
JOURNAL OF STUDENT RESEARCH
THE NKU
nysa
Vol. 5 2023

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Volume 5, 2022-2023



## About The Covers

The front cover was designed by Emily Hilbrecht, a junior musical theater major. Regarding her design, Emily writes, "Northern Kentucky University means different things to so many different people. For some, it is where they followed the footsteps of generations before them, and others, where they created those footsteps. For some, it is where they studied lab work, and others, where they studied play scripts. In this cover page for the Nýsa, Journal of Student Research, I wanted to highlight what it means to be a Norse, and the successes of their students. NKU is a university that not only helps every student succeed in school but gives them the knowledge and tools necessary to carry that success throughout their life."

The back cover was designed by Camilo Idrobo Iturralde. About his design, Camilo writes,"I am an international student from the beautiful country of Ecuador. I've been passionate about the arts since a very young age, after my family gifted me a video camera and I couldn't put it down. In high school I practiced photography for which I won awards, and clay sculpture. Now, I'm achieving my lifelong dream by studying filmmaking in the EMB program and making my imagination reality through my productions. For the design, I wanted to prioritize the title with a striking font, yet complement it with an appealing graphic that didn't take away too much from it. I looked for something publicly available that would represent research in its most essential but significant characteristics. Represented is a cancer cell, which I put through a color halftone filter and then restricted its colors to NKU yellow and black. The final design is a simple, asymmetrically enticing cover."

# NÝSA, THE NKU JOURNAL OF STUDENT RESEARCH

Nýsa publishes research from students at NKU and across the commonwealth. It is published by NKU's Institute for Student Research and Creative Activity. All submissions are peer-reviewed by an NKU faculty member and an NKU student.

## About The Title

Names are tricky things. Journals of student research are relatively common, and in looking for a name, it was important to find something evocative of the intellectual effort and exhilaration that accompany any research endeavor. If it could relate to our identity as The Norse, all the better. "Nýsa" worked perfectly. In the words of David Kime, Advising Coordinator for NKU's Honors College, who suggested it:

"The Viking raids were only one aspect of Norse society. The Norse were shipbuilders, farmers, philosophers, poets, artists, and merchants. The Norse were explorers who engineered new shipbuilding technology and navigation techniques. They sought new knowledge in the stars and from distant lands and cultures. In Old Norse, "nýsa" is a verb meaning to search or investigate; to peer into the unknown. The idea of "nýsa" applies to today's NKU students as much as it did to the Norse a thousand years ago as they peer into the unknown and produce new and exciting examples of research, scholarship, and creativity."

## From The Editor

Campus has largely returned to a normal bustle of classes, activities, work, and fun, and while the university is facing some financial headwinds, the scholarship of our students continues unabated. Our authors and their faculty mentors deserve admiration for their efforts, and we're thrilled to showcase their work here, but we also want to thank the student and faculty reviewers who took time out of their very busy lives to offer constructive, detailed, and supportive feedback. We wouldn't be able to function without them. Similarly, I want to thank, as always, our dedicated editorial board, copyeditor, and intern for their hard work. It's a mark of their dedication that we are able to present to you, our readers, this fifth volume of Nýsa.

Patrick M. Hare

# Experiences of College Students with Physical Disabilities

***Rachel C. Petri***
***Faculty mentor: Rachael Clark***
***Psychological Sciences***

**KEYWORDS:**
physical disability, student retention, freshman orientation, accessibility

## Rachel C. Petri

Rachel Petri graduated summa cum laude from Northern Kentucky University in May of 2022. She obtained a Bachelor of Arts degree in psychology and a minor in creative writing. This research was conducted under the guidance of Dr. Rachael Clark and was presented at NKU's Celebration of Student Research and Creativity in April of 2022, and earned the Steely Library Research Award. Since graduation, Rachel has been attending Union Institute and University's graduate program for clinical mental health counseling.

## Abstract

Social connection, academic support, and accessibility are documented needs of college students with physical disabilities. Past research lacks specific implementation recommendations and devalues individual stories, ignoring informative data. This project integrated literature and website reviews, interviews, and personal experience to gain an understanding of the perspectives of these students and investigated Northern Kentucky University's current understanding of and response to their needs. Emerging themes included involuntary self-disclosure and misunderstandings of disability. The project conclusions involved practical changes at NKU, including additional disability training in target areas, and possibilities for moving forward at NKU and in research on the topic.

## Experiences of College Students with Physical Disabilities

Academic research in the area of physical disabilities is growing. Yet, there are still recognized omissions in both research and application. Physical disabilities include any physical or medical condition that significantly impacts daily life. These include, but are not limited to, conditions such as visual or hearing impairments, mobility restrictions, and seizure disorders. In this research, physical disabilities are defined as those that primarily impact the body, and cognitive disabilities are those that primarily impact the mind. Although research does not distinguish between these two categories of disability, the purpose of this paper is to focus primarily on physical disabilities. People with physical disabilities face a variety of challenges and obstacles to everyday activities, independence, and educational and career achievement (Aamlid & Brownfield, 2019; Gaskin et al., 2021; Jensen et al., 2014; Kotera et al., 2021; Lippold & Burns, 2009; Salt & Jahoda, 2020). College students impacted by physical disability are limited in multiple ways. They are forced to consider physical accessibility over other factors like academics and finances when choosing a university, and often express significant loneliness (Jensen et al., 2014; Kotera et al., 2021; Wessel et al.. 2015 as cited in Aamlid & Brownfield, 2019). While some of these barriers are known through research, an in-depth study of the experiences of college students with physical disabilities is noticeably absent from the literature.

Partially due to the able-bodied voices dominating the current academic discussion, research consistently overidealizes current accommodations, assuming effectiveness without sufficient investigation (Aamlid & Brownfield, 2019). Case studies in which authors listen to an individual's representations of these issues are able to uncover the failing of current accommodations, but much of the mainstream research neglects these issues (Aamlid & Brownfield, 2019). When this is the case, universities and colleges may believe they are prepared for—and in fact be unaware of—the challenges that are faced by students on their campus. The presence of a disability-related office does not ensure that all students will have equal access and adequate accommodations. Each individual's needs vary significantly, so it is vital to include case studies, qualitative research, and individual perspectives in this type of research.

Much of the research on students with physical disabilities focuses on able-bodied peers' perception of those with disabilities, and other researchers overemphasize quantitative data, focusing on diagnosis details and utilization of specific resources among a population (Aamlid & Brownfield, 2019; Jensen et al., 2014). While these data are valuable, there is a significant lack of individual stories and perspectives. It is impossible to obtain a complete sense of one person's experience through descriptive statistics. College students with physical disabilities have their own views about what obstacles are most challenging or significant, and their own ways of processing and articulating these barriers. Additionally, there is a startling lack of disabled representation among these researchers, though some take measures to ensure that non-disabled researchers are appropriately understanding results (Aamlid & Brownfield, 2019). A shared perspective seems likely to add more insight and representation to research projects on this topic.

Additionally, many colleges are unprepared for students with physical disabilities (Aamlid & Brownfield, 2019; Kotera et al., 2021). As a student at Northern Kentucky University (NKU), I was interested in assessing the current preparedness of this university and ways to move forward. These aims were primarily accomplished through a combination of personal interviews and website reviews.

## Methods

### Participants

The interview portion of this research involved four participants. Another potential participant was contacted, but was not

**Table 1. Table of participant data**.

| Interview Number | Interview Format | Gender | Disability/ies | NKU Student | Graduated | Other Notes |
|---|---|---|---|---|---|---|
| 1 | Phone | Female | Paraplegic | Yes | Yes | |
| 2 | Phone | Male | Blindess | No | Yes | Currently working in higher education as a professor; interview format chosen based on accessibility (easier to communicate verbally than to read and respond to emails) |
| 3 | In Person | Female | Ehlers-Danlos syndrome; arthritis; auditory processing disorder; memory disorder | Yes | No | |
| 4 | In Person | Male | Traumatic brain injury (wheelchair and speech device) | No | Yes | Interview format chosen based on accessibility (difficulty in using speech device over the phone) |

interviewed due to time constraints and schedule conflicts. Two of the remaining participants were male, and two were female. Two attended NKU, and two attended other colleges in the Northern Kentucky area. A wide range of disabilities were represented. At least one participant's disabilities included some cognitive components, but all participants had at least one significant physical disability. All participants had either completed their degree, or were on track to graduate. One participant had a personal relationship with me, and the others were contacted through social media or snowball sampling. Participant and interview details are listed in Table 1.

### Materials

The qualitative interviews were semi-structured and conducted either in person at an agreed-upon location, or by phone. In two cases, the interview format was chosen based on accessibility needs. For the remaining interviews, the format was agreed upon between myself and the participant based on feasibility and convenience. For structured questions, see Appendix A.

Additional questions were used to obtain further information, clarification, or examples. I intentionally investigated the individual's personal narrative during the interview process, seeking further explanation for situations or concepts that were mentioned multiple times. Supplemental questions were often designed to uncover the relationship between disability and other aspects of the interviewee's life, and the issues that were of most importance to the participant.

### Procedure

A brief literature review was conducted using resources from NKU's Steely Library, APA Psychinfo® (https://www.apa.org/pubs/databases/psycinfo) and other databases, and the support of a research librarian on staff at NKU. My personal experience with disability informed the interpretation of these articles. As I read each paper, I journaled and took notes, highlighting significant results, research questions, and connections or applications in my own experience. I searched for common themes, and evaluated both qualitative and quantitative data.

Once themes and omissions in the current research had been assessed, I investigated NKU's preparedness and resources. I conducted a website review, involving pages directly related to disability and accessibility as well as pages likely to be visited by first-time freshmen (Northern Kentucky University 2022 March -a, Northern Kentucky University 2022 March -b, Northern Kentucky University 2022 March -c). This assessment also involved meetings and interviews with offices relevant to this research. I met virtually with a representative of NKU's Office for Student Accessibility to obtain information about what support is currently offered, what barriers exist to offering further support, and the prevalence and nature of disability on campus. I also met virtually with the staff member responsible for orientation, tours, and training for those volunteers to see what support measures are already in place and to assess staff willingness to pursue improvements.

Focusing on qualitative data, I then conducted four semi-structured interviews. Detailed notes were taken, and limited self-disclosure was used to build quick rapport, encourage elaboration on certain ideas, and identify common themes. When necessary, accommodations were made for the interviewee's disability, such as modifying pacing and streamlining questions for a speech device user (Interview 4) or repeating and rephrasing questions to accommodate the memory disorder (Interview 3).

#### Data Analysis

Data from all sources were combined and integrated. Details from the personal experiences and interviews informed understanding of NKU's accommodations, and NKU's system highlighted the specific barriers faced by students. Themes were identified from the data. In response to the themes, offices and key individuals at NKU were contacted both by email and through discussions at the Celebration of Research and Creativity to begin improvements and arrange next steps.

## Results

The results from the website review and interviews with offices on NKU's campus emphasized identification of current resources and barriers for students with disabilities at NKU. My personal experience with visual impairment highlighted issues with the orientation events for incoming freshmen. The environment was overstimulating due to noise and requiring every student to wear the same shirt, and volunteers were unprepared to provide assistance. The majority of the group programming was inaccessible, as my orientation group took stairs multiple times and did not sit in the front rows for presentations, despite my white cane indicating obvious visual impairment. The website review added to these concerns. The Frequently Asked Questions page on NKU's website for orientation included a number to call in case of disability issues, but it was not made obvious in any other area of the orientation information (Figure 1; Northern Kentucky University 2022 March -c). When registering for tours of campus and similar events, there was not a section in which to describe accommodation needs (Figures 2 and 3; Northern Kentucky University 2022 March -d).

Interviews with representatives from the offices of student accessibility and first year programs shed light on other aspects of accessibility on campus. Since 2019, when I went through orientation, there have been minor improvements. There is now an opportunity to disclose disability when registering for orientation (not tours of campus), but it was combined with a question about dietary needs and did not invite elaboration. Minor training for the volunteers had been added since 2019, but it was led by a staff member from the Office for Student Accessibility, not someone with personal experience. In an interview, a staff member from the Office for Student Accessibility described the office's routine function. Incoming freshman or new transfer students meet with a representative to outline required accommodations and prepare an accommodations letter. It is the student's responsibility to request a copy of that letter each semester and send it to their professors. If students return to the office with additional issues, these are addressed. However, the staff member did not mention actively seeking to support students outside of the accommodations letter.

**WHAT IF I NEED SPECIAL ACCOMMODATIONS?**

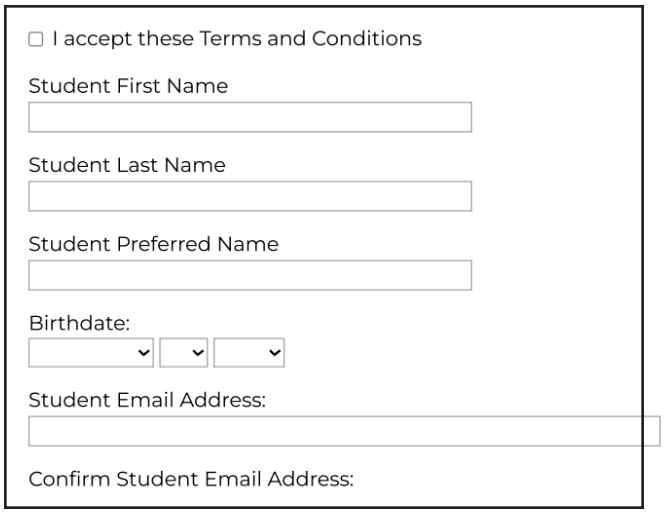
If you or your guest(s) have a disability or circumstances that require special accommodations during Northern Exposure, please call our office at (859) 572-5220 or include information regarding your accomodation during the time of online registration.

In addition, students with disabilities who require accommodations at Northern Kentucky University must register with the Disability Services Office. Disability Services (https://inside.nku.edu/studentaffairs/departments/osa.html) can be contacted at (859) 572-6373.

Figure 1. A screenshot from NKU's orientation Frequently Asked Questions page taken at the beginning of the research project, highlighting the limited information about accommodations (Northern Kentucky University 2022 March -c).

When I spoke of potential programs or events that could be designed for students with physical disabilities, the representative explained barriers they have faced in the past. Activities planned for students with physical disabilities were poorly attended.

Both the staff from the Office for Student Accessibility and the orientation staff shared independently about the shame or nervousness that can be experienced by these students in speaking about their disability or attending events intended specifically for disabled students. Events that were held in conjunction with other offices were often better attended, but the few events specific to students with disabilities were not effective.



☐ I accept these Terms and Conditions

Student First Name

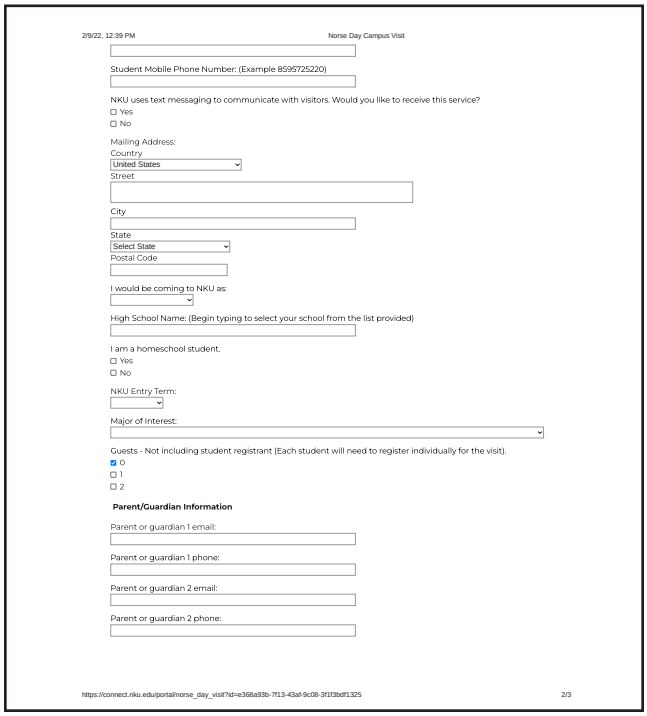
Student Last Name

Student Preferred Name

Birthdate:

Student Email Address:

Confirm Student Email Address:



2/9/22, 12:39 PM Norse Day Campus Visit

Student Mobile Phone Number: (Example 8595725220)

NKU uses text messaging to communicate with visitors. Would you like to receive this service?
☐ Yes
☐ No

Mailing Address:
Country
United States
Street
City
State
Select State
Postal Code

I would be coming to NKU as:

High School Name: (Begin typing to select your school from the list provided)

I am a homeschool student.
☐ Yes
☐ No

NKU Entry Term:

Major of Interest:

Guests - Not including student registrant (Each student will need to register individually for the visit).
☑ 0
☐ 1
☐ 2

**Parent/Guardian Information**

Parent or guardian 1 email:

Parent or guardian 1 phone:

Parent or guardian 2 email:

Parent or guardian 2 phone:

https://connect.nku.edu/portal/norse_day_visit?id=e368a93b-7f13-43af-9c08-3f1f3bdf1325 2/3

Figures 2 and 3. Screenshots of NKU's registration page for tours of campus, which were taken at the beginning of the research project and highlight the absence of any opportunity to disclose disability status or request accommodations (Northern Kentucky University 2022 March -d).

Since COVID, the office has largely stopped trying to plan events in favor of focusing on accommodation letters. In addition to this information, the interview with the Office for Student Accessibility led to obtaining data about the types and prevalence of disabilities at NKU, presented in Figures 4 and 5.

Notes were taken during interviews with current and past students. Each individual's story with disability, academics, and other aspects of life was considered when interpreting relevant statements and data. The identified themes listed below were highlighted by each interviewee independently. At least three of four interviewees mentioned each theme, but more often they were emphasized by all four participants. Each theme also resonated with my own experience. Themes, as well as permission to share results, examples, and limited participant data, were verified with the interviewees when appropriate. A large proportion of examples included in this paper were taken from Interview 3, both because of the participant's eagerness to have experiences shared, and because this was the only participant currently attending NKU at the time of the research.

Identified themes are as follows: Reactive nature of accommodations (not taking action until specific action is requested), failure of physical accommodations (when the agreed-upon accommodations are not provided or are not adequate), misunderstanding of disability from peers, involuntary or insufficient self-disclosure, social and emotional impact of disability, and stigma associated with physical disability. Further analysis on each theme, including examples and implications, is provided in the discussion section.

## Discussion

### Themes

Each of the emerging themes from the data has significant implications for understanding college students with physical disabilities. The reactive nature of accommodations is especially prevalent at NKU, but interviewees indicated that it is a present issue at other universities as well. Prior to the spring of 2022, NKU did not have tactile plates (a tool used by blind and visually impaired people to safely navigate the curb and street) in the roundabout outside the library. They were installed because blind students on campus expressed the need. While this sort of reactive assistance is vital and productive, it places the burden of accommodation solely on the students with disabilities. Aside from the accommodation letters, the majority of the supports that are in place are because students have directly requested them. Any other programs, accessibility features, or support that may be helpful is not likely to be implemented until students specifically express a need or desire for them.

Another theme that was constant across interviews and resonated with my personal experience was the failure of physical accommodations. While accessibility features are often in place and accommodation letters outline the support that is required, this is not always sufficient. For example, elevators are present on NKU's campus, but one interviewee shared that a malfunctioning elevator required her to take the stairs for nearly an entire semester. Because of this, she experienced heightened joint pain, tardiness, and embarrassment (Interview 3). In my own experience, depending on classroom layout, being assured front row seating may not equate to the ability to see the whiteboard or presentation screen. While my accommodation letter states that I require auditory explanation of all visual materials, instructors often forget or neglect that aspect of the letter. The presence of accommodations does not ensure their success.

Another major factor for most interviewees was the misunderstanding of disability from peers. Students not impacted by disability frequently have little knowledge of the terms and limitations associated with handicaps. This was reported to result in uncomfortable social interactions, increased loneliness, and decreased attempts to connect with peers outside of classes (Interviews 1 and 3).

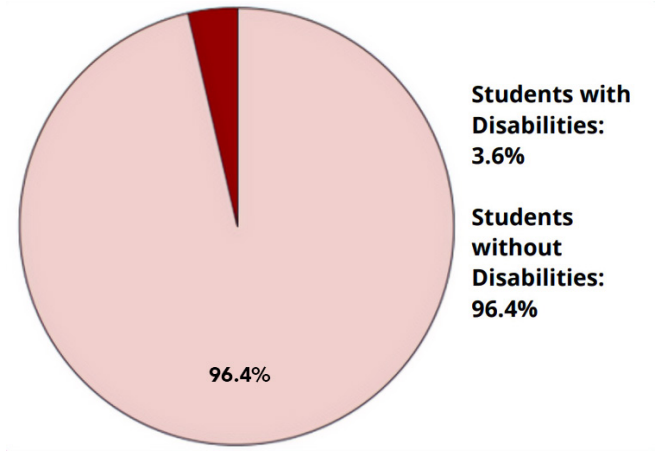



Figure 4. Data on NKU's student population in regards to disability in 2021-2022. The total enrollment number was obtained from a phone call to to the general inquiries line, and the number of students with disabilities was obtained from an interview with the Office for Student Accessibility.

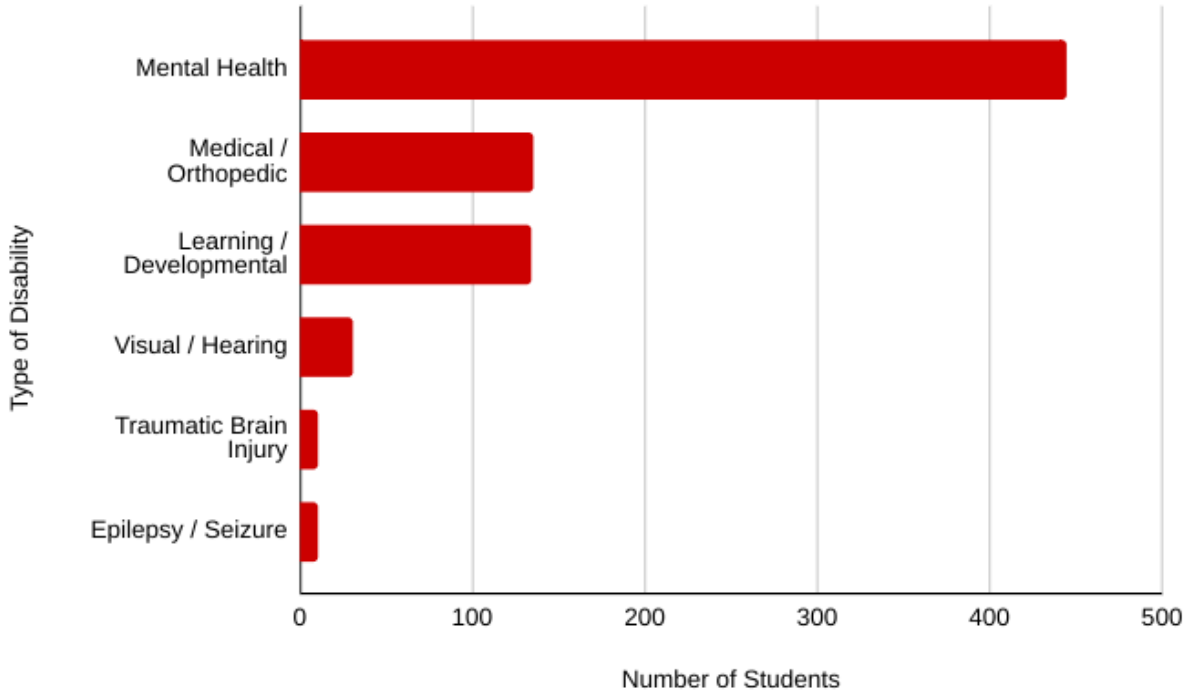



Figure 5. Data on types of disabilities and their prevalence in NKU's student population in 2021-2022, collected from interviews with the Office for Student Accessibility and follow-up emails. Some categories were combined for clarity.

In my experience, other students often do not consider the requirements of a visual impairment in relation to social events. A visual impairment makes it difficult to recognize familiar classmates by faces. This can lead to uncomfortable interactions wherein peers are unable to understand my lack of confidence or personal conversation. Interviewees reported similar experiences in relation to other disabilities. When peers do not understand disability, it creates unnecessary and uncomfortable social barriers.

These social misunderstandings, and other situations, frequently lead to involuntary or insufficient self-disclosure. This was a theme that echoed across all interviews, and was initially surprising to me. Upon further reflection, it seems to be a common challenge for people with multiple types of disabilities. It is often required either by social environments or accommodation needs that students disclose specific disability information to both peers and professors. One NKU student explained that though her accommodations letter specifies what support she needs, it does not address the reasoning. Because of this discrepancy, she often finds herself needing to verbally explain her specific diagnosis and day-to-day impacts of her disability to professors to obtain proper understanding and further adjustment (Interview 3). Similarly, another NKU student reported that in every successful social connection they have sustained outside of class, they had to disclose their disability or diagnosis, and this is true in my case as well. When peers were not aware of disability information, it became difficult or impossible to sustain a meaningful relationship. In light of my own experience and interview data, it seems that students with disabilities rarely have the opportunity to keep their disability or diagnosis details private.

In light of these and other challenges, it is clear that disability does not happen in isolation. Every interviewee expressed social and emotional impacts of disability, and this resonated deeply with my personal experience as well. Disability creates social barriers due to misunderstandings, specific social limitations, and isolation. There are also significant emotional impacts of disability. When the malfunctioning elevator required an NKU student to take the stairs for an extended period of time, she experienced tardiness to regular classes, and related embarrassment. She also expressed discomfort with taking the elevator on a regular basis, and wondered what other students thought (Interview 3). Another interviewee described intense depression and suicidal ideation after a traumatic brain injury (Interview 4). Clearly, the impact of physical disability goes beyond physical limitations.

Finally, the stigma associated with disability was a recurring theme. One interviewee, who is diagnosed with both Ehlers-Danlos syndrome (a painful tissue disorder affecting movement) and a memory disorder, described differences between stigma in physical and cognitive disabilities. She expressed that peers accepted her memory disorder as a cognitive disability, lacking a way to prove or disprove its existence. However, she often faces stigma and skepticism over her physical limitations, which are invisible to the average peer despite common expectations related to the visibility of physical limitations (Interview 3). An interviewee with obvious physical limitations said that after his classmates had spent sufficient time with him to adjust to his disability, he made more successful social connections (Interview 4). I have also noticed differences in how strangers and classmates react when I have my white cane (an assistive mobility device) compared to the times I do not bring it. Visible disabilities seem to sometimes be more easily accepted than invisible ones, but regardless of type, all participants expressed some level of experience with stigma.

## Implementation at NKU

This project resulted in significant changes at NKU. Faculty and staff in multiple offices were receptive to change during the interview discussions, and my own experience and participants' contributions highlighted simple, practical implementations. Some of these changes were minor, specifically in relation to orientation. When registering for orientation and tours of campus, there is now a section related to disability. If students confirm during registration that a disability is present, there is an option to share "what [we] need to know about your disability" in preparation for the event. Additional changes included discussion of calling students with disabilities to review needs before events, and making a detailed schedule available to every student ahead of time.

The most significant change at NKU as a result of this research was in relation to the volunteers for orientation. Both my own experience and this research highlighted issues with orientation, many of which stemmed from the volunteers' lack of knowledge about disability. As a result of this project, I will be preparing and conducting a disability-specific training for these volunteers before orientation for the 2022-2023 school year. This training will be incorporated in to the existing schedules for three different groups: Orientation leaders, VictorFest volunteers, and volunteers who lead campus tours. At the time of this writing, the training has not yet occurred, but the focus will be on identifying signals that a student with disabilities in the group is struggling, simple ways to assist, and who to go to for help. The aim of the training will be to eliminate uncertainty and common misunderstandings, and enable volunteers to feel comfortable welcoming students with disabilities alongside others.[1] Another aspect of the training will involve a disability pairing activity, adapted with permission from Joni and Friends' Family Retreat training (www.joniandfriends.org) that will give volunteers firsthand experience with imitations of disability. In this activity, participants will divide into pairs. One member of the pair will be assigned a specific disability, and imitate these restrictions using provided materials. The other member of the pair will gain experience helping someone with a disability-related limitation. A pencil and notepad will be used to imitate a speech impairment, blindfolds will imitate blindness or visual impairment, earplugs will imitate deafness or hearing impairment, oven mitts will imitate mobility impairment in the hands, and wheelchairs will imitate more severe or systemic mobility impairment.

Another immediate benefit of this research is the open discussion that has resulted. The staff member discussing orientation shared difficulties in accessing the direct perspectives of those with disabilities due to privacy issues. According to the interview with the Office for Student Accessibility, there are few or no programs or events directed towards discussion of these issues on campus. As part of the research process, open conversations about disability were held with staff and faculty in positions to enact change. Further, this research was presented at NKU's Celebration of Student Research and Creativity. The event was open to the public but also well attended by students, faculty, and staff at NKU. By expounding upon the research project and conclusions, I was able to encourage open discussion of disability and engage able-bodied members of the community. While it is impossible to tell what further changes may occur on NKU's campus in the future, open discussion is a vital step for growth.

## Limitations

Despite the invaluable qualitative data and impact of this research on NKU, there are multiple acknowledged limitations of the research, primarily in scope. Very few interviews were conducted. I emphasized personal narratives and individual experiences, which came at a cost of ignoring larger data trends and quantitative tools. I also acknowledge a significant personal bias in this research due to my own disability, and the potential for confirmation bias to impact the results and their interpretation. This, combined with the lack of a permanent record of interviews or independent coders in interpreting the qualitative interview data, lends considerable weight to the question of validity. Therefore, it is difficult or impossible to

1 The orientation training was very successful. Students were engaged during the activity and asked questions. Some students showed an eagerness to move forward with inclusion on campus, offering their own ideas. Positive feedback from both students and staff strengthened this impression. *(Comments added after review.*

generalize the current findings. More research will be required to assess external validity and replication.

## Future Research

Broader interviews and some quantitative measures can be used to assess whether these results are replicable, and the external validity of the measures. While some interviewees had experience at other universities, broader research will be required to investigate the differences between universities. More specific research could be conducted to assess the effectiveness of programs and supports already in place at these institutions, including NKU. Further research is required to determine the validity of the current results and the effectiveness of the implemented orientation training.

Another significant concept brought up both by interviewees and by an attendee at the Celebration of Student Research and Creativity was the self-disclosure of disability and its impact on subsequent performance. It is well known in much of psychological literature that the disclosure of mitigating factors such as gender before a math test can impact performance negatively (Kahalon et al., 2018). This effect may be even more pronounced with those who are impacted by disability, as they are often forced to disclose pertinent disability information before attending college and prior to beginning each individual course. This is supported by limited interviewee information and my personal experience, but significantly more research will be required to understand the nature and scope of this effect for students with physical disabilities.

Another topic for further research involves the relationship between stigma and type of disability. Multiple interviews and my own experience highlighted this. However, the specific factors involved (cognitive/physical, invisible/visible, etc.) and exact effects on stigma and perception are unknown.

## Conclusion

While research in the area of disabilities is growing, there is still insufficient qualitative data to provide full understanding. This study aimed to better understand the experiences of college students with physical disabilities and the current status of NKU as a provider of support and accommodations. Through interviews, website reviews, and literature reviews, the research has contributed to a greater understanding of the barriers facing students with disabilities, and the multi-faceted nature of disabilities and accommodations. Some changes have already been implemented at NKU as a result of this research, but there is ample room for further growth and research.

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## Appendix A

Structured questions used in each interview

"Tell me about your disability. How does it impact your day-to-day life?"

"How does your disability impact your education?"

"What accommodations do you need?"

"Do you feel that your professors and instructors met your needs?"

"What barriers do you face in higher education?"

"Are there specific things that you feel your university does well or poorly in relation to your disability?"

"What do you think is important for others to understand about physical disabilities in college?"

# A Modern Respiratory Therapist Guide to the Health Complications of Cannabis Use

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KEYWORDS:
Takotsubo cardiomyopathy, cannabis health complications, cannabis disorders, respiratory

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## Abstract

Although cannabis law reform has swept our nation, respiratory therapists have been left in the dark about the health complications associated with its use. Most respiratory therapists have received little to no formal education on these complications. The intent of this literature review is to educate respiratory therapists on the unique physiologic manifestations of cannabis-related health complications. By gaining knowledge on this topic, respiratory therapists will be better prepared to diagnose and develop treatment strategies for patients presenting with issues related to cannabis use.

## Purpose

Reforms allowing for the personal (recreational) use of cannabis have swept our nation. This process began more than a decade ago, with the states of Colorado and Washington first legalizing recreational cannabis use in November of 2012 (Dills et al., 2021). As of November 2020, thirteen states have followed suit by allowing cannabis to be used by adults over the age of twenty-one: Alaska, Oregon, California, Nevada, Maine, Vermont, Massachusetts, Michigan, Illinois, New Jersey, South Dakota, Arizona, and Montana (Dills et al., 2021). Ultimately, the legalization of cannabis has catalyzed an increase in the number of cannabis users over the last decade, with exponential growth seen within the last five years and reaching levels not seen since the 1980s (Ann Arbor: Institute for Social Research, 2021).

There are numerous motives behind modern cannabis law reforms. One of the most commonly referenced is the relative safety of cannabis compared to other controlled substances (Lachenmeier & Rehm, 2015). However, the potential health risks due to its use have eluded not only the population at large, but the vast majority of the healthcare community, as well (Ghonaim, 2018). Unfortunately, the topic of cannabis and the endocannabinoid system have yet to be included in most modern healthcare education programs (Mann, 2021).

The lack of common understanding surrounding an accurate health risk assessment of cannabis use is inherently linked to the complex and varying chemical compounds found within modern cannabis (Atakan, 2012). In total, over 400 chemicals have been identified within cannabis and approximately 60 of these chemicals, known as cannabinoids, are exclusively unique to this substance (Dewey, 1986). Some cannabinoids such as delta-9-tetrahydrocannabinol (Δ-9-THC) and cannabidiol (CBD), have been shown to have opposing effects, further complicating our understanding of the chemical interactions within the body from cannabis use (Pamplona & Takahashi, 2011). It is also known that individual users can respond to the varying chemical mixtures within cannabis in drastically different ways, based on variations within their own endocannabinoid systems (Atakan, 2012).

Within this review, it was found that many of the known health risks of cannabis use are associated with the most frequent forms of consumption: Smoking and vaping (Boyd et al., 2021; Tashkin, 2013). The inherent pulmonary and cardiovascular complications from these consumption methods are well within the scope of practice of registered respiratory therapists.

## Introduction

Patients may initially deny using cannabis because of the associated social stigmas, professional implications, legal ramifications, and false perceptions about the substance being completely harmless (Compton et al., 2016; Marcoux et al., 2013). Some of the signs, symptoms, and health complications cannabis users present with are specific or unique to this substance. An example is those patients with cannabis hyperemesis syndrome, from which patients present with cyclic vomiting and nausea that is only relieved by hot showers (Blumentrath et al., 2017). This, in turn, makes identifying the causation (cannabis use) of their presenting conditions relatively straightforward, regardless of the patient openly admitting to using cannabis or not.

However, some of the other signs, symptoms and conditions associated with cannabis use, such as chronic bronchitis or frequent pneumonia infections, are not unique to cannabis. This can make identifying the cannabis-based causation more difficult to identify, especially when the patient has not admitted to cannabis use. Some of the more generic signs and symptoms could be incorrectly assumed as the result of numerous other common diseases and illnesses. This can potentially lead to an inaccurate diagnosis, a slowed treatment process and readmissions due to continued cannabis use. Ultimately, a healthcare team lacking a formal education in identifying health conditions due to cannabis use can waste precious critical care resources on diagnostic testing, ineffective interventions, treatments, and therapies.

Some of the most serious health complications from cannabis use can include life-threatening cardiopulmonary conditions such as myocardial infarctions and cerebral vascular accidents. The need for critical care staff—specifically respiratory therapists—to be able to identify the signs, symptoms and causes of cannabis-related health conditions is integral to effective healthcare in the modern environment. Furthermore, the ability to identify patients who are at a high risk for complications from cannabis consumption is paramount in the preventative education process surrounding cannabis use.

## Research Question

The aim of this literature review was to compile a list of the currently known health complications associated specifically with cannabis use (short-term or one-time use) and abuse (long-term, frequent use) from modern, peer-reviewed medical journals. Emphasis was placed on identifying individuals who may have elevated risk factors for complications due to cannabis use, the unique clinical presentations associated with cannabis-induced health conditions, and the pathophysiology of health conditions associated with cannabis use.

## Methods

For a health condition associated with cannabis consumption to be included in this review, it must (1) be documented in a peer-reviewed medical journal, (2) have a direct or temporal relationship to cannabis, and (3) cause a severe health complication, for which a patient may be admitted for critical care.

The search strategy to identify studies for this review was initially based on compiling a list of resources cited in presentations by the two most renowned medical doctors who specialize in the pathophysiology of cannabis-related health conditions: Donald P. Tashkin and Paul Oh (Oh, 2018; Tashkin, 2017). After creating a list of the research studies cited in their presentations, the original source articles were located via online search databases including, but not limited to, The United States National Library of Medicine (https://pubmed.ncbi.nlm.nih.gov), Google Scholar (https://scholar.google.com/), and Northern Kentucky University's W. Frank Steely Library (https://inside.nku.edu/library.html). These databases were also searched for additional research articles based on health conditions related to cannabis use. Search terms included cannabinoid hyperemesis syndrome, stress cardiomyopathy, takotsubo, cannabis and marijuana. All found articles were read in full, then screened and separated based on the above inclusion criteria. Articles that met the criteria were designated to be included in this literature review.

## Results

Fourteen articles met the qualifications for inclusion in this review. Surprisingly, in each of the qualified articles, health conditions associated either directly or indirectly with cardiopulmonary function were identified.

Stress cardiomyopathy was the most frequently cited condition. Eight of the included articles focused on stress cardiomyopathy and its temporal relationship to cannabis use (Alliu et al., 2017; Del Buono et al., 2017; Greene, 2021; Kaushik et al., 2011; Meera et al., 2020; Nogi et al., 2014; Sanchez et al., 2019; Singh et al., 2017). Five of the articles referenced alternative titles for this condition, including takotsubo cardiomyopathy (Nogi et al., 2014; Sanchez et al., 2019), transient apical ballooning syndrome (Alliu et al., 2017) and broken-heart syndrome (Del Buono et al., 2017; Greene, 2021).

Myocardial infarction was identified as a health risk of cannabis use in three articles (Chami & Kim, 2019; Del Buono et al., 2017; Mittleman et al., 2001).

Changes to pulmonary tissues and/or deficits to immune function of the pulmonary system were the central focus of three articles (Tashkin, 2013; Tashkin, 2018; Tashkin & Roth, 2019). All of these articles were authored by Donald Tashkin, the renowned pulmonologist and professor specializing in this field of study, and whose presentation was used as a launch pad for identifying research studies to be included in this literature review. Frequent respiratory infections were also listed as a major health concern for cannabis users in two of the articles included in this review (Kumar et al., 2018; Tashkin, 2018). Supporting data for the proposed etiology cited in Tashkin's 2018 research originated from two previous studies on cannabis which were not included in this review due to their age (Kagen et al., 1983; Ungerleider et al., 1982).

Lastly, a temporal relationship between cerebral vascular accidents and cannabis use was identified in two articles (Meera et al., 2020; Uhegwu et al., 2015).

## Discussion

### Stress Cardiomyopathy

Stress cardiomyopathy is a relatively rare form of non-ischemic cardiomyopathy that typically presents with symptoms similar to that of an acute myocardial infarction (Alliu et al., 2017). Other common names for this condition include takotsubo cardiomyopathy, transient apical ballooning syndrome, and broken-heart syndrome. These names are all based on the observed balloon shape of the left ventricle (e.g.,takotsubo being an oblong shaped octopus' trap) or the related stress factors thought to be responsible for this condition (e.g.,a broken heart from the stress of a lost loved one). Stress cardiomyopathy has traditionally been observed in middle-aged mothers (females) dealing with very difficult life circumstances, such as those seen in war or extreme poverty. In males, this condition is extremely rare. However, it has been found that males who use cannabis have a fivefold increased risk for stress cardiomyopathy and similar cardiac events (Sanchez et al., 2019).

Symptoms of stress cardiomyopathy frequently lead to the suspicion of a myocardial infarction (heart attack). Most myocardial infarctions are the result of a major blockage in one of the coronary arteries; yet in stress cardiomyopathy, the coronary arteries are not blocked (Meera et al., 2020). Although it has yet to be proven, excessive catecholamine release has been theorized as the main pathogenesis of stress cardiomyopathy (Alliu et al., 2017). A widely accepted theory is that cannabis use directly creates an abrupt increase in catecholamines. This increase has been observed to cause tachycardia and the elevation of both systolic and diastolic blood pressure, which could lead to cardiac conditions such as stress cardiomyopathy (Sanchez et al., 2019). However, there is a second and equally accepted theory for the increased incidence of cardiac events (such as stress cardiomyopathy) in cannabis users that points

to the endocannabinoid system and its interaction with the autonomic nervous system's regulation of cardiac function (Singh et al., 2017).

Research from Green (2021) showed a twofold increase in the odds of developing stress cardiomyopathy in nondependent (below addiction-level use) cannabis users with a 95% confidence interval. Surprisingly, this association had no significance in dependent (addiction-level) cannabis users (Greene, 2021). Another case of stress cardiomyopathy connected to cannabis use was documented in the state of Hawaii. A 32-year-old female medical marijuana patient presented with a relatively well-known cannabis-related condition called cannabis hyperemesis syndrome, which is characterized by nausea and vomiting that is only relieved by taking a hot shower (Nogi et al., 2014). However, her EKG showed "dynamic T-wave changes," which are not associated with cannabis hyperemesis syndrome (Nogi et al., 2014). Her echocardiogram was interpreted as "ventricular wall abnormalities suggestive of stress cardiomyopathy" (Nogi et al., 2014). The patient admitted to recently "ingesting" cannabis after abstaining from use for a period of around three months (Nogi et al., 2014).

Research from Sanchez et al. (2019) highlighted the case of a 50-year-old male with a history of hypertension and "regular" cannabis use. He presented with chest pain radiating to his back. Due to an abnormal electrocardiogram and positive cardiac biomarkers for acute coronary syndrome, a coronary angiography was conducted. Surprisingly, no significant coronary obstruction was found. However, a left ventriculogram showed the "characteristic apical ballooning" of stress cardiomyopathy (Sanchez et al., 2019).

Meera et al. (2020) reported on the case of a 56-year-old male with no known past cardiac history who presented with symptoms of confusion, aphasia, and left-sided weakness. His wife reported increased somnolence, poor appetite, and lethargy for a few days. His blood pressure was 148/105 mmHg with a heart rate of 102 beats per minute (Meera et al., 2020). Computed tomography (CT) and magnetic resonance imaging (MRI) revealed "no acute intracranial pathology" (Meera et al., 2020). His chest X-ray revealed "pulmonary congestion" and a 12-lead electrocardiogram showed an ST segment depression and QTc interval prolongation (Meera et al., 2020). An echocardiogram revealed a mildly dilated left ventricle cavity with severe hypokinesis resulting in a "markedly reduced ejection fraction" (Meera et al., 2020). However, a coronary angiography showed no signs of obstruction. When questioned, the patient denied any recent emotional stress, but admitted to using cannabis heavily for several days before this presentation.

Kaushik et al. (2011) researched a case of recurrent stress cardiomyopathy in a 59-year-old woman presenting with angina. She denied any recent physical or emotional stressors, but admitted to years of dependent cannabis use. Physical examination revealed jugular venous pulsation, bilateral lung crackles, and left ventricular gallop (Kaushik et al., 2011). A 12-lead electrocardiogram showed poor R-wave progression, ST-segment elevation, and T-wave inversion (Kaushik et al., 2011). An echocardiogram was used to estimate the left ventricular ejection fraction, which was found to be 20% to 25%; this is below the normal range of 50%-75% (Kaushik et al., 2011). The echocardiogram was also used to identify severe hypokinesis of the apical and midsegments (Kaushik et al., 2011). Cardiac catheterization revealed normal epicardial coronaries, and a ventriculogram was consistent with apical ballooning indicative of stress cardiomyopathy (Kaushik et al., 2011). This patient had four admissions in the previous three years, with similar clinical course and diagnostic findings (Kaushik et al., 2011). She had admitted cannabis use and tested positive for Δ-9-THC on each of the previous occurrences. Therefore, her final diagnosis was recurrent stress cardiomyopathy due to cannabis abuse (Kaushik et al., 2011).

## Myocardial Infarction

One documented case of stress cardiomyopathy with a temporal relation to cannabis use resulted in the death of an otherwise healthy 23-year-old woman. The cause of death was documented as cardiac arrest (myocardial infarction) due to ventricular fibrillations associated with apical ballooning syndrome (del Buono et al., 2017). It was found that she had smoked cannabis a few times over the days leading up to her death. Her autopsy revealed subendocardial hemorrhaging, which hints at the pathophysiology of this poorly-understood condition (del Buono et al., 2017). Subendocardial hemorrhaging (as observed in this patient with apical ballooning syndrome) has been found to occur the most frequently in the upper part of the interventricular septum, where the left branches of the atrioventricular bundle are located, suggesting a possible mechanism for the ventricular arrhythmia (Seidl, 2005).

A study conducted by Chami and Kim (2019) looked at 292,770 patients with a history of cannabis abuse and compared their risk for myocardial infarction (MI) to 10,542,348 patient controls matched for age and sex. This study found the three-year cumulative incidence of MI was significantly higher in the cannabis abuse group than in controls, concluding a 1.37% vs. 0.54% relative risk factor with a 95% confidence interval. Women aged 40-44 years and men aged 35-39 years were the highest-risk groups, reaching up to 4.78% relative risk (Chami & Kim, 2019). Furthermore, the subgroup of dependent cannabis users showed a significant correlation to myocardial incidents (adjusted odds ratio: 1.72; 95% CI). This was independent of advanced age, sex, hypertension, coronary artery disease, diabetes, and other substance abuse (Chami & Kim, 2019).
A research study from Mittleman et al. (2001) was based on

interviewing 3,882 patients with previous acute myocardial infarctions. Of the 3,882 patients included in their study, 124 (3.2%) reported smoking cannabis within the last year. Thirty-seven patients admitted to smoking cannabis within 24 hours prior to the onset of their symptoms, and nine of the 3,882 patients smoked cannabis within one hour prior to symptom onset. Mittleman et al. (2001) concluded that the risk of myocardial infarction onset was elevated 4.8 times over baseline (95% CI) in the 60 minutes following cannabis use, and that the elevated risk rapidly decreased thereafter.

## Similarities between Cannabis and Tobacco Pulmonary Pathophysiology

In 2013, Tashkin conducted research that found an association between smoking cannabis and visible and microscopic injury to the large airways. Interestingly, the injuries were found to subside after cessation (Tashkin, 2013). Tashkin looked further into this concept when he conducted his 2018 research study that was designed to compare the bronchial mucosa of a non-smoker, a cannabis smoker, and a tobacco smoker via bronchoscopies with bronchial biopsy. The cannabis smoker's large airways showed less reddening of tissues (erythema) compared to the tobacco smoker (Tashkin, 2018). Conversely, the small airways (bronchioles) of the cannabis smoker showed substantially more swelling (edema) compared to the tobacco smoker (Tashkin, 2018). A third study conducted by Tashkin and Roth in 2019 found that tobacco smokers and frequent cannabis smokers both show similar magnitudes of destruction to ciliated epithelium cells, hyperplasia of mucus-secreting goblet cells and cellular disorganization. Therefore, it is postulated that the frequency of chronic cough and the overproduction of sputum between cannabis smokers and tobacco smokers is similar (Tashkin & Roth, 2019).

One major difference between tobacco smoke and cannabis smoke is their effect on alveolar macrophages. Tashkin and Roth (2019) found that the alveolar macrophages in cannabis smokers show a reduced ability to produce cytokine as well as a deficit in antimicrobial and fungicidal activity. This downregulation of alveolar macrophage activity has never been observed in the cells of tobacco smokers (Tashkin & Roth, 2019). They speculated that the known immunosuppressive effect of Δ-9-THC, along with the presence of CBR2 (cannabinoid) receptors on alveolar macrophage cells, are both responsible for the downregulation of activity (Tashkin & Roth, 2019).

Another potential pathophysiological difference in cannabis smokers was noted in Tashkin's 2013 study, which referenced several case reports that implicated frequent smoking of cannabis as a possible etiologic factor in pneumothorax, pneumomediastinum and bullous lung disease. However, it was noted that an epidemiologic study has not been conducted to produce evidence of the "causal link" between these conditions and smoking cannabis (Tashkin, 2013).

## Frequent Respiratory Infections

Even though the evidence is generally inconclusive regarding the relative risk factor for lower respiratory tract infections, it has been postulated that smoking cannabis predisposes users to these infections in a few different ways (Tashkin, 2018). As previously stated, damage to ciliated epithelial cells, cellular disorganization and the hyperplasia of mucus-secreting goblet cells have been observed in both tobacco smokers and cannabis smokers alike (Tashkin, 2018). These cellular changes lead to an increase in mucus production, while simultaneously impairing the mucociliary escalator. Ultimately, this creates an ideal substrate for pathogenic microbial organisms like *Pseudomonas aeruginosa* to colonize in the lower respiratory tract (Tashkin, 2018). However, as previously mentioned, in cannabis smokers the downregulation of alveolar macrophage activity clearly perpetuates the frequency and severity of these infections in the respiratory tract. In addition to an increased likelihood of infections such as *P. aeruginosa*, the cumulative cellular changes observed in frequent cannabis smokers also provides a clue into the longstanding association between cannabis use and chronic bronchitis symptoms (Tashkin & Roth, 2019).

An additional mechanism for an increased risk of pneumonia in cannabis smokers was identified in a case study from Kumar et al. (2018). The study was based on a 23-year-old male who presented with a three-day history of fever, hemoptysis, and dyspnea (Kumar et al., 2018). Palpation and auscultation of the chest revealed crepitations with decreased breath sounds on the left (Kumar et al., 2018). CT imaging helped identify an area of necrotizing pneumonia involving the left upper lobe (Kumar et al., 2018). Upon questioning, the patient admitted to using a "small water pipe or bong" to smoke cannabis daily over the span of four years. Interestingly, the patient elaborated that the bong was being used for its supposed benefit of filtering the cannabis smoke. Cultures were obtained not only from the patient's sputum and pleural fluid, but also from the water in the bong. All three cultures grew *P. aeruginosa* (Kumar et al., 2018). It is theorized that during the process of inhaling cannabis smoke through the bong, the patient was inadvertently and repeatedly inhaling water aerosols contaminated with *Pseudomonas aeruginosa*, which had led to the necrotizing pneumonia infection.

A final factor adding to the increased likelihood of respiratory infections in cannabis smokers is the frequency at which cannabis has been found to be contaminated with *Aspergillus fumigatus* and potentially pathogenic gram-negative bacteria (Kagen et al., 1983; Tashkin, 2018; Ungerleider et al., 1982). The effects of combusting *A. fumigatus* and bacteria during the

smoking process are unknown; however, the potential consequences of their introduction into lung tissues of cannabis smokers—whose lungs are already immunocompromised—provides another possible mechanism for an increased risk of respiratory infections (Tashkin, 2018).

### Cerebral Vascular Accidents

Accounts of cerebral vascular accidents (strokes) from cannabis use have been reported (Uhegwu et al., 2015). The postulated etiologies include reversible cerebral vasospasms, vasculitis, postural hypotension, and increased carboxyhemoglobin leading to reduced oxygen transportation capacity (Uhegwu et al., 2015). Reversible cerebral vasoconstriction syndrome (RCVS) is a unifying term for a variety of a cerebral vasospasm activity which results in the clinical manifestation of cerebral ischemia (Uhegwu et al., 2015). RCVS, sometimes referred to as drug-induced cerebral angiopathy, is typically characterized by a transient, multifocal, cerebral arterial vasoconstriction and dilatation cycle. Research from Uhegwu et al. (2015) found that cannabis abuse is a common etiologic factor for RCVS, as well as other types of cerebral vascular accidents.

The previously mentioned case study on stress cardiomyopathy from Meera et al. (2020) also included elements of a reversible cerebral vascular accident. The 56-year-old male patient who admitted to using cannabis heavily for several days before this presentation had no known cardiac or neurological history. He presented with symptoms of confusion, aphasia, and left-sided weakness. His wife also has noticed left-sided facial droop and impaired coordination over the previous few days. Physical examination revealed that his motor strength was reduced in the left upper and lower extremities (Meera et al., 2020). However, due to the reversible nature of RCVS, CT and MRI revealed "no acute intracranial pathology" (Meera et al., 2020). The patient was drug screened and only tested positive for Δ-9-THC with zero traces of cocaine, opioids, amphetamines, barbiturates, benzodiazepines, or alcohol (Meera et al., 2020). Blood glucose and thyroid function tests were also within normal range (Meera et al., 2020). After being monitored for a few days, the patient was discharged, yet continued to experience transient neurological deficit, with the only known contributing factor being heavy cannabis use.

## Conclusion

According to the United Nations 2020 World Drug Report, 3.9 percent of the global population aged 15-64 (192 million people) used cannabis within the past year (United Nations, 2020). Not surprisingly, past-year cannabis use within the North American subpopulation is substantially higher, coming in at 14.6 percent (United Nations, 2020). Usage rates have continued to rise. We believe this is likely due to the widely accepted, yet false, notion that cannabis is completely safe. Furthermore, cannabis legalization reforms have swept across the United States in recent decades, perpetuating its social acceptance and availability.

Regardless of the common misconceptions surrounding the relative safety of cannabis, its use can result in severe adverse health effects including, but not limited to, stress cardiomyopathy, myocardial infarction, pulmonary tissue damage, increased occurrences of severe pulmonary infections, and cerebral vascular accidents. Although they are frequently underreported, adverse cardiovascular and pulmonary events are being described at an alarming rate. Surprisingly, it has been found that younger adults have the highest relative risk for experiencing many of the more severe cardiovascular events.

Based on the information found within this literature review, future critical care implications for respiratory therapists should include (1) Δ-9-THC drug screening of patients who are presenting with idiopathic conditions that align with cannabis use, yet have not disclosed using cannabis (potentially due to the misconception of it being completely harmless), (2) advising cardiac patients (chronic, acute or in rehabilitation) of the potentially lethal risks of cannabis use, and (3) educating cannabis users who are suffering from pulmonary conditions such as chronic bronchitis or pneumonia of the known etiology connecting cannabis use and their condition.

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# Melodies as Curves

***Peter Lefkovitz***
***Faculty mentor: Steven Wilkinson***
***Mathematics***

## Peter Lefkovitz

Peter Lefkovitz is a mathematics and music composition major at Northern Kentucky University. This research was done under the guidance of Dr. Steven Wilkinson, in collaboration with CINSAM's UR-STEM program. It was previously presented at the 2020 Heather Bullen Summer Research Celebration online, the KYMAA 2021 Annual Meeting, and the 2021 MAA Mathfest. After graduating, Peter plans to go to grad school to continue studying relationships between mathematics and music.

KEYWORDS:
Math in music, music theory, mathematical curves, mathematical computations

## Abstract

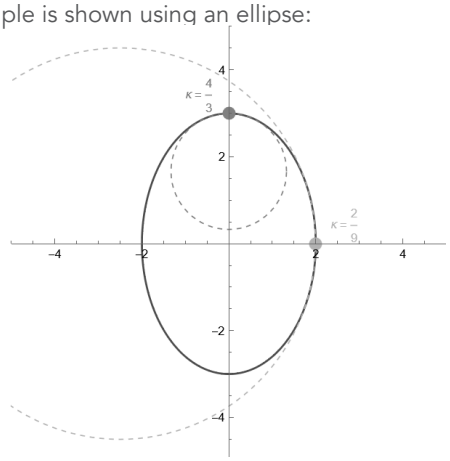
In music, a melody is a string of single notes that is central to the piece it is in. This melody can appear several times throughout a composition, but each time can include small variations, including transpositions, inversions, and retrogrades. In mathematics, curvature is a measure of how much a curve bends at a given point, and does not change when the curve is translated, reflected, or rotated. By creating a relation between the two, we can generate melodies from mathematical curves, as well as find mathematical curves from melodies. We hope that this can be used as both a compositional tool, as well as for analysis of existing melodies.

## Introduction

Mathematics and music are fundamentally linked. Each note is a vibrating wave of a specific frequency, which we combine to create melodies, songs, symphonies, and more. We define intervals based on ratios of the vibrating frequencies, and use basic arithmetic to study rhythms and to put beats together. There are many ways to use mathematics to generate music. One of the most well known is 12-tone theory[1] developed by Arnold Schoenberg. This is a method of generating melodies which assigns each pitch a number, and dictates that each pitch must be used at least once before any are allowed to repeat. With a few more constraints and processes, Schoenberg was able to compose new melodies with this idea. Some other mathematical ways of writing music use randomness, while others are procedural. Some methods focus more on melodies, harmonies, or rhythms.

In music, one of the most important aspects of a piece is its melody. In most works, thethe melody appears throughout the composition, but may be varied in different ways each time. Common transformations include transposition (moving the whole melody up or down pitches without changing the internal structure), retrograde (playing the melody backwards so that the first note becomes the last, and vice versa), or inversion (flipping each interval about a certain pitch, so that a step up becomes a step down). These three melodic transformations are comparable to well known transformations in mathematics: Ttransposition is similar to a translation, retrograde is a horizontal reflection, and inversion is a vertical reflection. No matter what is done to the melody, it is still a central aspect of the composition, and is used to tie a whole piece together, even if it is transformed.

In mathematics, curvature is defined as a measure of how sharply a curve is bending at a given point[6]. A straight line is defined as having zero curvature, while circles are defined as having a constant curvature (a circle with radius r has a curvature of =1/r ). Given any non-circular smooth curve, the curvature at each point is found by using the circle of best fit (the circle that best approximates the curve at the given point). An example is shown using an ellipse:

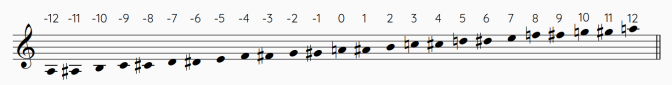



If a curve f(t) is defined parametrically as *f(t)=(x(t),y(t))*, then its curvature *k* can be calculated by the following formula:

$$\kappa = \frac{(x\prime(t)y\prime\prime(t) - x\prime\prime(t)y\prime(t))}{(x\prime(t)^2 + y\prime(t)^2)^{3/2}}$$

Curvature is invariant under translations, and the absolute value is invariant under reflections, similar to a melody, so it makes sense to create a connection between the two. Furthermore, by using the formula and solving it backwards, if one has a curvature function, the equation for a curve can be derived from it.

There are numerous ways to relate pitches and numbers. Since curvature can be both positive and negative, we want our numbering system to include positive and negative numbers. Thus, we will use a numbering system where we choose 0 curvature (a straight line) to represent some fundamental frequency (e.g. 440 Hz, ***do,*** C4), and have notes above be positive, and notes below be negative. The number of half steps (the smallest unit distance in classical Western music theory) above or below that fundamental frequency will be the number assigned to each note (e.g. A=0, B=2, G#=-1). Below is a visual, with A4 being defined as our fundamental frequency:




This is similar to 12-tone theory, but allows for negative numbers, and has a distinct value for every pitch, rather than using pitch classes – each note letter name is the same pitch, regardless of octave. Thus, we have a way to relate curvature and pitch.

Our overall goal is to see if this is an interesting, worthwhile way to relate mathematics and music. Will using curves and their curvatures create usable melodies that are pleasing to listen to? Will transforming melodies into curves be a good way to describe them? Is there value in creating this relationship?

## Methods

For this project, we wrote code to do the mathematical computations and to create the graphics, as well as play the tunes. This was done in *Wolfram Mathematica*[7].

The first code we created allowed us to input a curve that we found interesting and generate a melody from it. The majority of the curves we used are well known in mathematics[3]. By plugging in the curve, we were able to calculate the curvature function using the formula that was priorly given. We would use this to determine what the curvature was at each point, and then we would round this to the nearest integer (to make it one of the twelve notes of Western harmony). We would then create an audio file that played these notes. Usually, we would round the music to the nearest chromatic note. However, we also had the ability to round to the nearest note in a major or minor scale, or any mode we liked.

Our second code allowed us to input a melody and generate a curve from it. We defined each melody as a list of note pairs, with one note in the pair representing pitch, and the other length. We then interpolated these data into a function with pitch as a function of time. We treated this as a curvature function, and were able to use that to solve for the parametric equation of a curve. Thus, we were able to generate a curve for any song.

## Results and Discussion

From the curves, we were able to generate several new melodies. See Figures 1, 2, 3, and 4.

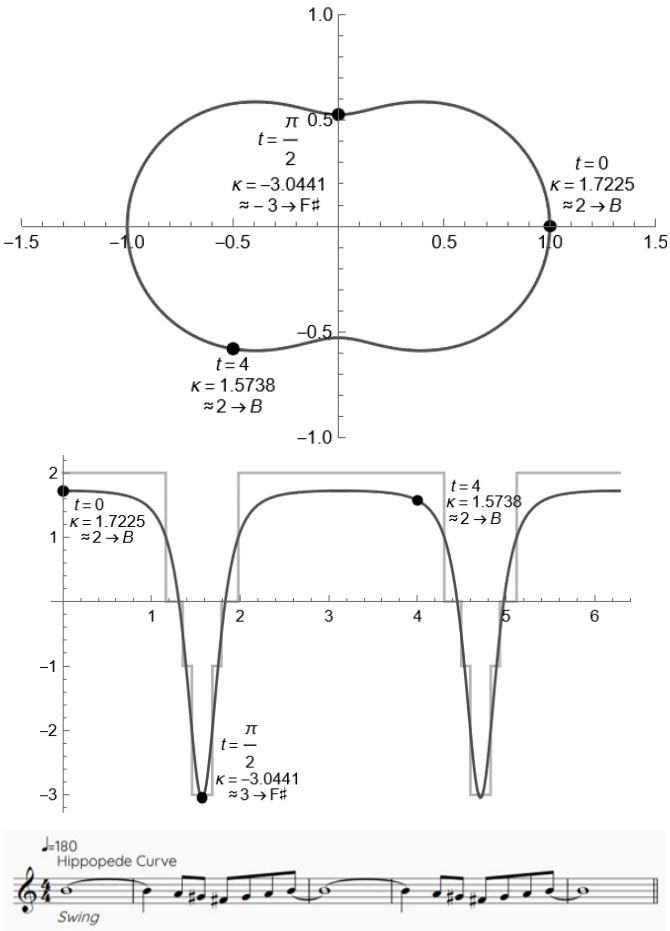



Figure 1. Hippopede curve (top), its curvature function (middle), and melody produced (bottom). The melody is rounded to the notes of the major scale, hence why some pitches are skipped. Three example points and their curvatures are given on both the original curve and its curvature function, which are rounded to the notes B, F#, and then B again, respectively. On the curvature function, the way the pitches are rounded can be seen. While the melody notated is not an exact replication, it represents how a composer may interpret the sound this curve makes.

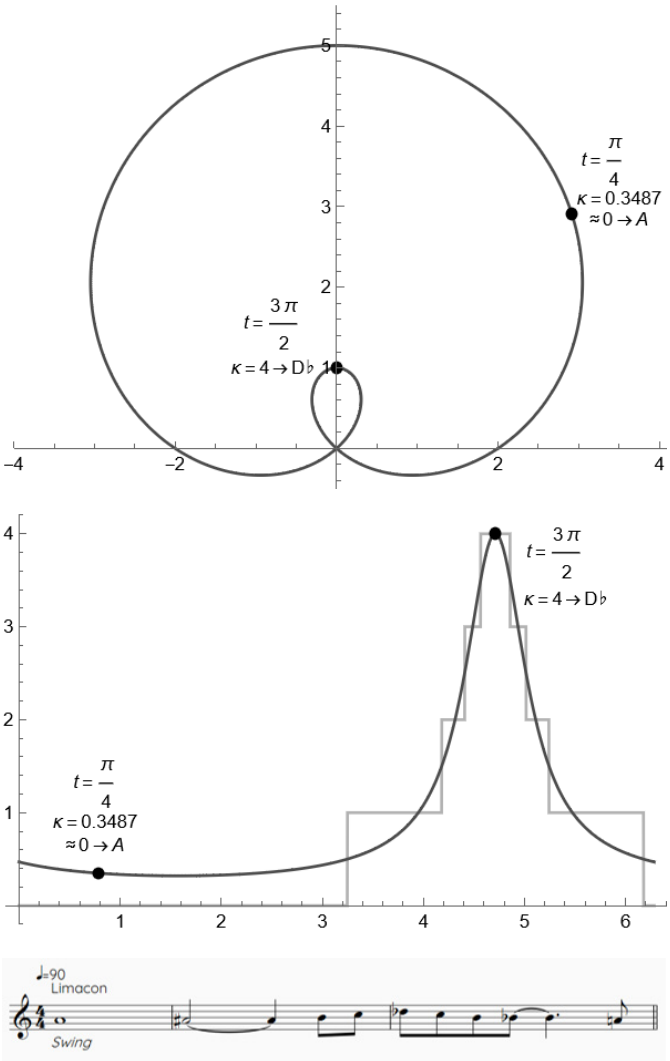



Figure 2. Limacon (top), its curvature function (middle), and melody produced (bottom). The melody is rounded to the notes of the chromatic scale.

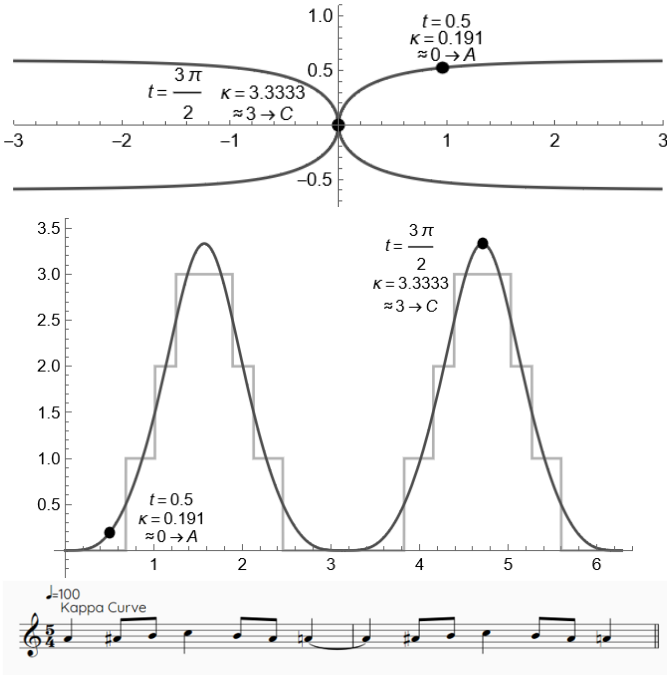



Figure 3. Kappa Curve (top), its curvature (middle), and melody produced (bottom). This melody is rounded to the chromatic scale.

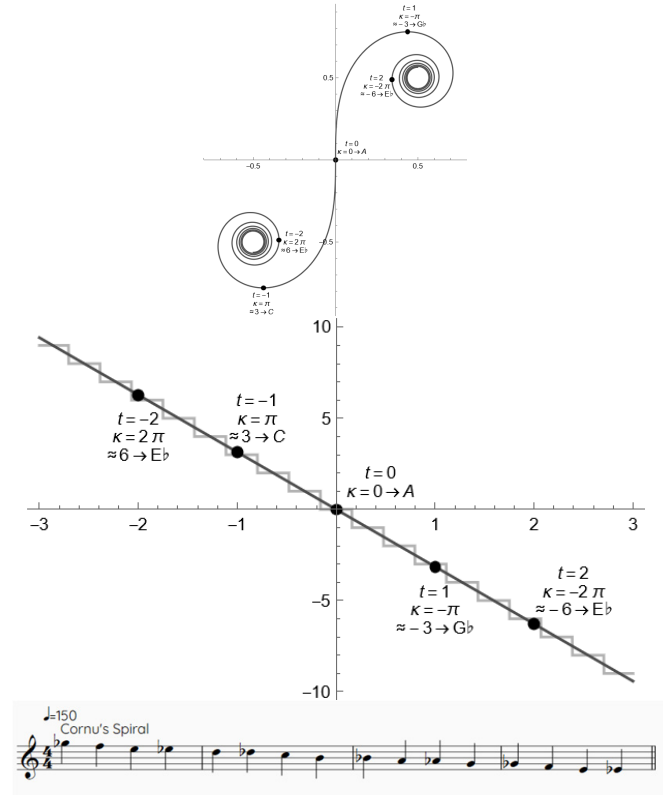



Figure 4. Cornu's Spiral (top left), its curvature (top right), and the melody produced (bottom). This melody is rounded to the chromatic scale. This example is particularly interesting, as the curvature function reveals that the curvature is constantly changing. This means that the melody produced by this curve will simply be the scale it is being rounded to (with some rhythmic variance depending on the scale).

We noticed that most curves that generated aesthetically pleasing melodies tended to not have sharp bends – that is, places where the curvature changes too fast. When curvature moves through several different numbers too quickly, the resulting melody has a sharp glissando up or down. This led us to realize that there is a stability in melodies.

We can also vary the graphs, and thus vary the melody that comes from them. By dilating the graph and making it bigger, we decrease the curvature at every point. This makes the melody more subdued. Likewise, if we make the graph smaller, we increase the curvature at every point. Thus, the melody becomes more dramatic (see Figures 5 and 6). With any curve, any kind of transformation can be made to create a new melody.

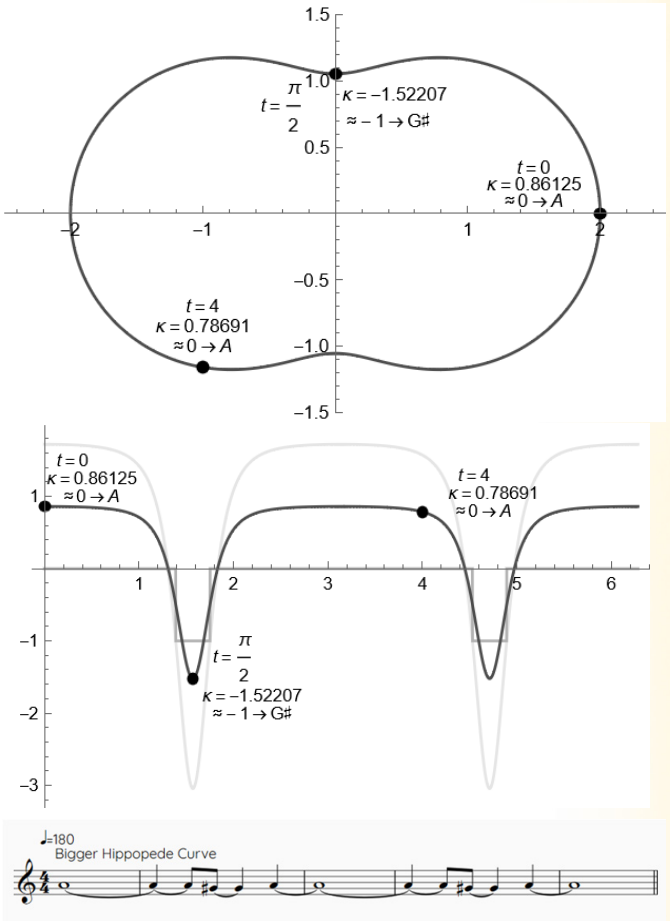



Figure 5. A Hippopede curve dilated to be bigger (top), its curvature (middle), and the melody produced (bottom). Like in Figure 1, this melody is rounded to notes of the major scale. On the curvature graph, the curvature of the non-dilated curve is shown faintly. Note that the values for curvature are less so than before, and thus the melody produced is not as extreme.

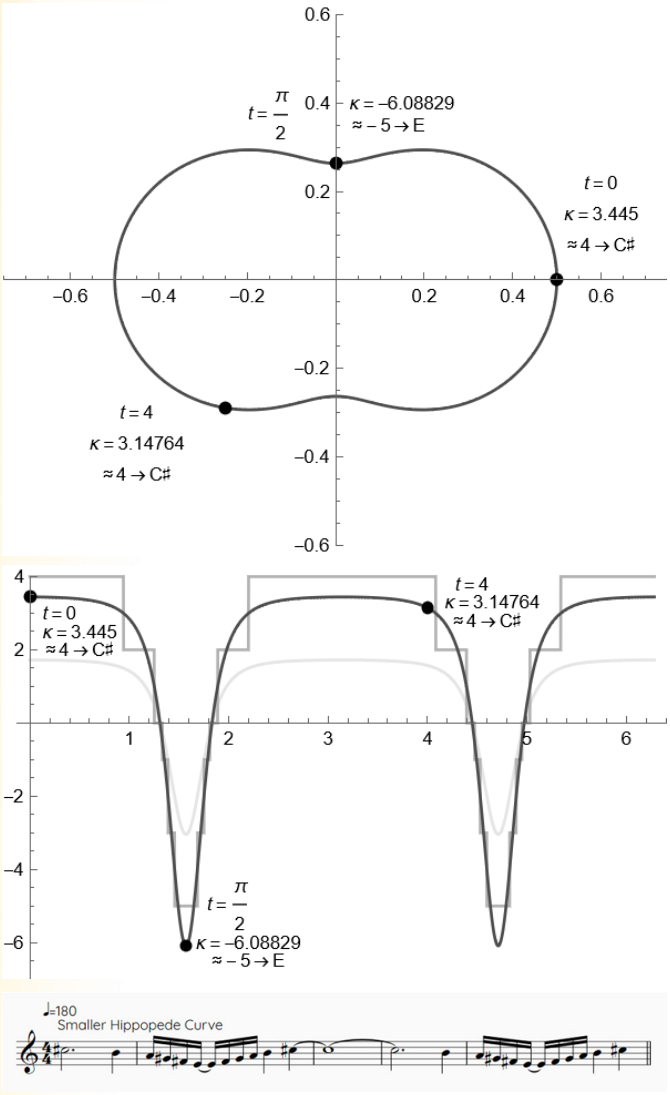



Figure 6. A Hippopede curve dilated to be smaller (top), its curvature (middle), and the melody produced (bottom). Like in Figure 1, this melody is rounded to notes of the major scale. Note that since the values for curvature are more extreme than before, there are more notes, and the melody is considerably more dramatic.

We were also able to generate a curve for any melody. See Figures 7,8, 9, and 10:

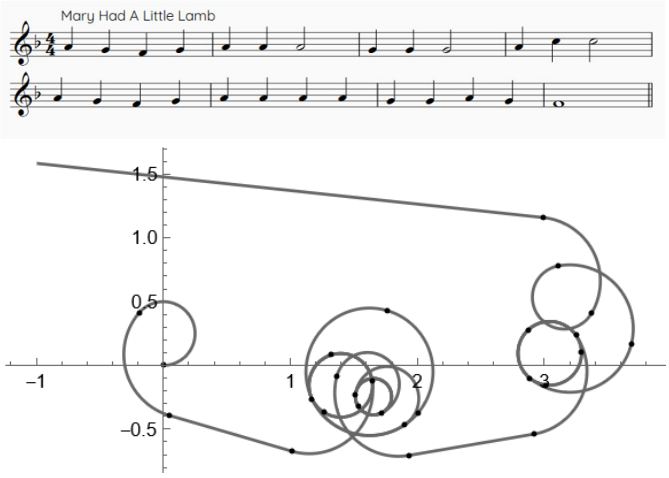



Figure 7. Mary Had A Little Lamb – melody (top) and curve (bottom). Visible on the curve are the points where each note begins. Notice that between each dot, constant curvature is kept, which results in several large circular sections. Whenever the piece returns to *do,* which in this example is F4, the curve becomes straight, as we defined *do* to represent zero curvature.

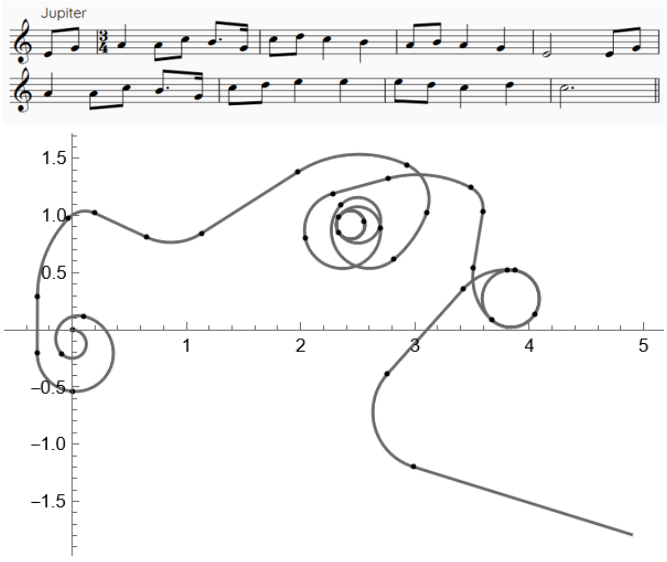



Figure 8. *Jupiter* by Holst[5] – melody (top) and curve (bottom). The fundamental frequency is defined as C5.

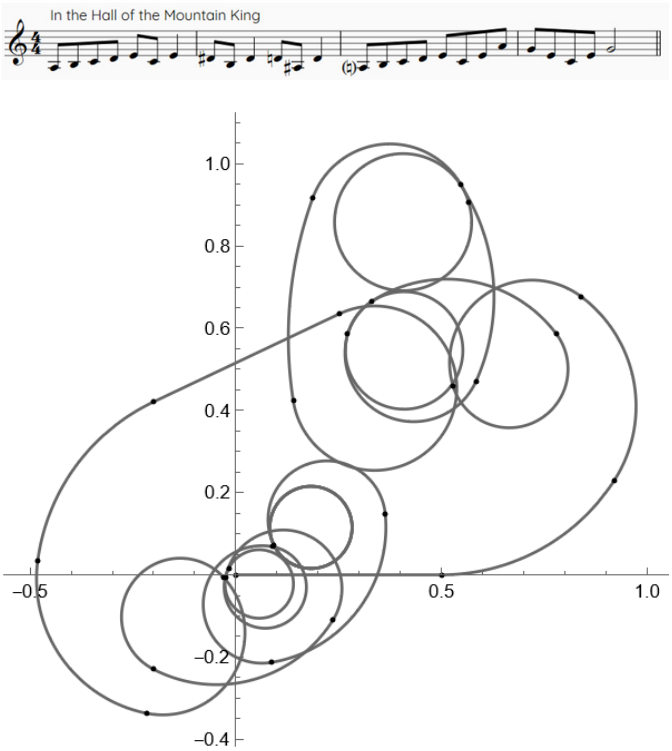



Figure 9. *In the Hall of the Mountain King* by Grieg[4] – melody (top) and curve (bottom). the fundamental frequency is defined as G3.

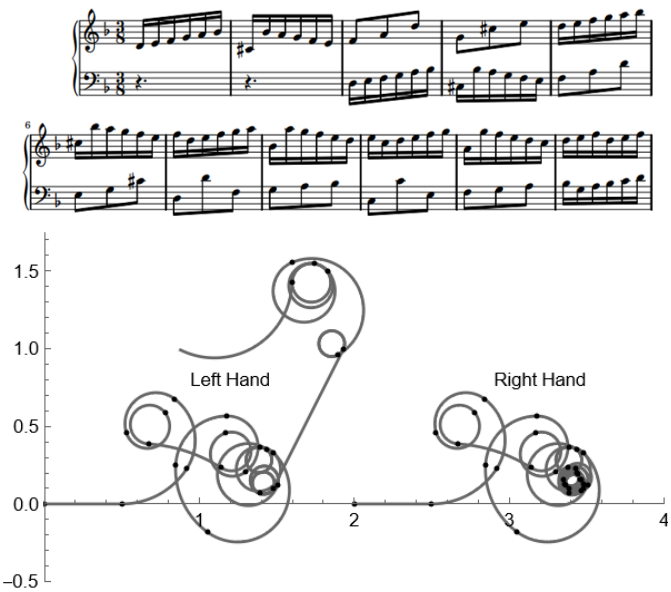



Figure 10. *Invention No. 4* by Bach[2] – melody (top) and curve (bottom). The left hand and right hand are shown separated from each other to avoid overlap. The fundamental frequency is defined as .

While we were not able to find any overarching pattern to the curves, there are still numerous observations one can make. For example, repetitions in a melody became more obvious, as the curves would have parts that were similar to each other. Examining contrapuntal music (music that has more than one line playing at once) like Bach's *Invention No. 4* also revealed something similar: Where the lines were similar, they created the same resulting curve. However, once the lines began to differ, they went off in their own directions. This allows us to visually inspect where the lines replicate each other and how they vary.

## Conclusions

Due to the large number of melodies we are able to generate via this method, with each one being unique, this is a useful and novel way to generate melodies. While some curves create simple melodies (such as the Cornu's Spiral), others create melodies of more rhythmic and melodic complexity (like the Hippopede curve). Of course, the use of these melodies in song depends heavily upon the skills, tastes, and style of the composer, but with the wide variety of curves available in mathematics, it should be easy to implement as a way of mathematically generating music.

Using this method to visually analyze melodies is not as fruitful as we had hoped it to be, but still has some merits. While we were unable to find some distinct, recognizable pattern that united all curves, they all have common similarities – straight lines highlight where *do* is in the piece, and the curves tend to wind upon themselves in one singular area before moving away [note in *Mary Had a Little Lamb* how there are three distinct clusters around the origin, the point (1.5, 0), and the point (3, 0)]. Furthermore, curves of melodies that repeat themselves, or otherwise imitate themselves, reveal this repetition visually by having parts that resemble each other (like Bach's *Invention No. 4*). Therefore, this method of analyzing melodies is not entirely useless.

Overall, the goal of creating a worthwhile relationship between mathematics and music has been achieved. This process, while not good at analyzing existing melodies, has limitless capabilities of generating new ones, up to the tastes of the composer using it. As long as there are more mathematical curves to use, a new melody may be generated from it by using this method.

## Glossary

**Major:** Possibly the most used scale in Western music. On a piano, it is played from one C to another C while only using white keys.

**Minor:** Arguably the second most used scale in Western music. On a piano, it is played from one A to another A while using only white keys. It can be thought of as a major scale, but the third, sixth, and seventh scale degrees are lowered by a half step.

**Chromatic:** A scale in Western music that utilizes every possible note by using only half steps.

**Mode:** Any kind of scale. Usually defined by the pattern of whole steps or half steps (e.g. major is defined as WWHWWWH). Some use larger intervals.

**Transpose:** To move a group of notes, such as a melody or chord, up a certain interval so that the internal structure of the notes is the same, but the note names are different.

**Retrograde:** To play a melody backwards, starting from the last note.

**Inversion:** To play a melody, but to flip each interval so that when the original melody would go up, the inversion would go down, and vice versa.

**Contrapuntal:** When two or more lines play simultaneously, moving independently. Bach is well known for his counterpoint.

**Glissando:** To ascend or descend pitchwise very rapidly (think the beginning of Gershwin's *Rhapsody in Blue*, or a trombone slowly moving their slide).

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# Effects of Note-taking and Retrieval Practice on Memory Performance

***Vincetta Kahmann***
***Faculty Mentor: Kalif Vaughn***
***Psychological Sciences***

## Vincetta Kahmann

Vincetta Kahmann graduated summa cum laude from Northern Kentucky University in December of 2022 as a University Honors Scholar. She obtained a Bachelor of Arts degree in Psychology with a minor in Foundation of Knowledge Honors, and a focus in Educational Studies. This research was conducted under the guidance of Dr. Kalif Vaughn, and was presented at NKU's Celebration of Student Research and Creativity in April of 2022. Since graduation, Vincetta has been working as a clinical research coordinator, with an interest in pursuing graduate school.

KEYWORDS:
retrieval practice, guided-notes, memory, study habits

## Abstract

Note-taking is a valuable skill that can influence student learning and achievement (for a review see Friedman, 2014). We explored (a) whether note-taking was more effective with guided prompts (guided notes) versus without prompts (unguided notes) and (b) whether those prompts were more effective when used for note-taking or retrieval practice. Participants were divided into four groups: control, retrieval, guided notes, and unguided notes. The control group watched a video and took a final test on its contents. Both the retrieval and guided notes groups watched the video and received prompts (e.g., ATP); however, the retrieval group received them after the video (as retrieval cues) and the guided notes group received them during the video (as note-taking cues). The unguided notes group did not receive any prompts but were given the chance to take notes during the video. All groups took a final test comprising of two question types (multiple choice and true/false questions) and answered questions about content familiarity. The results from the final test suggested that although there was a significant main effect of question type, there was no main effect of group (nor a significant group × question type interaction). Implications and limitations are discussed.

## Introduction

Graduating from college can be a challenging feat. As of 2021, the national 6-year graduation rate is only 62% (National Center for Education Statistics, 2021) and as many as 56% of students in the United States drop out within 6 years (Hanson, 2021). Although there are a multitude of reasons for why students might drop out of college (e.g., financial troubles, overbearing work schedules, etc.), perhaps a primary reason may be that some students lack the essential study skills necessary to effectively learn their course content. For instance, many college students rely on passive and ineffective study strategies such as highlighting and rereading (Dunlosky et al., 2013). In contrast, research has repeatedly demonstrated benefits from *retrieval practice*, which refers to attempting to recall information from memory (e.g., Roediger & Butler, 2011). Research has also shown the benefits of *guided notes*, or notes that consist of an outline or key prompts provided by the instructor (Biggers & Luo, 2020). In our experiment, we explored the efficacy of retrieval practice compared to guided notes. Assuming no subsequent practice occurs, is it more advantageous to use teacher-provided prompts to engage in retrieval practice or to take guided notes? Below, we describe both strategies and the current evidence supporting their usage.

### Retrieval Practice

Retrieval practice involves actively recalling information from memory (Roediger & Butler, 2011). By actively retrieving information from memory, an event known as the *testing effect* may occur. The testing effect refers to the phenomenon in which test performance is improved following retrieval practice versus no retrieval practice (Roediger & Karpicke, 2006; see also Roediger et al., 2011). Students engage in retrieval practice in situations such as using flash cards, completing practice tests, and completing end-of-the-chapter reviews (Roediger & Butler, 2011). Retrieval practice tends to be most effective when the retrieval attempt is more effortful (e.g., Duchastel, 1981; Pyc & Rawson, 2009), when there are more correct recalls (e.g., Vaughn & Rawson, 2011), when items are practice tested versus not tested at all (McDaniel et al., 2013), and when there are multiple recall attempts spanning across longer time intervals (Roediger & Butler, 2011).

Although retrieval practice is a potent learning strategy (Roediger & Butler, 2011; Roediger & Karpicke, 2006; Kornell & Vaughn, 2016), many students underutilize this technique (Hartwig & Dunlosky, 2012). In contrast, students readily engage in note-taking during lectures, with estimates ranging from 96% (Morehead et al., 2019) to 99% (Palmatier & Bennet, 1974). But is note-taking effective, and if so, is it more effective than retrieval practice?

### Note-taking

Note-taking is a broad term and has many variations (e.g., Cornell notes, sketch noting, traditional notes, etc.). First, we will discuss general note-taking and how it influences academic performance. In a later section, we will discuss guided notes specifically.

Research suggests that note-taking is a valuable skill that can enhance learning in college students; however, many students fail to take good notes (e.g., transcribing the lecture verbatim; see Friedman, 2014 for a review). Although note-taking quality can influence performance (e.g., Chen 2013; Peverly et al., 2007), the act of taking notes does not guarantee improved performance. Furthermore, the process of taking notes is cognitively demanding (Roussey & Piolat, 2003, as cited in Piolat et al., 2005), as students are expected to listen, process, transcribe, store, and later recall information being presented in a short amount of time. Given limited working memory resources (e.g., Baddeley, 2010), it is perhaps unsurprising that many students engage in poor note-taking strategies (e.g., Bui, Myerson, & Hale, 2013). For instance, Hartley and Marshall (1974) revealed that students' notes contained, on average, approximately 11% of the critical information from lecture, potentially interfering with students' ability to accurately make connections between concepts covered in lecture and their notes (Nakayama et al., 2014, as cited in Biggers & Luo, 2020). Yet, students tend to overly rely on this skill to learn and memorize course material for future examinations (Morehead et al., 2019).

### Guided Notes

To help alleviate some of the cognitive strain imposed by traditional note-taking procedures and to further enhance note-taking quality, one alternative is *guided notes* (e.g., Biggers & Luo, 2020). Guided notes are a type of note-taking in which the professor provides some material or handout containing key points, concepts, and/or cues that relate to important content to be covered in lecture (e.g., Biggers & Luo, 2020; Heward, 1994; Konrad et al., 2011). Studies suggest that guided notes can lessen the cognitive demand compared to traditional notetaking (for a review, see Biggers & Luo, 2020). By alleviating the strain on working memory, students can better focus on the lecture and participate more in class. Additionally, maximizing available working memory may help students take higher quality notes. For example, Glodowski

and Thompson (2018) suggest that students who use guided notes during a lecture often included more critical points and examples within their notes, which could boost subsequent test performance. Furthermore, Chen et al. (2017) report that 96.9% of participants rated guided notes favorably and that 100% of participants agree that guided notes are beneficial to test preparation.

### Purpose of the Study

The purpose of the current study was to investigate the effects of retrieval practice and note-taking on memory performance. To equate exposure to information, prompts (e.g., ATP) were created that could either be used as note-taking cues or retrieval practice cues. First, we explored whether note-taking was more effective when using these prompts versus without these prompts (guided notes versus unguided notes). Second, and of primary importance, we explored whether these prompts were more effective when used for note-taking (i.e., providing them during the video) or retrieval practice (i.e., providing them after the video). Both note-taking and retrieval practice can improve student learning, but which learning strategy is more effective? Based on the notion that note-taking can enhance learning (for a review see Friedman, 2014), we predicted that taking notes would improve performance relative to not taking notes. Based on the perceived added benefits of guided notes (Biggers & Luo, 2020), we predicted that note-taking would be further enhanced when prompts were given (guided notes group) versus not given (unguided notes group). Lastly, based on the benefits of retrieval practice (Roediger & Butler, 2011), we predicted that prompts would be more effective as retrieval cues versus guided note-taking cues.

Of secondary interest, we also explored how retrieval practice and note-taking influenced performance on two question types: Multiple-choice questions and true/false questions. Although we did not predict that the pattern of results would change based on question type, an interaction between study strategy and question type remained possible.

## Method

### Participants

A repeated measures power analysis was completed to detect a potential within-between interaction at 95% power. The analysis revealed that 76 participants were necessary to detect such an effect, but to account for attrition, we tried to collect data from a minimum of 90 participants. Participants completed the study by clicking a link in SONA (an electronic platform for recruiting research participants), which then directed them to an external website. The web-based study took approximately 20 minutes to complete, and participants received two SONA credits for completing the study. Participants were excluded if they did not finish the experiment ($n$ = 12), watched the video more than once ($n$ = 1), used outside resources ($n$ = 7), werenot fluent in English ($n$ = 2), or completed the main portion more than once ($n$ = 3). In total, 49 participants [$M$age = 20.71 years old, age range: 18 – 49 years (with 4 participants not entering their age); 35 females, 14 males; majority (67.35%) white] completed the experiment.

### Materials

An eight-minute-long video about cellular respiration was used as the study material in this experiment. This video described the prokaryotic and eukaryotic cells, ATP production, and the stages of cellular respiration (Amoeba Sisters, 2021). The prompts utilized for the guided notes group and retrieval practice group were chosen to represent the main concepts from the video and are listed in Table 1.

### Procedure

Participants logged in to SONA to access the experiment. All study procedures were administered online. Participants were randomly assigned to one of four groups. All participants first viewed an eight-minute video about cellular respiration. Participants' roles varied during and preceding the video, depending on their assigned group. The participants that were randomly assigned to the guided notes and unguided notes groups took notes electronically (i.e., typing with their keyboards) during the video. The guided notes group received prompts during the video to serve as note-taking cues, whereas the unguided notes group did not receive such prompts. The prompts the guided notes group received were cued at the start of the video and were displayed on the right side of the visual field for the entirety of the video. Each prompt (e.g., ATP) appeared along with a corresponding

Table 1. Electronic prompts administered to the guided notes group and retrieval practice group

| Prompts |
|---|
| ATP |
| Prokaryotic cells |
| Eukaryotic cells |
| Aerobic Cellular Respiration |
| Glycolysis |
| Intermediate State |
| Krebs Cycle |
| The Electron Transport Chain and Chemiosmosis |

text box beneath it for students to type in their notes. The unguided notes group received one large text box on the right side of the visual field without any prompts. The participants randomly assigned to the no notes (control) and retrieval practice groups did not take notes during the video, and thus, did not receive a text box during the video presentation. After the video, participants in the guided notes, unguided notes, and retrieval practice groups had four minutes to review. This amount of review time was chosen to allow for approximately 30 seconds of processing for each of the eight prompts in the guided notes and retrieval practice groups. During this time, participants in the retrieval practice group received the same prompts that the guided notes group received during the video, with those prompts serving as retrieval cues. The control group did not have a four-minute review and instead proceeded directly to the distractor task. For all groups, the distractor task was administered immediately before the final test, and instructed participants to recall as many countries as possible for two minutes. After the distractor task was finished, participants completed the final test, which lasted approximately seven minutes.

## Results

### Prior Knowledge

After the final test, we asked students if the concepts described in the video were familiar to them. We wanted to ascertain the degree of prior knowledge that participants had with the content, as this could have influenced the final recall results. Although some participants indicated that they were highly familiar with the content ($n$ = 7), their scores did not vary significantly from those who were not highly familiar with the content for either multiple choice questions, $\Delta M$ = 0.02, 95% CI [-0.21,0.26],$t(7.22)$= 0.24,$p$ = 0.820 or true/false questions, $\Delta M$ = 0.06, 95% CI [-0.16,0.27],$t(7.22)$ = 0.62, $p$ = 0.557. Given no differences in scores, we included these individuals in the analyses below.

### Performance

Performance as a function of group and question type is plotted in Figure 1. We conducted a 4 (Groups: Control, guided notes, retrieval practice, unguided notes) x 2 (Question type: Multiple choice, true/false) repeated measures ANOVA. There was no main effect of group, $F(3, 45) = 0.41$, $p = 0.744$, partial eta squared = 0.027. There was a significant main effect of question type, $F(1, 45) = 39.06$, $p < 0.001$, partial eta squared = 0.465. Lastly, there was no significant interaction between group and question type, $F(3, 45) = 0.96$, $p = 0.422$, partial eta squared = 0.060.

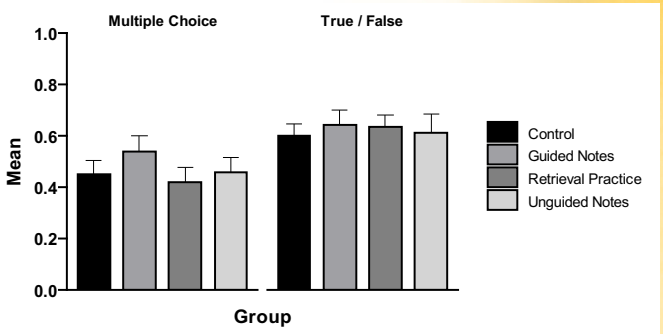


Figure 1. Mean performance as a function of group and question type. Error bars represent the standard error of the mean.

## Discussion

Although research has shown that both guided notes and retrieval practice are potent learning strategies, we are unaware of any prior studies that have directly compared the benefits of these two strategies. We investigated the effects of retrieval practice and note-taking on memory performance. Participants viewed a video on cellular respiration (a concept readily taught in a variety of biology courses), during which they either took notes (with guided prompts or unguided prompts) or did nothing (retrieval practice and control group). After viewing the video, participants in the retrieval practice group attempted to recall key concepts from the video (having received the same prompts as the guided notes group). Participants in the control group completed no extra review of the video, and provided a baseline level of performance. Results suggested that participants scored higher on true/false questions compared to multiple choice questions; however, performance did not vary between our groups. These results are inconsistent with prior literature showing robust testing effects (Roediger & Karpicke, 2006).

In contrast to the prior literature, we did not find a benefit of retrieval practice (Roediger & Butler, 2011). One potential reason is that the prompts provided during the retrieval practice phase were related to major concepts from the video (e.g., ATP). These types of concepts are wide in scope and multifaceted, requiring recall of many intricate details. As such, a student could have been overwhelmed during the recall phase, failing to retrieve some (or most) pertinent content. Although retrieval success is not required to benefit from retrieval practice (Kornell et al., 2015), we might have observed more benefits of retrieval practice with more targeted prompts.

### Limitations

There were several limitations within our experiment. The first limitation is that we failed to collect data from 76 participants,

which was deemed necessary to detect a potential within-between interaction at 95% power. Given the limitations in sample size, these results are considered preliminary findings.

A second limitation is that despite being explicitly instructed to take notes, a fair number of participants (n = 9) did not. There are a variety of reasons that students might not have taken notes, including lack of effort and/or a lack of understanding of the content. Additionally, the participants who did take notes might not have taken adequate notes (which is a perennial issue; see Friedman, 2014 for a review). Future research could explore ways to increase note-taking behavior, as well as improve the quality of their notes.

A third limitation is that final performance was assessed only a few minutes after the material was presented. A possible future direction would be to increase the delay between initial learning and the final test to assess potential differences in performance with an increased retention interval.

A fourth limitation is that, as opposed to the note-taking groups, participants in the retrieval practice and control groups might have paid less attention to the video. Research has recently shown that taking notes can help prevent mind-wandering during a lecture (see Wong et al., 2021), which has been shown to impair learning (see Blondé et al., 2022). A future study could investigate the role of distraction by altering the structure of the video. For instance, periodic "checkpoints" could be inserted into the video to verify that participants are paying attention. In any case, if guided notes (or note-taking in general) help keep students focused, this is an important issue to explore further. Perhaps a particularly potent strategy would be to have students engage in guided notes during lecture to keep them focused, with subsequent retrieval practice occurring afterwards to facilitate recall of the concepts. Conversely, intermittent retrieval prompts during the video would also (presumably) keep students focused, which might allow for a fairer comparison regarding the efficacy of note-taking versus retrieval practice.

A fifth limitation was that participants in the retrieval practice group may have inaccurately recalled information during the practice test phase. If an item was not recalled correctly on the practice test, the learner had no opportunity to correct their mistake given that no feedback was provided. Therefore, an item missed during the practice test would have a high probability of being missed on the final test. Future studies could mitigate this concern by providing correct-answer feedback after the recall phase (or an additional opportunity to review the video).

A final limitation is that we utilized a video that was accessible to the general public and may have covered concepts that were familiar to participants. Despite this possibility, participants' final test scores did not provide any indication that they were overly familiar with the material (i.e., performance scores were below ceiling). Furthermore, those that did indicate high familiarity with the content scored no better than their low-familiarity counterparts.

## Conclusions

We explored the benefits of note-taking (particularly guided notes) versus retrieval practice in learning from a video lecture on cellular respiration. Although participants in the guided notes group scored the best (numerically) on the final test, this difference was not statistically significant. Future research is needed to explore whether these results would emerge if we controlled for potential attentional differences, whether a combination of strategies would be more effective than any one strategy in isolation, and whether these results will persist across a longer retention interval.

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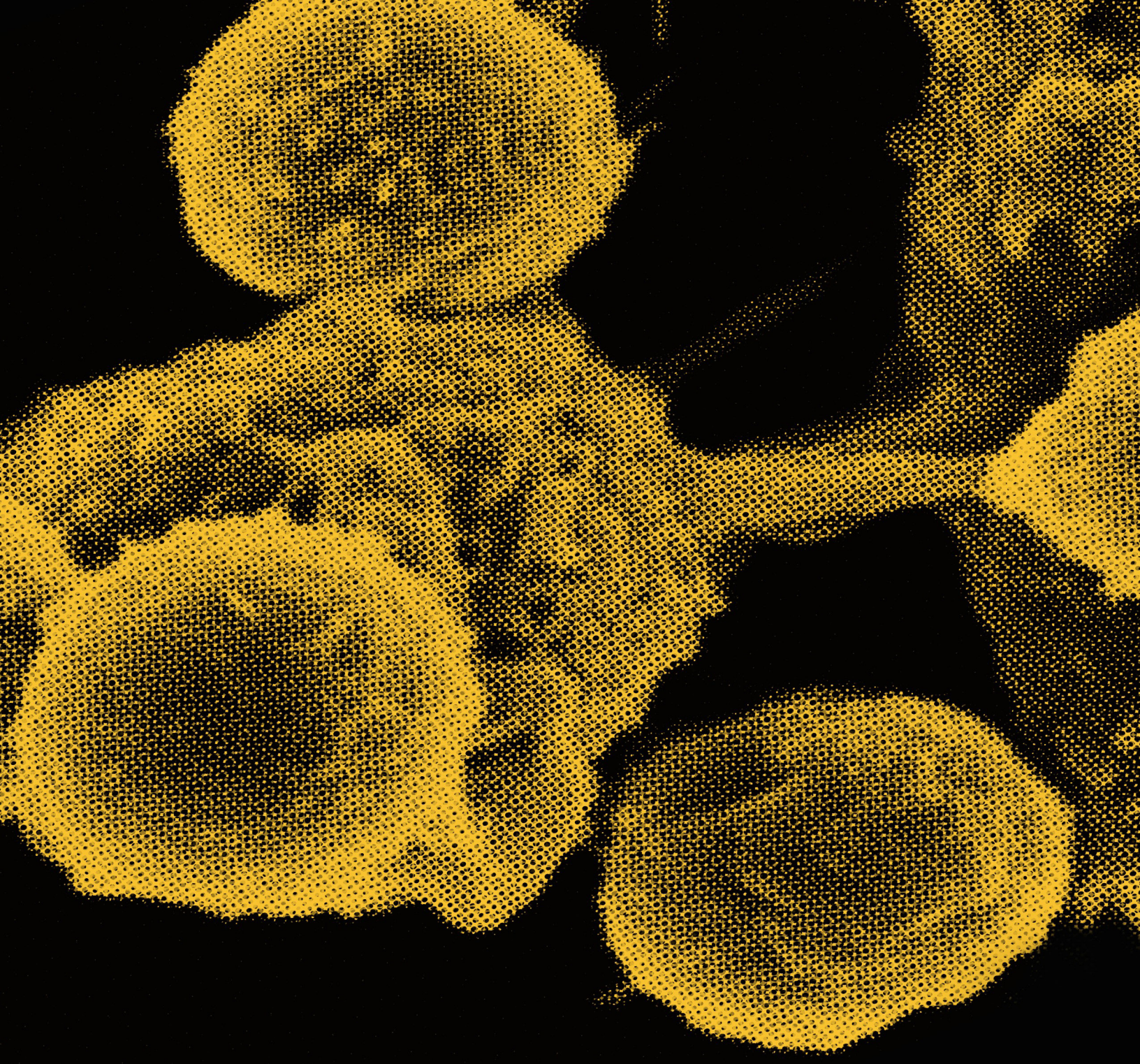

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Volume 5, 2023