving a 900 μg dose, six receiving a 1,800 μg dose, and 10 receiving a placebo dose. The JACI-35 groups consisted of 6 participants who received a 15 μg dose, six who received a 60 μg dose, and 4 who received a placebo (Rafii et al., 2022).

Once the ACI-35.030 low-dose group was seen to experience no adverse effects following at least two injections, the mid-dose group (900 μg) was extended by an additional 13 patients to allow for stronger confirmation of the treatment's safety and immunogenicity prior to advancing to further clinical testing, while also more accurately comparing these factors between low, mid, and high-dose groups. Long-term immune responses were tracked over 74 weeks to analyze antibody development and response to booster injections (Rafii et al., 2022).

The 2025 study noted that 100% of patients receiving ACI-35.030 at all dose levels responded to anti-pTau IgG within 14 days of their first injection. Additionally, median anti-pTau antibody titers increased nearly 100-fold from baseline in the same time following one mid-dose injection. However, JACI-35.054 patients required at least 3 injections to achieve a stable antibody titer (Rafii et al., 2022).

ACI-35.030 also showed a clear preference for ePHF, with anti-ePHF titers increasing 10-fold within just eight weeks. Contrarily, JACI-35.054 stimulated antibody titers against healthy Tau. Levels of pTau217 were significantly reduced in ACI-35.030 groups; a significant detail considering pTau217 levels exhibit a nearly perfect correlation to Tau tangle density (Gueorguieva et al., 2025). Finally, the study showed zero ARIA cases and only 16.7% of patients experienced injection site reactions or headaches (Rafii et al., 2022).

Due to ACI-35.030's performance advantages over JACI-35.054, the former was selected for the larger, currently ongoing Phase 2b ReTain trial. The ReTain trial aims to determine the possibility that ACI-35.030, now dubbed JNJ-2056 after its new sponsor, Johnson and Johnson, can prevent Alzheimer's disease onset before the onset of symptoms if treated during the preclinical stage. A lesser-known but incredibly promising treatment developed and utilized successfully in Cuba, but not yet FDA-approved, is called NeuroEPO plus, or NeuralCIM. In the randomized, double-blind, placebo-controlled, and adaptive trial known as ATHENEA, researchers at Cuba's Centro de Inmunología Molecular strove to determine the drug's neuroprotective effects in the treatment of mild to moderate AD (Sosa et al., 2023). NeuroEPO works by increasing the threshold of oxidative stress required to trigger apoptosis in neural tissue. Erythropoietin (EPO) naturally induces hematopoiesis when produced endogenously (Sosa et al., 2023). When administered exogenously, like in blood doping, overexposure to the hormone can lead to polycythemia, where the body produces excess red blood cells (RBCs), putting individuals at increased risk for clots.

If Sialic Acid, a component of EPO that increases its half-life to ensure it can float around the bloodstream and bind to EPO receptors (EPOR), is removed and the hormone is administered in a nasal spray, the new compound, NeuroEPO, binds to EPORs in the hippocampus and cerebral cortex before it can trigger adverse effects (Garzón et al., 2018). Here, it stimulates Janus kinase 2 (JAK2), which "turns on" the PI3K/Akt pathway, in which the

Akt protein is phosphorylated. As a result, it can inhibit pro-apoptotic proteins and ultimately promote Bcl-2 expression (Rama et al., 2019).

Bcl-2 prevents apoptosis by stabilizing mitochondrial membranes and blocking the release of Cytochrome c, which triggers apoptosis; consequently, the neuron can survive even when it is antagonized by amyloid-beta plaques (Rama et al., 2019). NeuroEPO also plays a role in shifting microglial activity from pro-inflammatory to anti-inflammatory, reducing the release of proinflammatory cytokines that could inadvertently damage surrounding neural tissue (Zhang et al., 2020). It binds to EPORs expressed on the surface of the microglia, which, in a process called dimerization pulls two JAK2 molecules together, allowing them to autophosphorylate each other (Subiros et al., 2016). From here, Signal Transducer and Activator of Transcription 3 (STAT3) transcription factors bind to the phosphorylated EPORs so that further JAK2 proteins can phosphorylate the STAT3 (Subiros et al., 2016).

This STAT3 then undergoes its own round of dimerization, exposing a Nuclear Localization Signal (NLS), which allows the new STAT3 dimer to be transported into the neuron's nucleus by Importin-α and Importin-β (Sosa et al., 2023). Once inside, the RanGTP enzyme binds to the STAT3/Importin complex, causing the STAT3 dimer to dissociate while the Importins are recycled (Sosa et al., 2023). The dimer targets the promoter regions of Gamma-Activated Site (GAS) genes, stimulating RNA Polymerase II recruitment and supporting expression of the anti-inflammatory M2 phenotype. Additionally, NF-κB signaling, a key pathway implicated in the pathogenesis of neurotoxicity and Alzheimer's disease, plays a crucial role in the response of neurons and glial cells (Sun et al., 2022). Commonly, oxidative stress activates the neuron's IκB Kinase (IKK) complex and renders it perpetually "on". As a result, IKK phosphorylates IκBβ, an inhibitory protein that isolates NF-κB in the cytoplasm so it can't translocate into the nucleus and trigger the transcription of neurotoxic cytokines (Sosa et al., 2023). IκBα is attached to ubiquitin, tagging it for destruction by the 26S Proteasome. In the absence of IκBα, NF-κB can initiate its neurotoxic activity. Additionally, NeuroEPO has been shown to inhibit the activation of the IKK complex by activating the PI3K/Akt and JAK2/STAT5 pathways, leading to the production of SOCS proteins that act as molecular decoys by occupying the IKK complex (Rama et al., 2023, pp. 123-135). The complex binds to prevent upstream inflammatory enzymes from docking, degrading NF-κB Essential Modulator (NEMO) and TNF Receptor-Associated Factor (TRAF) proteins. These act as the "scaffold" that positions necessary enzymes for inflammation to occur (Sosa et al., 2023). Lastly, activation of the PI3K/Akt pathway has been shown to play a significant role in neuronal cell signaling and survival, including the inhibition of GSK-3β, which, in turn, promotes transcription factors beneficial for long-term cellular survival and aerobic respiration (Kitagishi et al., 2014). This shift effectively "starves" the proinflammatory machinery of its preferred glycolytic fuel while providing the high-yield ATP necessary for M2 microglia to maintain membrane integrity and sustain the clearance of neurotoxic aggregates (Sosa et al., 2023).

The study aimed to assess responses to treatment in healthy individuals, specifically whether NeuroEPO could reach the central nervous system without triggering hematopoietic side effects (Sosa et al., 2023). This study included 174 participants with mild to moderate Alzheimer's disease, aged 60 to 80 years (mean age 74.0 years), who were randomized into three groups as part of the adaptive ATHENEA trial (Sosa et al., 2023). The Low Dose group received 0.5 milligrams of NeuroEPO, the High Dose group received 1.0 milligrams, and the placebo group received an inactive placebo. Each dose was administered three times per week for 48 weeks. The researchers determined that, while both the low and high dose groups showed significant improvements of 3.6 and 3.5 points, respectively, on the ADAS-Cog11, the difference was not significant enough to justify continuing the high dose (Sosa et al., 2023). That said, the placebo group experienced a 4.1-point decline. Additionally, 78% of the low-dose group and 74% of the high-dose group experienced improvement, compared to 12% of the Placebo group (Sosa et al., 2023). Next, the researchers continued through the 96-week mark to determine whether the previously discussed cognitive improvements were permanent or required further doses to maintain the effects. In this phase, 115 participants aged 60-80 were grouped into four treatment histories and observed. The "continuous" group received NeuroEPO treatment for the entire 96 weeks. A "delayed start" group comprised participants who occupied the placebo group during the first 48 weeks but transitioned to a treatment group during the subsequent 48 weeks (Sosa et al., 2023). Another group, the "Discontinued" group, started in the treatment group for the first 48 weeks before joining the placebo group for the following year. Lastly, a control group was never administered an active dose across all 96 weeks (Sosa et al., 2023). In the "continuous" group, participants experienced a median improvement of 6.0 points on the ADAS-Cog13 from baseline. Conversely, the control group saw a severe, 11.0-point decline in the same metric. Additionally, although specific numerical data were not provided, researchers claim that patients in the "discontinued" and "delayed start" groups showed declines or improvements following removal or administration of a treatment dose (Sosa et al. , 2023). Overall, NeuroEPO is considered safe and effective for the treatment of mild to moderate AD.

CONCLUSION

Encouraging healthy and Alzheimer's patients to make lifestyle changes, including exercise and nutrition, remains best practice. Prescribing medications for AD risk factors or neural degeneration is also essential. While Alzheimer's is incurable, slowing disease progression is possible with research-based interventions and approved medications such as cholinesterase inhibitors, NMDA receptor antagonists, or anti-amyloid monoclonal antibodies. Further innovation in disease-modifying therapies, stem cell therapy, rTMS, immunotherapy, and TREM2 agonistic antibodies shows promise, but larger trials are needed.

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Urban Green Spaces and Natural Forests: A Comparative Study of Bird Diversity

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ABSTRACT

Urbanization reduces canopy cover, habitat connectivity, and native plant diversity. Avian communities, particularly specialist species, are highly sensitive to variation in vegetation structure and anthropogenic disturbance, making birds effective bioindicators of habitat quality.

In this study, we compared avian species richness, diversity, and the proportions of generalist and specialist species between two sites in Salisbury, Maryland: Salisbury University, an urban green space, and Pemberton Historical Park, a relatively less disturbed natural area. Avian surveys were conducted at both sites alongside assessments of vegetation structure. Pemberton Historical Park supported higher avian species richness and diversity than Salisbury University, where vegetation was dominated by non-native plant species and characterized by reduced canopy cover. Although no significant differences were observed in the proportions of habitat generalists and specialists, Pemberton Historical Park supported a greater proportion of dietary specialists.

Overall, these results highlight the relationship between urbanization, habitat complexity, and the availability of functionally suitable habitat, and its influence on avian community structure. While urban green spaces can support moderate levels of biodiversity, they do not fully replicate the structural complexity of less disturbed ecosystems. These findings underscore the importance of habitat quality and vegetation characteristics in maintaining avian diversity across urban and natural landscapes. As urbanization continues to expand, effective management of urban green spaces will be increasingly important for conserving native wildlife and maintaining ecological resilience.

Keywords: bird diversity, fragmented habitat, canopy cover, native species, anthropogenic disturbance, Salisbury University, Pemberton Park

INTRODUCTION

Urbanization is a leading driver of habitat loss, fragmentation, and biotic homogenization, resulting in measurable declines in biodiversity and ecosystem function (Magura et al., 2010; Dong et al., 2024). These local and global changes alter resource availability and community composition, ultimately reducing the persistence of many species. Consequently, the ecological importance of urban green spaces has increased, as these areas are intended to mitigate biodiversity loss by providing habitat refuges and resources within otherwise highly modified environments.

Birds are widely recognized as effective bioindicators of habitat quality due to their rapid responses to variation in vegetation structure, composition, and levels of anthropogenic disturbance (Canterbury et al., 2000). Given that urbanization continues to reshape natural habitats across multiple spatial scales, examining avian community responses to these environmental gradients is essential for assessing ecosystem conditions and guiding urban conservation and management strategies (Li et al., 2025).

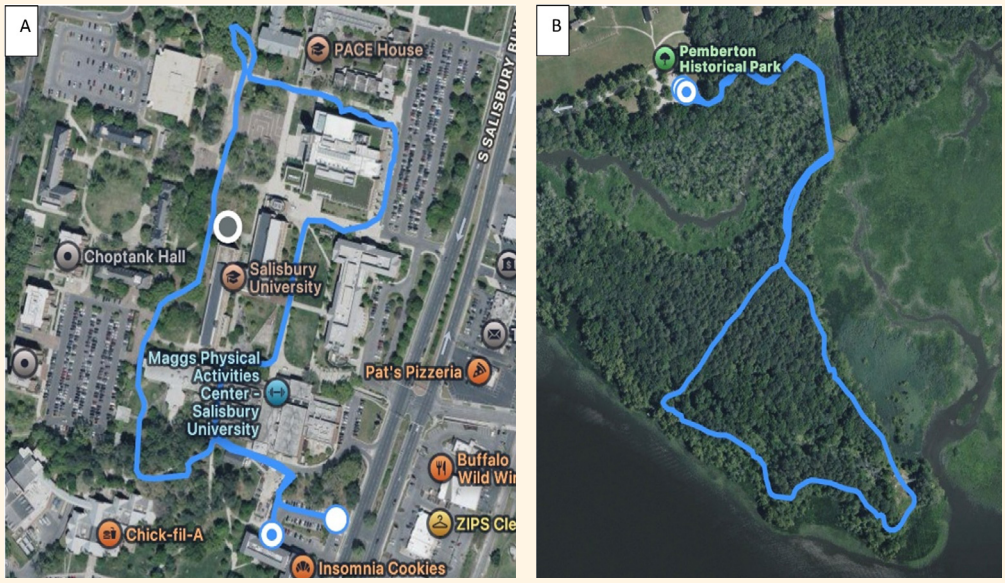
This study compares two ecologically contrasting sites in Salisbury, Maryland. The Salisbury University campus contains a highly managed arboretum (Glenda Chatham Clarke Arboretum) and is characterized by high horticultural diversity, consisting of both locally native species and a large proportion of introduced ornamental plants. This composition contributes to fine-scale habitat heterogeneity and the potential for diverse microhabitats; however, vegetation is fragmented by campus buildings, pathways, and other infrastructure, resulting in discontinuous canopy cover. In addition, the site is subject to frequent anthropogenic disturbance associated with human activity typical of an urban university setting. Collectively, these factors may reduce habitat quality and suitability for disturbance-sensitive bird species, even in the presence of relatively high plant species diversity.

In contrast, Pemberton Historical Park (hereafter "Pemberton") represents a relatively undisturbed habitat with minimal human alteration. The site is characterized by mature forest stands and meadow systems dominated by locally native vegetation. This contributes to larger areas of canopy cover, high structural complexity, and habitat heterogeneity (Wicomico County Recreation and Parks, n.d.). As a relatively undisturbed natural area, Pemberton provides a baseline for evaluating the ecological function and biodiversity of the more heavily managed urban Salisbury University campus landscape.

Given that vegetation composition and canopy cover are key determinants of avian habitat suitability (such as nesting opportunities, foraging resources, and microhabitat conditions), we combined field-based surveys with Geographic Information Systems (GIS) analysis. This approach allowed us to quantify and compare percent canopy cover and evaluate its relationship with avian species richness and diversity across the two study sites. Previous research has shown that canopy cover strongly influences bird diversity and evenness (Basile et al., 2025) and has identified canopy expansion as a priority for conservation and management, particularly for supporting specialist species (Lerman et al., 2021). In addition, we quantified habitat edge as edge-dominated landscapes can reduce habitat quality for interior-dependent species through increased exposure to disturbance, altered microclimatic conditions, and elevated predation risk (Ries and Sisk, 2004; Fahrig 2003). Thus, the proportion of edge habitat was included as a landscape configuration metric, given evidence that increased edge density is frequently associated with declines in specialist bird species and reduced community integrity (Ewers & Didham, 2007).

Together, these spatial and field-based approaches provide a framework for evaluating how vegetation structure and landscape fragmentation jointly influence avian diversity patterns. This integrative methodology also supports the identification of vegetation characteristics that most effectively enhance avian biodiversity in urban environments,

FIGURE 1. **(A)** Satellite imagery of Salisbury University showing the survey route (blue line) used for field observations, with a total walking distance of approximately 1.62 miles. **(B)** Satellite imagery of Pemberton Historical Park showing the Bell Island Trail (blue line) used for field observations, with a total walking distance of approximately 1.8 miles.



offering direct applications for restoration planning and landscape design aimed at improving overall ecological function (Arson et al., 2014). More broadly, this study addresses the extent to which urban green spaces maintain ecological integrity and support functional biodiversity (Paker et al., 2014).

We hypothesize that Pemberton will support higher avian species diversity and richness due to its greater habitat heterogeneity, higher proportion of locally native vegetation, and more developed, continuous canopy structure. These characteristics are expected to provide a wider range of nesting substrates, foraging opportunities, and microhabitat conditions that collectively support a more diverse avian community. In contrast, the Salisbury University campus is expected to exhibit comparatively low levels of avian diversity, with community composition skewed toward habitat generalists and urban-adapted species. This expectation is based on the campus's higher degree of habitat fragmentation, greater prevalence of non-native ornamental vegetation, and increased exposure to anthropogenic disturbance, all of which may limit habitat suitability for specialist species.

METHODS AND MATERIALS

STUDY SITES

Bird surveys were conducted at two locations in Salisbury, Maryland: the Salisbury University campus (38.3455° N, 75.6064° W) and the Bell Island Trail within Pemberton (38.347415° N, −75.6430967° W). The Salisbury University transect comprised a 1.62-mile route (**Fig. 1A**) while the Pemberton transect consisted of a 1.8-miles (**Fig. 1B**).

OBSERVATION SCHEDULE AND SURVEY PROTOCOL

Field observations were made from September 23 to October 19, 2025, and were conducted in three standardized daily time periods. At Salisbury University, a total of 48 observations took place and at Pemberton, 50 observations took place (**Table 1**).

Line-transect surveys were conducted following established protocols outlined by Emlen (1971) that include walking in a line on a pre-determined path while recording birds seen and heard along the transect. Prior to data collection, all observers were trained in avian identification and standardized survey protocols, including repeated practice walks along each transect to ensure methodological consistency. Surveys were conducted by slowly walking each transect while also incorporating point-transect sampling, during which observers paused at fixed intervals for 3 minutes to record birds detected primarily through auditory cues (Buckland et al., 2001; Buckland, 2006). Species identification was based on both visual and auditory observations, using binoculars (10–12× magnification) to enhance visual detection and the Merlin Bird ID application (Cornell Lab of Ornithology, n.d.-a 2025) to assist in confirming species identifications and recognizing vocalizations. All detections were recorded using the eBird platform, which was also used to document and map transect distance as well as capture GPS-based spatial data (following Sullivan et al., 2009).

Each detection was classified as auditory, visual, or both. Only individuals recorded within the defined transect boundaries were included in analyses. Because the Salisbury University site lacks wetland habitat, wetland-associated plant and bird detections recorded along the Pemberton transect were excluded to

TABLE 1. Times, amount, and locations of bird observation periods.

Time	Salisbury University	Pemberton
Morning	16	17
Afternoon	17	16
Evening	15	17
Total	48	50

ensure comparability between sites. Following each survey, acoustic identifications generated using Merlin Bird ID were reviewed collectively by all observers to verify accuracy. When available, photographic evidence was also examined to confirm species identifications. Only records confidently verified were retained for subsequent analyses.

Bird species were classified as habitat generalists or specialists using Species Specialization Index (SSI) values for North American breeding birds reported by Martin and Fahrig (2018; Appendix S2, Table S1) and supplemented with data from Birds of the World (Cornell Lab of Ornithology, n.d.-b). These SSI values were originally derived using the method developed by Julliard et al. (2006) and Devictor et al. (2008), which quantifies habitat specialization as the coefficient of variation in species density across land-cover types. Specifically, SSI is calculated as σ/μ, where σ represents the standard deviation of species densities and μ is the mean density across habitat classes. Species with lower SSI values were classified as habitat generalists, whereas those with higher values were classified as habitat specialists.

PLANT SURVEY METHODS

Complete tree record databases for the 200+ acre arboretum at Salisbury University are updated quarterly with GIS mapping, and the database of tree species was obtained from Julie Golightly (CPH, Horticulturist & Arboretum Curator, personal communication November 11, 2025). Plant species at Pemberton were recorded and collected into a list using the Seek mobile app by *iNaturalist* (Seek by iNaturalist, 2025) along with additional identifications from former Salisbury University Botanist Professor (Dr. R. T. Wilkens personal communication, October 8, 2025). Databases from both regions were trimmed to retain only records of plants that could be identified to the species or subspecies level.

Plant species were classified into three categories based on native range. Locally native species were defined as those whose native distribution includes the Maryland and Delaware Coastal Plain, extending north through Kent County in both states. CONUS-native species were those native to the contiguous United States but not the local region, and non-native species were those introduced from outside the contiguous United States. Vegetation range information was obtained from the USDA Plants Database (Natural Resources Conservation Service [NRCS], n.d.), supplemented with the North Carolina Extension Gardener Plant Toolbox (NC Extension Gardener Plant Toolbox, n.d.) and the Missouri Botanical Garden (Missouri Botanical Garden, n.d.) as necessary. Cultivars and ornamental hybrids were classified as non-native, as they are human-developed selections distinct from naturally occurring native populations (Reichard & White, 2001; Blackburn et al., 2011).

GIS ANALYSIS

Canopy cover was quantified using a foliage and canopy cover dataset obtained from the Maryland iMAP open GIS portal (Maryland Department of Planning, Maryland iMAP, & Maryland State Department of Assessments and Taxation, n.d.). A 10-meter negative buffer was applied to exclude edge habitats, allowing for

FIGURE 2. Boxplot of average number of bird species observed at Pemberton and Salisbury.

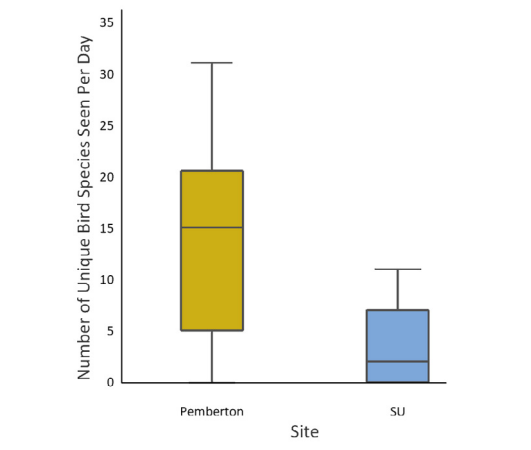


FIGURE 3. (A) SSI estimates for unique bird species at Pemberton and Salisbury demonstrating the high number of unique bird species at Pemberton (H′ =2.822) as compared to Salisbury University (H′ = 2253). **(B)** Logarithmic rank-abundance curve of bird species observed showing higher species diversity and higher species evenness at Pemberton as compared to Salisbury University.

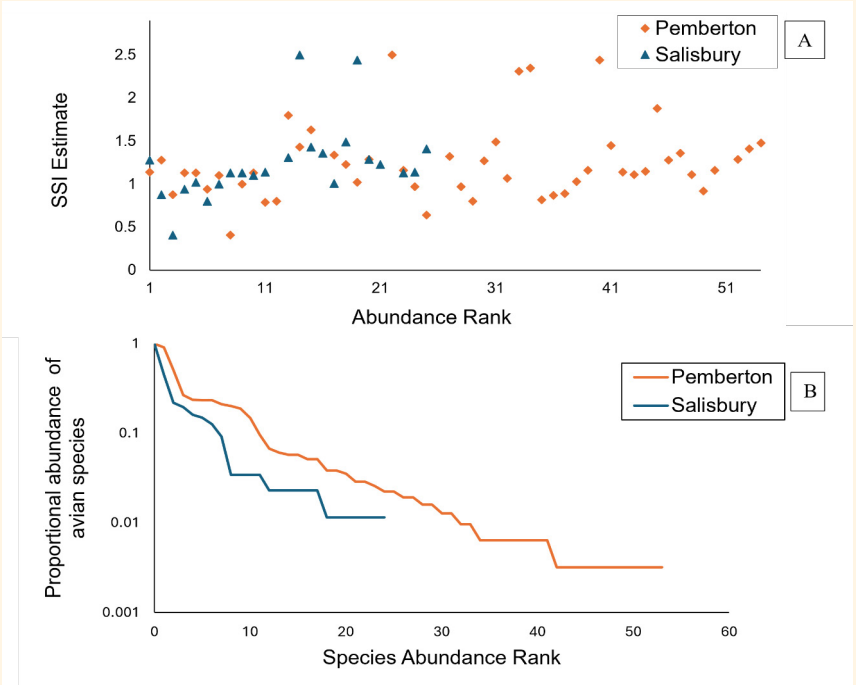


FIGURE 4. Proportion of dietary specialists and generalists between sites, indicating that Pemberton has a significant difference in dietary specialization compared to Salisbury University (p = 0.03).

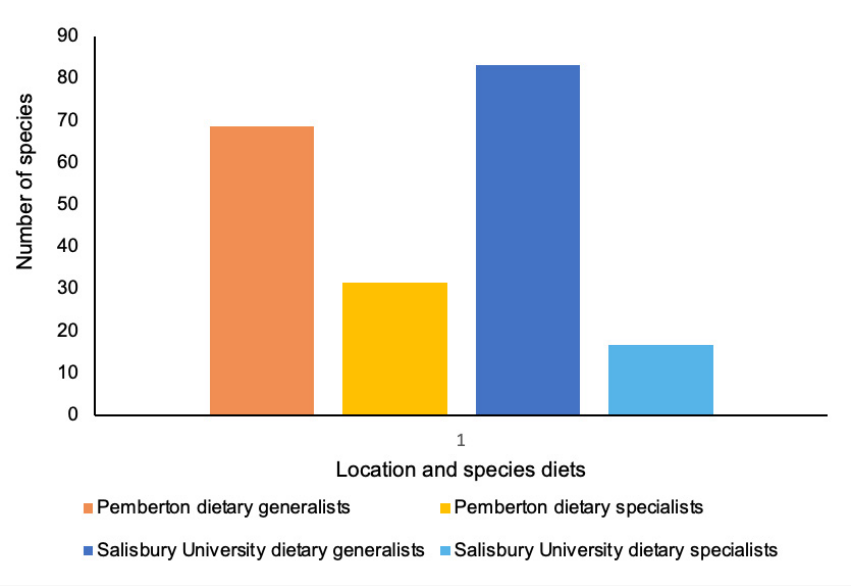
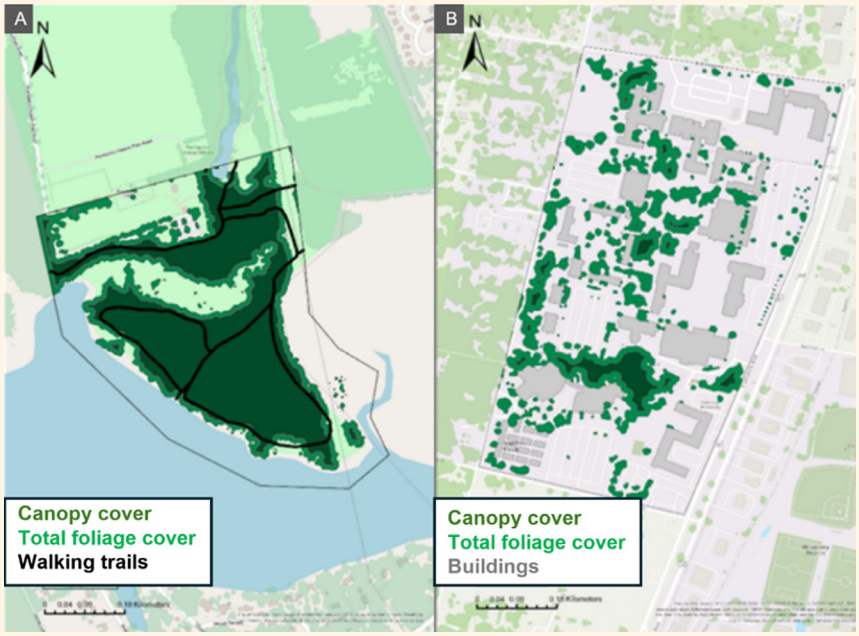


FIGURE 5. (A) Spatial distribution of canopy cover, walking trails, and usable avian habitat within Pemberton. Forest canopy cover is shown in dark green, and walking trails are indicated in black. A dark green buffer delineates areas classified as usable habitat for bird species, while lighter green represents total foliage cover. **(B)** Spatial distribution of canopy cover, usable avian habitat, and built environment at Salisbury University. Forest canopy cover is shown in dark green, with a buffer indicating usable avian habitat. Lighter green represents total foliage cover, and developed areas are included within the built environment layer.



a more conservative estimate of interior canopy cover that is likely most suitable for the majority of bird species.

DATA ANALYSES AND FIGURES

Data analyses and figures were conducted and in Minitab (Minitab, LLC, 2023) and Microsoft Excel (Microsoft, 2026; MedCalc Software Ltd., 2023), respectively. GNU Image Manipulation (GIMP Development Team, 2023) was also used to aid in visualization of data. Non-parametric Mood's Median Tests were performed in Minitab. This follows the equation below to obtain the Chi-square statistic (Alexander Mood, 1950), where O is the observed value and E is the expected:

$$x^2 = \sum \frac{(O-E)^2}{E}$$

RESULTS

BIRD SPECIES RICHNESS AND DIVERSITY

A total of 1,567 birds were observed at Pemberton and 239 birds were observed at Salisbury. Daily bird species richness differed significantly between the two sites (Mood's Median Test, $X^2(1) = 11.66$, $p = 0.001$), with Pemberton having a higher average daily species richness as well as overall species richness during the study (**Fig. 2**).

Shannon Wiener diversity indices (based on SSI index) were higher at Pemberton ($H' = 2.822$) than at Salisbury ($H' = 2.253$; **Fig. 3A**). A log-rank abundance curve shows how the relative abundance and evenness in each community differs, such that the longer curve at Pemberton indicates more species and evenness compared to Salisbury University (**Fig. 3B**).

A mix of habitat generalist and habitat specialist species was observed at both sites, with no significant difference between the median SSI index of all unique species seen at each site, regardless of rank (Mood's Median Test, $X^2(1) = 0.27$, $p = 0.604$). However, evaluating the difference between dietary specialists and generalists reveals a significance between sites ($X^2(1) = 0.471$, $p = 0.03$; **Fig. 4**).

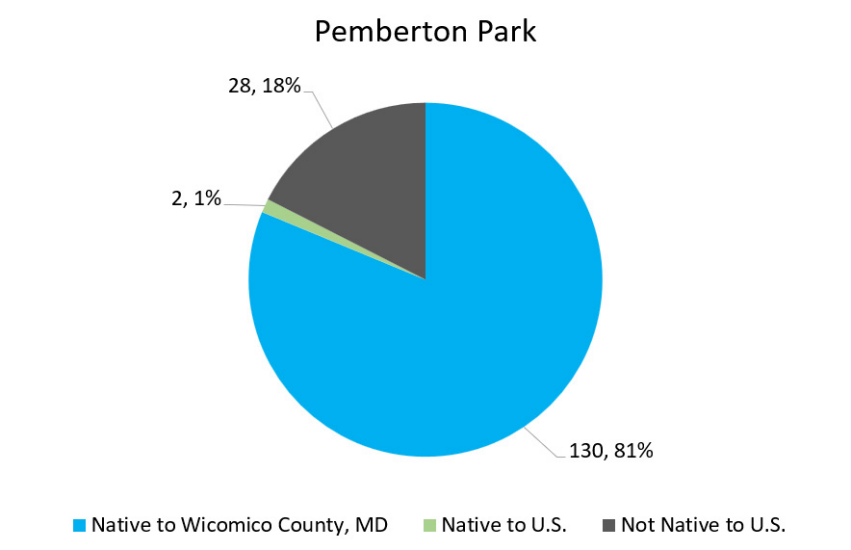
TEMPORAL PATTERNS IN BIRD ACTIVITY

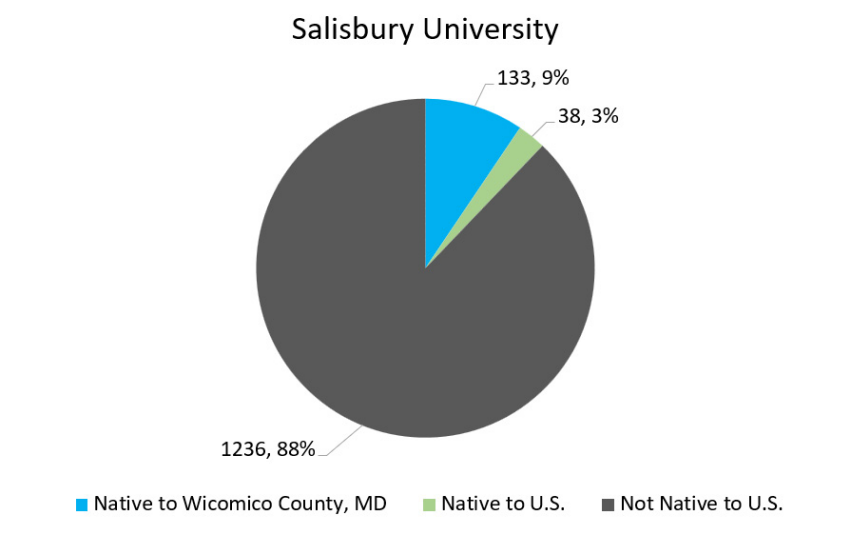
Temporal trends were consistent across both sites, with the highest number of detections occurring during morning surveys and the lowest during midday. This pattern reflects typical diurnal activity in birds, characterized by increased vocalization and movement during

TABLE 2. Sums and proportions of native versus introduced plant species at both sampling sites. The 'Introduced' row includes species non-native to Wicomico County & surrounding area, and species non-native to the contiguous U.S. as well as cultivars.

Plant Species	Pemberton	Proportion of Total	Salisbury University	Proportion of Total
Native (within Wicomico County)	130	0.1875	171	0.1215
Introduced/non-native (to Wicomico County)	30	0.8125	1,236	0.8785
Sum	160		1,407	

FIGURE 6. (A) Composition of the plant community at Pemberton Historical Park by native status, including locally native (Wicomico County region), U.S.-native, and non-native species.er. **(B)** Plant community composition by native status at Salisbury University.





early morning hours (Chandler, 1981; Robbins, 1981). These trends were consistent across sites despite differences in habitat structure, disturbance, and local environmental conditions.

CANOPY COVER

Using estimated polygon boundaries delineating the two study sites, land-cover analysis in ArcGIS indicated that approximately 20.08% of Salisbury University was covered by foliage, compared to 54.02% of Pemberton (**Fig. 5A, B**). Following the exclusion of edge habitats, 68.84% of the foliage cover at Salisbury University was classified as "usable" habitat, defined as vegetation located more than 10 meters from the habitat edge. At Pemberton, 72.45% of the foliage cover met this criterion. Consequently, usable habitat comprised 13.82% of the total area of Salisbury University and 39.14% of the total area of Pemberton.

PLANT COMMUNITY RESULTS

Plant community composition differed substantially between sites (**Table 2**). A total of 160 plant species were recorded at Pemberton Historical Park, compared to 1,407 species reported for the Glenda Chatham Clarke Arboretum at Salisbury University. Twenty-two species occurred at both sites, of which 20 are native to the Wicomico County region and two are non-native to the contiguous United States. Salisbury University was the only site containing cultivars. The proportions of locally native, U.S.-native, and introduced plant species at each site are presented in **Figure 6A** and **B**.

DISCUSSION

This study examined differences in bird species richness and diversity between an urban green space at Salisbury University and a comparatively less disturbed ecosystem at Pemberton. By comparing these contrasting

habitats, we evaluated how habitat structure, fragmentation, and anthropogenic disturbance influence avian community composition across different land-use types. Assessing the capacity of managed urban green spaces to support bird communities is critical for informing conservation planning, urban landscape design, and biodiversity management strategies, particularly as urbanization continues to alter natural ecosystems.

Our study revealed substantial differences between the two sites in avian species diversity, evenness, abundance, and landscape characteristics. Pemberton supported a more diverse avian community than Salis0bury University, as demonstrated by higher species diversity and greater community evenness based on the Shannon–Wiener diversity index and rank-abundance curve. Pemberton, however, had much lower plant species diversity with few nonnative plants and in contrast, Salisbury University exhibited greater overall plant species richness yet a much lower diversity of birds. A large proportion of this richness at Salisbury University consisted of nonnative ornamental species, primarily introduced from East Asia, including China and Japan (NC Extension Gardener Plant Toolbox, n.d.; Missouri Botanical Garden, n.d.). Additionally, Salisbury University had lower canopy cover, and GIS analyses indicated that the vegetation was highly fragmented and interspersed with buildings and other developed infrastructure.

These findings suggest that habitat quality, native vegetation composition, and landscape configuration may be more influential determinants of avian diversity than plant species richness alone. Although Salisbury University contained a vastly greater number of plant species, the predominance of nonnative vegetation likely reduced the availability of suitable food resources, nesting substrates, and habitat for many native bird species. Consequently, the avian community at Salisbury University was dominated by a relatively small number of dietary specialist species that are urban adapted, whereas Pemberton, with its greater abundance of native vegetation and more contiguous habitat, supported a richer and more evenly distributed bird community.

In addition to Salisbury University's predominance of nonnative vegetation and lack of canopy cover, differences in human activity and microhabitat characteristics may have contributed to the observed variation between sites. Anthropogenic disturbances, including noise and artificial lighting, can alter bird behavior and reduce habitat suitability for disturbance-sensitive species (Shannon et al., 2016; Halfwerk et al., 2021; Amjad et al., 2024; Bahia et al., 2024). Consequently, urban green spaces are often dominated by ecological generalists that tolerate a broad range of environmental conditions, whereas specialists are more prevalent in less disturbed ecosystems, though see below. This pattern is consistent with previous research demonstrating that urbanization favors adaptable species while reducing ecological specialization and promoting biotic homogenization (McKinney, 2006; Groffman et al., 2017).

At Salisbury University and Pemberton, the European Starling, Blue Jay, and American Robin were the most frequently observed species at both sites. Their high abundance is consistent with their classification as ecological generalists, possessing broad habitat and dietary preferences that enable them to thrive across a wide range of environments, including urban landscapes (Savard et al., 2000; Billerman, 2020-present). In contrast, habitat specialists occurred at relatively low abundances, particularly at Salisbury University, although the difference between sites was not statistically significant. Given that anthropogenic disturbance often reduces the abundance of avian specialists (Zhang et al., 2021), this finding was unexpected. However, our surveys were conducted during early to mid-fall, after the peak breeding season, when many species expand their habitat use following the abandonment of breeding territories (Newton, 1998; Wiens, 1989; Cornell Lab of Ornithology, n.d.-c). Consequently, seasonal shifts in habitat use from habitat specialists to generalists may have reduced detectability of differences in habitat specialization between the two sites.

Although no significant differences were observed in the proportions of habitat generalists and specialists between sites, Pemberton supported a significantly greater proportion of dietary specialists than Salisbury University. This pattern suggests that the less disturbed habitat at Pemberton provides a wider range of specialized food resources, likely due to primarily native plants and increased canopy cover. Because dietary specialists perform distinct ecological functions, their loss may disproportionately affect ecosystem processes. For example, nectar-feeding birds are key pollinators for many plant species, and their loss can reduce plant reproductive success and contribute to local population declines (Bawa, 1990). Likewise, frugivorous birds play a critical role in seed dispersal, facilitating forest regeneration and plant recruitment; declines in these species can therefore impede natural succession and long-term ecosystem recovery (Howe & Smallwood, 1982).

Additional concerns arise from the potential loss of dietary specialist birds, as their decline may reduce natural pest control, increasing herbivory pressure and crop damage with associated ecological and economic consequences (Monteagudo et al., 2023; Ferrari et al., 2025). Similarly, scavenging specialists facilitate carrion removal, reducing the accumulation of decomposing organic matter and limiting pathogen transmission in wildlife and human systems (Houston, 1986). Together, these examples highlight that specialist species perform ecological functions that cannot be fully replaced by generalists, underscoring their importance for ecosystem stability and resilience. Consequently, understanding how urban landscapes support both specialist and generalist species have important conservation implications beyond Salisbury University and Pemberton, reflecting broader patterns across urbanizing regions (Hughes et al., 2022).

Increasing native vegetation, reducing anthropogenic disturbance, and preserving structurally diverse habitat patches may enhance the capacity of urban green areas to support more diverse and functionally rich avian communities (Berthon et al., 2021). Canopy cover continuity is also a key determinant of habitat suitability, as it provides nesting sites, predator refuge, thermal regulation, and foraging opportunities, while facilitating movement between habitat patches (MacArthur & MacArthur, 1961; Fahrig, 2003). Together, these management strategies may support not only native bird and specialist conservation but also broader ecosystem stability and resilience in urban environments (Hu and Lima, 2024).

Overall, our findings suggest that while urban green spaces can support moderate avian diversity, they do not fully replicate the ecological complexity and habitat functionality

of less disturbed natural systems, even where plant diversity is high. Greater canopy cover at Pemberton likely enhances habitat quality (Evans et al., 2009) by reducing edge effects, maintaining more continuous interior forest conditions, and supporting higher proportions of native vegetation. These structural features increase habitat suitability for disturbance-sensitive and specialist species, as well as species richness and diversity (Humphrey et al., 2023). Consistent with previous research, greater canopy cover, habitat complexity, and reduced fragmentation are positively associated with avian diversity and species richness in urban landscapes (Schütz & Schulze, 2015). Accordingly, increasing canopy cover and planting native plant species on the Salisbury University campus may improve habitat quality and support more diverse and stable bird communities (Sanllorente et al., 2023).

Future research should incorporate systematic observations across breeding, non-breeding, and migratory seasons to account for seasonal variation in habitat use and species composition. In addition, expanding sampling to include a broader gradient of habitat types – from relatively undisturbed natural ecosystems to highly urbanized environments – would provide a more comprehensive understanding of how land-use intensity influences avian communities. Such an approach would also allow for stronger inference regarding the effects of habitat fragmentation, vegetation structure, and anthropogenic disturbance on species richness, evenness, and the relative abundance of specialist taxa. Together, these approaches would help clarify how fine-scale habitat variation and species-specific ecological requirements interact to shape avian community structure across heterogeneous landscapes.

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Cross-Frame Identity Tracking and Temporal State Smoothing for Automated Oyster Monitoring

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ABSTRACT

Manual shellfish inspection remains slow and inconsistent, and the frame-by-frame computer vision detectors used for automated oyster monitoring are similarly noisy: A single blurry or occluded frame can produce an incorrect state label or an inflated count. This paper investigates whether adding cross-frame identity tracking and temporal state smoothing to a frame-level oyster detector improves the stability of oyster counts and Open/Closed state classification. Using a YOLOv8s detector (precision 0.625, recall 0.512, mAP@0.5 0.565) as a frame-level baseline, we implemented an IOU/distance-based tracker to assign persistent identities across frames and a confidence-weighted temporal smoothing method to stabilize each tracked oyster's predicted state. Across 18 test videos, temporally smoothed state labels were correct more often than raw per-frame labels at every IOU matching threshold tested and confirmed oyster counts had lower mean error against ground truth than raw per-frame counts. Both improvements were consistent but modest. These results provide preliminary evidence that lightweight, client-side tracking and smoothing can improve monitoring stability over frame-only detection, and they motivate future work on adaptive, per-oyster smoothing and evaluation designs with tighter frame-level alignment between ground truth and detection.

Keywords: cross-frame tracking, temporal smoothing, oyster monitoring, computer vision, aquaculture, YOLOv8

INTRODUCTION

Shellfish aquaculture is a fast-growing segment of the U.S. seafood industry and depends on healthy, well-monitored oyster populations (Verdegem et al., 2023). Beyond their commercial value, oyster reefs provide ecological benefits including water filtration and shoreline stabilization (Beck et al., 2011), yet fisheries such as the Chesapeake Bay have seen oyster abundance decline by as much as 99.7% since the late 1800s (Lima, 2025). Farmers still largely inspect shellfish manually, a slow and inconsistent process (Essandoh et al., 2024), motivating interest in computer vision as a faster alternative.

Prior work has shown that machine learning models can classify oysters into open, closed, and indeterminate states from still images (Corcoran, 2025; Karim et al., 2025). This classification, however, happens frame by frame, and a single blurry, occluded, or ambiguous frame can produce an incorrect state label or an inflated count when the same oyster is detected inconsistently across frames. Cross-frame object tracking is well established in the broader computer vision literature as a way to use information from neighboring frames rather than treating each frame independently (Bochinski et al., 2017; Bewley et al., 2016), but it has not been a focus of prior oyster-monitoring work, which has concentrated on improving frame-level detection accuracy.

This paper investigates whether adding lightweight, cross-frame identity tracking and confidence-weighted temporal state smoothing to a frame-level oyster detector can improve the stability of two outputs directly relevant to oyster monitoring: oyster counts and Open/Closed state labels. We built on an existing browser-based, TensorFlow.js oyster-detection application (Karim et al., 2025) by adding an IOU/distance-based tracker that assigns and maintains oyster identities across frames, and a confidence-weighted smoothing method that stabilizes each tracked oyster's state using its recent detection history. To test this, we (1) trained a YOLOv8s frame-level detector as a baseline, (2) added cross-frame identity tracking, and (3) added temporal state smoothing, then compared the tracked and smoothed outputs against raw frame-level detection across a held-out set of 18 test videos.

RELATED WORKS

Prior oyster-monitoring research has focused primarily on improving frame-level detection. Karim et al. (2025) selected YOLOv8s for a browser-only deployment with no server dependency and updated the training dataset, reporting an mAP@0.5 of 0.86 and precision/recall of 0.85/0.85, while noting a "slideshow" jitter effect and reduced accuracy in turbid or occluded footage. Essandoh et al. (2024) expanded the training dataset and built a more accessible web interface for farmers using YOLOv10. Corcoran (2025) trained three YOLOv8 model sizes to classify oysters as Open, Closed, or Indeterminate, finding that the Indeterminate class reduced overall performance and recommending larger models and dataset re-annotation.

While this line of work has concentrated on frame-only classification, cross-frame tracking is well established elsewhere in computer vision. Bochinski et al. (2017) introduced the IOU Tracker, which associates detections across frames using bounding-box overlap alone, without appearance or motion models, making it well suited to lightweight, real-time applications. Bewley et al. (2016) extended this idea in Simple Online and Realtime Tracking (SORT), combining a Kalman filter with the Hungarian algorithm for detection-to-track association. Wojke et al. (2017) later introduced Deep SORT, which adds appearance embeddings to reduce identity switches during occlusion, at additional computational cost. Because our browser-based application is intended to run entirely client-side without server dependencies, our tracking approach follows the spirit of the IOU Tracker and SORT rather than the heavier, appearance-based matching used in Deep SORT.

MATERIALS AND METHODS

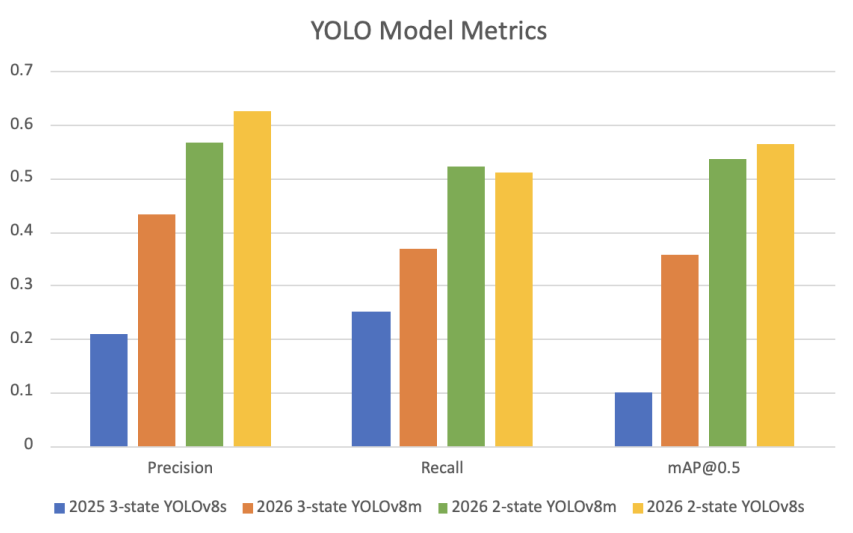
DATASET AND BASELINE DETECTOR

The research question in this paper concerns what happens after frame-level detection, so the detector itself is treated here only as the baseline the tracking and smoothing methods build on. The training dataset combined existing 2023 and 2025 REU

TABLE 1. Metric comparison for trained YOLOv8 models

Model	Training Data	Test Data	Precision	Recall	mAP@0.5
YOLOv8s	2026 2-state dataset V6	2026 2-state dataset V6	0.625	0.512	0.565
YOLOv8m	2026 2-state dataset V4	2026 2-state dataset V6	0.568	0.521	0.536
YOLOv8m	2026 3-state dataset	2026 3-state dataset	0.432	0.369	0.356
YOLOv8s	2025 dataset	2026 3-state dataset	0.208	0.250	0.099

FIGURE 1. Precision, recall, and mAP@0.5 for the 2025 YOLOv8s baseline and the 2026 YOLOv8m and YOLOv8s models trained on the curated 3-state and 2-state datasets.



annotations (Comfort et al., 2023), Roboflow image sets, and newly collected footage, including contributions from the Smithsonian Environmental Research Center's Oyster Cam project (Smithsonian Environmental Research Center, 2014) and Dr. Xiaomin Lin's ODYSSEE project (Lin et al., 2025), yielding 9,615 annotated images (24,588 Open, 61,251 Closed instances) split 75%/20%/5% into training, testing, and validation sets after an Oyster-Indeterminate class was removed for reducing detector performance. We trained and compared YOLOv8n, YOLOv8s, and YOLOv8m and selected YOLOv8s as the frame-level baseline for this study, since it offered the best balance of accuracy and inference speed for a lightweight, client-side deployment. The final model, trained with hue, brightness, exposure, blur, and noise augmentation, achieved a precision of 0.625, recall of 0.512, and mAP@0.5 of 0.565 on a held-out two-state test set (**Table 1**). It is run once every ten animation frames, with detections below a 0.4 confidence threshold discarded by non-maximum suppression, to produce the raw per-frame detections used as the baseline throughout this paper.

CROSS-FRAME IDENTITY TRACKING

To assign persistent identities to oysters across frames, each new detection is compared against currently tracked oysters using two spatial criteria, checked in order:

1. Intersection-over-Union (IOU): if a tracked oyster's most recent bounding box overlaps a new detection with IOU ≥ 0.5, they are matched.
2. Center-point distance: if no IOU match is found, a new detection is matched to the nearest previously tracked oyster if the distance between box centers is below 80 pixels and the IOU between the two boxes is greater than zero.

A newly matched oyster inherits its existing ID; an unmatched detection is assigned a new ID. An oyster must be matched for at least three consecutive frames before it counts toward the confirmed oyster total, and a tracked oyster left unmatched for more than 15 consecutive frames is dropped. IOU is checked before distance because it also accounts for the size and shape of each bounding box rather than only the position of its center point, which reduced identity switches compared with an earlier, distance-only implementation (Tracking Consistency).

TEMPORAL STATE SMOOTHING

Each tracked oyster maintains a rolling history of its seven most recent raw state predictions (Open or Closed) and their associated detection confidences. At each frame, the confidence scores within this history are summed separately for the Open and Closed classes. Once an oyster has accumulated at least three observations, its displayed ("smoothed") state changes from the current smoothed state only when the opposing class holds at least 65% of the total accumulated confidence weight; otherwise, the previous smoothed state is retained even if the most recent raw prediction disagrees. If the Open and Closed confidence weights are exactly tied, the previous smoothed state is also retained. Frames with no detection for a given oyster do not contribute a vote, so a brief occlusion or missed detection does not by itself change its state. This design allows an isolated misclassification to be overridden by an oyster's recent detection history, while still allowing a genuine, sustained state change to register once it accumulates majority support.

EVALUATION DESIGN AND A LIMITATION OF FRAME ALIGNMENT

Ground-truth state and count labels for the 18 test videos (ranging from 7 to 20 seconds in length) were annotated at 30 frames per second. The browser application, by contrast, runs the detector once every 10 animation frames, and its playback frame rate does not necessarily match the 30 fps used for annotation. As a

TABLE 2. Comparison of average confirmed and average per-frame oyster counts to true total oyster counts on test set videos

Video	True Total Count	Average Per Frame Count	Average Confirmed Count
1	30	4.563	5.063
2	20	8.786	12.286
3	12	9.400	9.500
4	21	15.211	15.105
5	22	12.300	12.800
6	11	11.059	14.029
7	17	8.500	9.143
8	13	11.929	12.786
9	17	16.657	20.914
10	28	33.160	33.480
11	17	6.895	7.842
12	5	3.984	5.194
13	39	11.000	9.833
14	32	26.385	27.231
15	29	18.588	19.647
16	2	1.133	1.800
17	2	1.719	1.969
18	2	0.000	0.000
Overall	**319**	**201.267**	**218.621**

TABLE 3. Mean absolute error and mean percentage error of average per-frame and confirmed counts against ground-truth totals across 18 test videos

Count Signal	Mean Absolute Error (oysters)	Mean Percentage Error
Average per frame count	7.12	37.5%
Average confirmed count	6.98	34.5%

result, a given detection frame does not always correspond exactly to an annotated ground-truth frame, and detections were matched to the nearest ground-truth annotation in time. This introduces a source of error that is independent of detector or smoothing accuracy: a prediction may be scored as incorrect because it is compared against a ground-truth frame that is offset in time, not because the underlying detection or state estimate was wrong. This limitation applies to both the counting comparisons in Counting Accuracy and Stability and the state-smoothing comparisons in State Smoothing Accuracy, and should be kept in mind when interpreting the size of the reported improvements.

RESULTS

DETECTOR PERFORMANCE

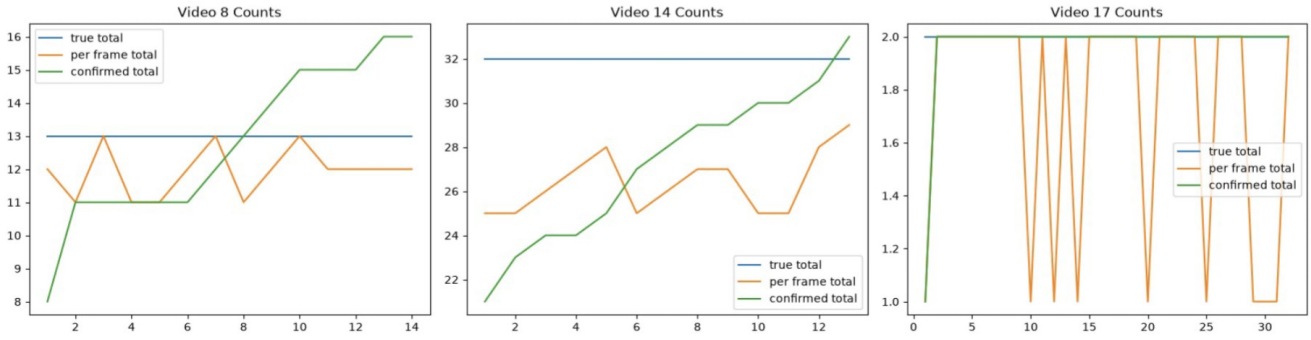
Table 1 and **Figure 1** summarize detector performance; this is background for the tracking and smoothing results that follow, not this paper's contribution. The 2025 YOLOv8s baseline (Karim et al., 2025) performed substantially worse on our new test set (mAP@0.5 = 0.099) than originally reported (0.86), which we attribute to training-data quality issues and to its original evaluation set overlapping with its training data. Our retrained YOLOv8s model reached a precision of 0.625, recall of 0.512, and mAP@0.5 of 0.565, and is used as the frame-level baseline throughout this paper. The model produces both false positives and false negatives and struggles more with Open oysters than Closed oysters, likely reflecting the dataset's remaining class imbalance (roughly 2.5 Closed instances per Open instance); because detector accuracy caps what any downstream tracking or smoothing method can recover, this imbalance is a relevant limitation independent of the methods evaluated here.

COUNTING ACCURACY AND STABILITY

Each of the 18 test videos was run through the browser application, and two count signals were logged: the per-frame detection count and the confirmed oyster count produced by the tracker described in Cross-Frame Identity Tracking. For each video, we averaged both signals over time (excluding the first two detection frames, to allow oysters time to reach the 3-frame confirmation threshold) and compared each average to the video's ground-truth total oyster count (**Table 2**).

The average confirmed count fell closer to the ground-truth total than the average per-frame count in 12 of the 18 videos (66.7%). Because comparing averages can obscure how far a count strays over the course of a video,

FIGURE 2. Confirmed and per-frame counts throughout Videos 8, 14, and 17 compared to true total counts. In these cases, the average confirmed count fell closer to the true total than the average per-frame count.

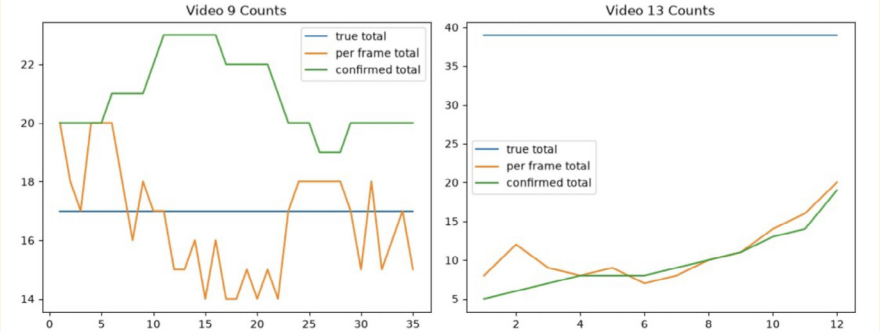


Per frame count remains mostly below the true total. Confirmed count gradually increases and goes beyond the true total, making the average close to the true total.

Per frame count again remains mostly below the true total. Confirmed count increases as the video goes on, reaching the true total towards the end.

Per frame count fluctuates throughout the video as detections are lost. Confirmed total reaches the true total and remains for the duration of the video.

FIGURE 3. Confirmed and per-frame counts throughout Videos 9 and 13 compared to true total counts. In these cases, the average confirmed count fell farther from the true total than the average per-frame count.



Confirmed total remains greater than the true total throughout the video, indicating double counting. Per frame total fluctuates.

Confirmed total gradually increases throughout the video but generally falls slightly behind per frame counts.

an estimate can start well below the true count and climb well above it, netting out close to the correct average, we also computed the mean absolute error and mean percentage error between each signal and its video's ground-truth total, calculated directly from the counts in **Table 2** (**Table 3**). Across all 18 videos, the confirmed count had a lower mean absolute error (6.98 oysters) than the per-frame count (7.12 oysters), and a lower mean percentage error (34.5% vs. 37.5%). As with the state-smoothing results in State Smoothing Accuracy, tracking-based counting produced a consistent, but modest, improvement over frame-only counting.

Video-level patterns help explain this modest gain. In some videos (e.g., Videos 8, 14, and 17; **Figure 2**), the confirmed count started below the true total and increased steadily until it approached or matched the ground truth, while the per-frame count fluctuated around a lower value throughout. In other videos (e.g., Video 9; **Figure 3**), the confirmed count rose above the true total and stayed there, suggesting an oyster was double-counted after losing and regaining a stable track. In Video 13 (**Figure 3**), the confirmed count consistently trailed slightly behind the per-frame count, suggesting the three-frame confirmation requirement delayed some oysters from being counted. Across all 18 videos, however, the confirmed count consistently increased and then plateaued, while the per-frame count fluctuated from frame to frame throughout the video (**Figure 4**). This stability, independent of whether the confirmed count exactly matched the ground truth, suggests that the confirmed count may be more suitable for real-time monitoring than the fluctuating per-frame count.

TRACKING CONSISTENCY

The IOU/distance tracker described in Cross-Frame Identity Tracking performed differently depending on how much the camera moved during a video. In videos with a stationary or slow, steady camera, oyster IDs remained consistent throughout, and oysters that were

TABLE 4. Number of detected oysters correctly classified by smoothed versus raw state labels

IOU Threshold	Oysters Detected	Detected Oysters w/ Correct Smoothed Label	Detected Oysters w/ Correct Raw Label	% Correct Smoothed	% Correct Raw
0.3	6265	4956	4923	79.106%	78.579%
0.4	3607	2927	2896	81.148%	80.288%
0.5	1700	1491	1472	87.706%	86.588%

FIGURE 4. Confirmed oyster count remaining stable across frames even when detection misses an oyster, compared with the fluctuating current-detection count.

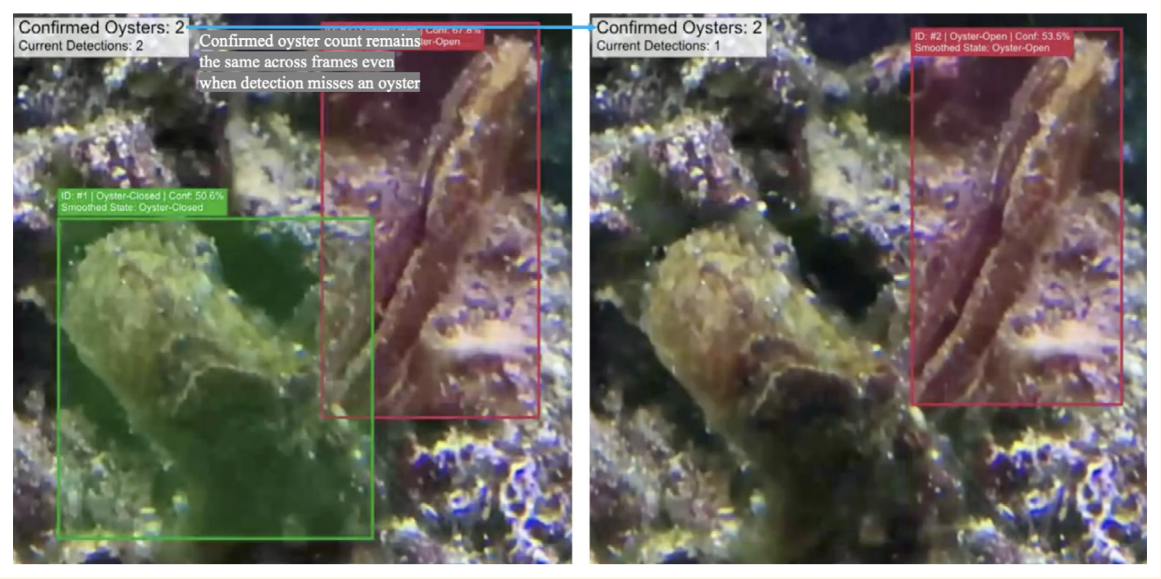


FIGURE 5. Oyster detection, counting, and tracking in the browser application.

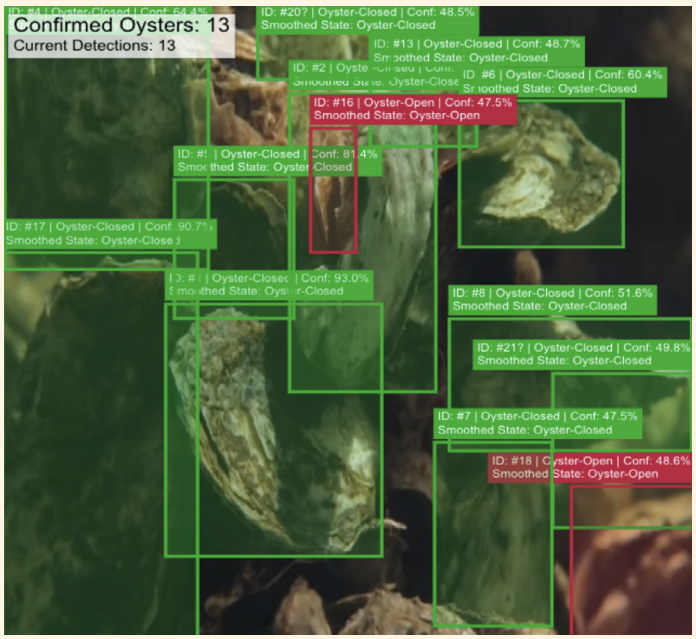
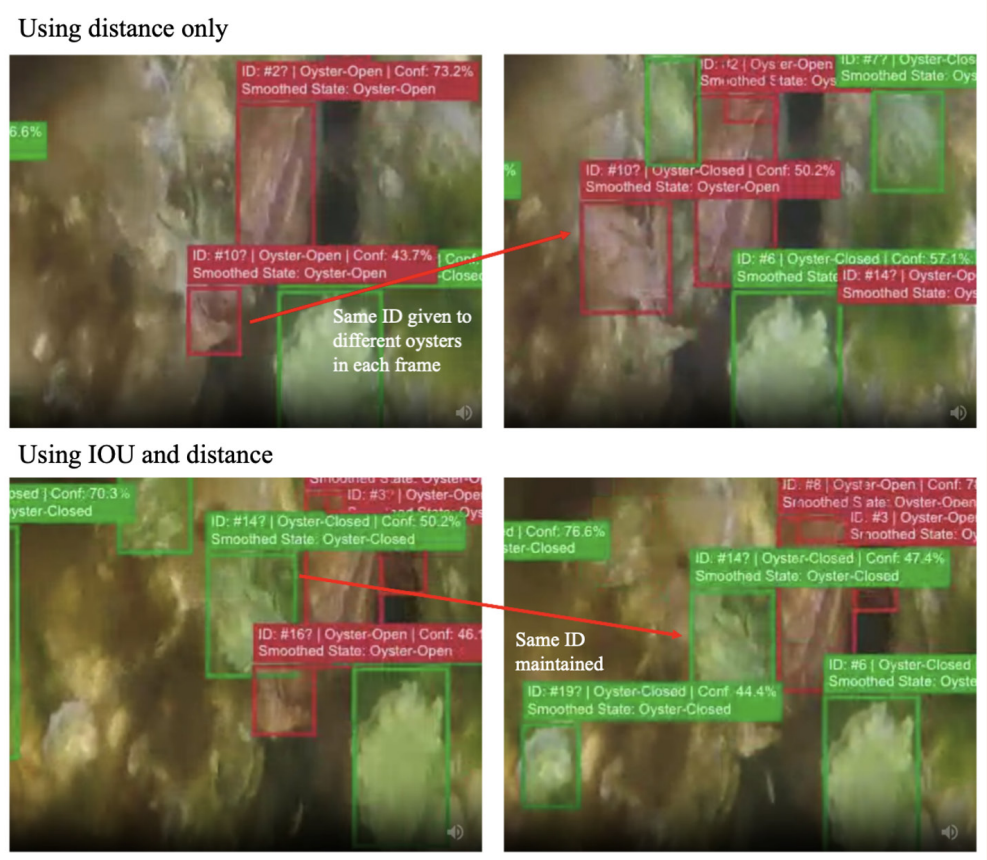


FIGURE 6. Oyster tracking using a distance-only method versus distance combined with IOU. The distance-only method assigns the same ID to different oysters across frames; adding IOU maintains the correct ID.



briefly missed by the detector were correctly re-identified once they reappeared (**Figure 5**). In videos with fast or erratic camera movement, IDs were more likely to be reassigned, and a single oyster could occasionally be counted as more than one oyster across frames.

Figure 6 illustrates why IOU matching was added rather than relying on center-point distance alone. Using distance only, oyster IDs sometimes switched when two oysters were close together and camera movement made one oyster's new position closer to the other's previous position than to its own. Adding an IOU check, which also accounts for the size and shape of each bounding box rather than only its center point, corrected this failure mode in the same clips. We did not compute a numerical tracking metric, such as an identity-switch count, for this evaluation; doing so, for example, by comparing tracked IDs against a hand-labeled ground-truth identity for each oyster, is a natural next step for more precisely quantifying tracking performance, and we identify it as a direction for future work in the Discussion.

STATE SMOOTHING ACCURACY

To evaluate whether temporal smoothing improved state classification, we compared the smoothed and raw per-frame state labels produced by the browser application against ground-truth annotations across the 18 test videos. Detected oysters were first matched to ground-truth oysters by bounding-box IOU, evaluated separately at three IOU thresholds (0.3, 0.4, and 0.5) to test sensitivity to the strictness of the matching criterion. For each set of matched detections, we then compared both the smoothed state label and the raw, single-frame state label against the ground-truth label (**Table 4**).

At every IOU threshold tested, the smoothed state label was correct more often than the raw label, though the margin was modest: 79.1% vs. 78.6% at IOU ≥ 0.3, 81.1% vs. 80.3% at IOU ≥ 0.4, and 87.7% vs. 86.6% at IOU ≥ 0.5, improvements of roughly 0.5 to 1.1 percentage points. As discussed in Evaluation Design and a Limitation of Frame, part of this modest margin is likely attributable to the mismatch between the 30 fps ground-truth annotation rate and the browser application's slower, once-every-ten-frames detection rate, which means some comparisons were made between predictions and ground-truth frames that were not perfectly aligned in time. The detector's own precision and recall (Detector Performance) place a further ceiling on how much any temporal method can improve on raw predictions, since smoothing can suppress isolated misclassifications but cannot recover information the detector never captured. Within these constraints, temporal smoothing produced a consistent, if modest, improvement in state-classification accuracy over raw frame-level predictions.

DISCUSSION

Across both evaluations in this study, adding cross-frame identity tracking and temporal state smoothing produced consistent but modest improvements over frame-only detection: confirmed oyster counts had lower mean error

than per-frame counts, and smoothed state labels were more often correct than raw per-frame labels at every IOU threshold tested. Neither improvement was dramatic, but both point in the same direction, which supports the underlying premise of this work, that using information from neighboring frames, rather than treating each frame independently, can make automated oyster monitoring more stable.

Several factors likely limit the size of these improvements. First, the frame-level detector itself has modest precision and recall (Detector Performance), which caps how much any downstream tracking or smoothing method can recover; a smoothing method can suppress an isolated misclassification, but it cannot correct for an oyster the detector never found. Second, the mismatch between the 30 fps rate used for ground-truth annotation and the browser application's slower detection rate (Evaluation Design and a Limitation of Frame) means some of the reported error may reflect timing misalignment rather than incorrect predictions; a test set with detection and annotation performed at matching frame rates would allow a cleaner measurement of the smoothing method's effect in isolation. Third, our tracking evaluation (Tracking Consistency) was qualitative; a numerical metric such as identity-switch rate, computed against hand-labeled ground-truth identities, would allow tracking performance to be compared more directly across videos and camera-motion conditions.

The temporal smoothing method used in this work applies the same window size, minimum history, and switch threshold to every tracked oyster, regardless of how clearly or consistently that oyster is visible. An oyster that is consistently well lit and unobstructed may not need aggressive smoothing, while a partially occluded or intermittently detected oyster may benefit from a longer history or a different switch threshold. Developing a per-oyster adaptive smoothing method that adjusts its parameters based on an oyster's detection consistency is a natural extension of this work, along with appearance-based tracking methods such as Deep SORT (Wojke et al., 2017), which could reduce identity switches during fast camera movement without requiring server-side processing.

CONCLUSION

This work tested whether adding lightweight cross-frame identity tracking and confidence-weighted temporal state smoothing could improve the stability of oyster counts and Open/Closed state classification over frame-only detection. Using an IOU/distance tracker and a smoothing method that weighs an oyster's recent detection history by confidence, we found consistent, if modest, improvements in both counting accuracy and state-classification accuracy across 18 test videos, along with qualitative evidence that IOU-based matching reduces identity switches compared with distance-only tracking. These results provide preliminary evidence that video context can meaningfully, if incrementally, improve automated oyster monitoring.

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Are Hostile Traits Associated with Health Behaviors in Emerging Adults?

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ABSTRACT

The goal of this research project was to understand if hostile traits are a predictor of positive vs negative health outcomes in emerging adults. Specifically, the study examined the role of hostility, anger, physical aggression, and verbal aggression on physical, social, and mental health outcomes in emerging adults (ages 18-29). Participants (n=180) completed a survey on the online platform Prolific measuring hostile traits, health behaviors, and emerging adulthood characteristics. Analysis indicated that hostility is a significant predictor of decreased health behaviors (social connection, physical activity, nutrition) in Emerging Adults.

Emerging adulthood is a distinct developmental period experienced from ages 18-29 (Arnett, 2000). This is the time between adolescence and young adulthood, where individuals are often making important life-choices, gaining tertiary education, joining the workforce, and forming relationships (Arnett, 2000). Emerging adulthood is defined by identity explorations, instability/negativity, self-focus, feeling in-between, a sense of possibilities, and other focus (being focused on collectivist values such as family responsibilities) (Arnett, 2000; Mitra & Arnett, 2025). These characteristics set Emerging adulthood apart from adolescence and young adulthood, making this a distinct time where individuals are transitioning into adult life (Arnett, 2000). Emerging adulthood is the first time in adult life where people are making independent decisions and exploring their identities, often leading to higher risk-taking behaviors and less stability (Arnett, 2000). Lifestyle choices during emerging adulthood may contribute to health disparities both during emerging adulthood as well as later in life, making it important to understand the health choices made during this time (Siegler et al., 2003; Daw et al., 2017). Understanding how hostile traits may contribute to certain lifestyle factors can give a better indication of the association between hostility and health. Emerging adulthood is a crucial developmental stage, and the decisions made throughout this period may influence health and security later in life.

Many factors can influence the decisions made during emerging adulthood, and the experience of this time in life can differ for people all over the world. The six pillars of emerging adulthood (identity exploration, instability/negativity, self-focus, feeling in-between, a sense of possibilities, and other focus) are often universal in individualistic and western countries, including the United States (Arnett, 2010; Arnett, 2000). Emerging adulthood is experienced in a sociocultural context, meaning this developmental period can vary because of a difference in culture, personality, and the society in which we live (Arnett, 2010; Mitra & Arnett, 2025).

Since the experience of emerging adulthood can differ, it is important to look at the factors that can lead to differences in experience. Socioeconomic factors such as culture, family structure, home environment, income, and geographic location are some examples of ways that an emerging adulthood experience can differ, with quality of childhood and relationship with parents also being an important factor in emerging adult mental health (Maly et al., 2023; Daw et al., 2017). Differences in experience can lead some emerging adults to flourish while others struggle, and it was found that emerging adults who flourish tend to avoid risk-taking behaviors (Nelson et al., 2013). Risk behaviors have been linked to decreased health in emerging adults, and this form of negative decision making has been found to increase with hostility (Siegler et al., 2003). Hostility has been found to be associated with low socioeconomic status and psychosocial risk, meaning that individuals with poor economic resources with low social support are more at risk to experience hostility (Appelberg et al., 1991; Elovainio et al., 2001; Smith & Frohm, 1985). It is crucial to consider the time period of emerging adulthood when conducting research on hostile attitudes and health, and previous research has found that higher levels of hostility during college age were associated with increased likelihood of negative health indicators during midlife such as smoking, drinking more than recommended, perceptions of inadequate social support, evaluations of achievements as worse than expected, and higher levels of depressive symptoms (Siegler et al., 2003).

Hostility can be defined with animosity toward others, mistrust, and cynicism, with the belief that others wish to cause harm (Asberg, 2013; Ermakov et al., 2016). Feelings of hostility can be created from one's cognitive perception of being treated wrongly, which differs from anger, verbal aggression, and physical aggression (Ingram et al., 2007). Hostility is a conscious perception, while anger often reflects a non-conscious physiological response, and aggression as a behavioral desire to harm; showing that different responses are elicited for hostility, anger, and aggression (Eckhardt et al., 2002; Ingram et al., 2007; Tsikandilakis et al., 2020;). Though the experience of these feelings may differ, hostility, anger, and aggression are closely related, and can exist together (Ingram et al., 2007). The combination of these characteristics is referred to as hostile attitudes because of how they can coincide together (Asberg, 2013). Although these attitudes can exist together, it is not necessary for someone to display all the hostile attitudes (Ingram et al., 2007). The current study assesses these characteristics separately from one another, defining each independently to see the full picture of how these characteristics may contribute to the lifestyle and health of emerging adults in the United States. The question of how these attitudes may lead to behaviors and life choices is crucial to understanding human health throughout the lifespan, and how the time of emerging adulthood plays a role in this.

Components of hostile attitudes (e.g., social isolation and aggression) can be associated with a variety of mental disorders. (Asperg, 2013). For example, individuals who are at high-risk for depression have been found to have higher levels of hostility and anger (Ingram et al., 2007; Mao et al., 2003). A study on emotional regulation in college students and the associated mental health effects found that hostility and

anger are mediators in the relationship between emotional regulation and depression symptoms, indicating the role that these attitudes can play in college student mental health (Asperg, 2013). Along with the increase in negative emotion experienced by hostile individuals, there may be an increase in unhealthy coping mechanisms that are detrimental to health (Asperg, 2013; Siegler et al., 2003). Furthermore, a longitudinal study that measured cognitive functioning in hostile individuals 25 years apart (25 years old and again at 50 years old) found that hostility was associated with less cognitive functioning at 50 years old (Albanese et al., 2016). Overall, greater amounts of hostility have been found to be associated with health risk factors throughout the lifespan, but more research needed to be done on hostility during the period of emerging adulthood with a diverse sample of participants (Iribarren et al., 2005; Jackson et al., 2007; Leiker et al., 1988; Miller et al., 1996; Siegler et al., 2003; Versey et al., 2012).

In the current research study, hostile traits were considered to determine how personality may influence the health and lifestyle decisions made during emerging adulthood. Specifically, this study measured how hostile attitudes can play a role in the important decisions made during emerging adulthood, potentially resulting in health outcomes that can influence the present and the future. Personality plays a role in overall decision making, meaning that certain personality characteristics may be associated with health behaviors (Cheng et al., 2015). Specifically, I explored whether hostility, anger, verbal aggression, and physical aggression are associated with lifestyle choices during emerging adulthood. This study looks at hostility, anger, and aggression separately, while also prioritizing a diverse sample of emerging adults throughout the United States. It is hypothesized that having more hostile attitudes (hostility, anger, verbal aggression, physical aggression) will be associated with greater amounts of negative health behaviors in emerging adulthood.

METHODS

After an extensive literature review, a survey was created on Qualtrics using validated measures to assess hostile attitudes, health behaviors, and the emerging adulthood characteristics. The scales used in the survey include The Aggression Questionnaire--Short Form (Buss & Perry, 2001), the Shortened Version of the Emerging Adulthood Inventory (Mitra & Arnett, 2025), and the Lifestyle Medicine Health Behavior Scale (Pangalangan et al., 2024). The Aggression Questionnaire--Short Form (Buss & Perry, 2001) is a 12-item abbreviated version of the original 29 item Buss-Perry Scale, that measures each of the four subscales of hostile attitudes (hostility, anger, verbal aggression, physical aggression) on a 5-point Likert scale, ranging from 1 (extremely uncharacteristic of me) to 5 (extremely characteristic of me). The Shortened Version of the Emerging Adulthood Inventory (Mitra & Arnett, 2025) is a shortened version of The IDEA: Inventory of the Dimensions of Emerging Adulthood which measures the emerging adulthood characteristics (Identity Explorations, Negativity/Instability, Self-focus, Other-Focus, and Experimentation/Possibilities) on a 4-point Likert scale, ranging from 1 (strongly disagree) to 4 (strongly agree). Finally, the Lifestyle Medicine Health Behavior Scale (Pangalangan et al., 2024) is a 23-item self-report tool measuring the six health behaviors (sleep, nutrition, physical activity, stress, substance abuse, and social connection) on a 5-point Likert scale ranging from 0 (never) to 4 (always).

Salisbury University IRB approval was gained (IRB #520), and the Fulton Grant was applied for to fund the data collection and pay participants. With the Fulton Grant, I was able to collect data using the online platform Prolific, which created an anonymous sample (n=180) that is well representative of the population of emerging adults (18-29) in the United States. Participants were equally split by age with half being 18-23 and half being 23-29. This ensured an even age distribution that accounts for all ages in the emerging adulthood timeframe. Prolific is a reliable platform used for research studies by ensuring anonymity to gather high quality data. Each participant received $2 for their participation in my survey, with the survey being expected to take an average of 15 minutes. After the first data collection period was over, I spent spring 2026 analyzing the data and presenting the findings at the National Conference on Undergraduate Research (NCUR) and the Salisbury University Student Research Conference (SUSRC).

RESULTS

Reliability analyses were conducted on all scales and Cronbach's alpha indicated that each of the scales yielded reliable results. A Pearson correlation as well as several multivariate multiple linear regression analyses were conducted. Results from the Pearson correlation analysis indicated that there is a significant correlation between hostility, anger, verbal aggression and physical aggression ($p < .001$ for all variables). Since the measures (hostile traits, health, and emerging adulthood) were on different scales, a z-score conversion was conducted. This conversion made it so all measures were on a similar scale, and the analyses were comparable. The analyses were conducted using the z-scores, rather than the raw score values.

The first multivariate multiple linear regression was conducted by entering the four hostility traits (hostility, anger, verbal aggression, and physical aggression) as predictor variables and the six health measures (sleep, social connection, stress, physical activity, nutrition, and substance use) as dependent variables. Results from the multivariate multiple linear regression analysis indicated that only hostility was a significant predictor of health behaviors, $F(6,171) = 8.437$, $p < .001$. Anger, verbal aggression, and physical aggression were not significant predictors of the health.

When it comes to the health behaviors, the variables significantly predicted by hostility were social connection, stress, physical activity, and nutrition. Social connection was significantly predicted by hostility ($\beta = -.483$, $p < .001$), indicating that increasing hostility is associated with a decrease in social connection (R^2 adj=.206). Stress was significantly predicted by hostility ($\beta = -.527$, $p < .001$), indicating that increasing hostility is associated with a decrease in feelings of stress (R^2adj=.260). Physical activity was significantly predicted by hostility ($\beta = -.224$, $p = 0.019$), indicating that increasing hostility is associated a decrease in physical activity (R^2 adj=.015). Finally, nutrition was significantly predicted by hostility ($\beta = -.202$, $p = .034$), indicating that increasing hostility is associated with a decrease in nutrition (R^2 adj=.023).

The second multivariate multiple linear regression was conducted by entering the four hostility traits (hostility, anger, verbal aggression, and physical aggression) as predictor variables and the six emerging adulthood characteristics (identity explorations, negativity/instability, feeling in-between, sense of possibilities, self-focus, and other focus) as dependent variables. Results from the multivariate multiple linear regression analysis indicated that only hostility was a significant predictor of the emerging adulthood characteristics $F(6,171) = 5.092$, $p < .001$. Anger, verbal aggression, and physical aggression were not significant predictors of the emerging adulthood variables.

For the emerging adulthood subscales, the variables significantly predicted by hostility were experimentation/possibilities, negativity/instability, and self-focus. Experimentation/possibilities was significantly predicted by hostility ($\beta = -.166$, $p = .006$), indicating that increasing hostility is associated with a decrease

in experimentation (R^2 adj=.029). Negativity/Instability was significantly predicted by hostility ($\beta = .221$, $p = .003$), indicating that increasing hostility is associated with an increase in negativity/instability (R^2 adj=.096). Self-Focus was significantly predicted by hostility ($\beta = -.168$, $p = .001$) indicating that an increase in hostility is associated with a decrease in self-focus (R^2 adj=.062). Findings also indicated that there was a difference based on age with 18–23-year-olds experiencing more negative health behaviors than 23–29-year-olds.

DISCUSSION

Although hostile attitudes consist of hostile traits including hostility, anger, verbal aggression, and physical aggression (Buss & Perry, 2001; Asberg, 2013), only hostility was found to predict greater amounts of negative health behaviors. The finding that increased hostility is associated with decreased social connection is consistent with previous research on older adults that found an association between hostility and loneliness (Segal-Karpa & Ayalon, 2020). Individuals with hostile attitudes tend to believe that people are out to get them, and these results indicate that hostility may lead emerging adults to distance themselves from social connections. Loneliness is known to be associated with worse health outcomes throughout the lifespan, making it important to understand predictors of social connection in emerging adulthood (Mann et al., 2022). The result that higher hostility is associated with decreased stress is not consistent with previous research findings, which indicate that stress usually increases alongside hostility (Heponiemi et al., 2007; Murdock et al., 2017; Taylor et al., 2012). This could have occurred due to a type 1 error due to sample size. The finding that increased hostility is associated with decreased physical activity and nutrition are consistent with previous research which found that lifestyle factors such as physical activity and nutrition may be mediators in the relationship between hostility and coronary artery disease (Jackson et al., 2007; Vella & Friedman et al., 2009). Furthermore, higher levels of hostility are known to be associated with more negative health behaviors as a form of emotional coping, which is a contributing factor in the relationship between hostility and physical health later in life (Daw et al., 2017).

Since there is limited research on hostility in emerging adulthood, no a-priori hypotheses were stated. Results indicated that experimentation/possibilities, negativity/instability, and self-focus were predicted by hostility. Based on the definition of hostility, it makes sense that hostile emerging adults will experience less experimentation and more negativity because of the belief that others are out to get you (Asberg, 2013; Ermakov et al., 2016). These characteristics are a part of the defining traits of emerging adulthood, indicating that hostile individuals may experience a different emerging adulthood than non-hostile individuals. Findings also indicated that there was a difference based on age with 18-23-year-olds experiencing more negative health behaviors than 23-29-year-olds.

No a-priori hypotheses were stated when predicting the outcome of each hostile trait (hostility, anger, verbal aggression, physical aggression), meaning it was not known if the hostile traits would all yield significant results. Hostility was found to be the sole predictor of health behaviors and characteristics of emerging adulthood, with no significant results from the traits anger, verbal aggression, and physical aggression. This indicates a difference between hostility, anger, verbal aggression, and physical aggression, and stresses the importance of measuring hostile traits separately from each other. This aligns with previous research that looks at hostility, anger, and aggression as separate variables, even though the three can be closely related (Asberg, 2013; Ermakov et al., 2016; Ingram et al., 2007).

CONCLUSION

Overall, results were significant and consistent with hypothesis, but more research is needed to confirm the results of this study. Next steps include collecting more data with a larger sample size that is even more representative of the population of emerging adults (n=600). It is hypothesized that results will remain consistent, apart from the finding that stress decreases with increasing hostility. Limitations of this study include the size of the sample, and the self-report nature of survey data.

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