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Lofi: Modern Concentration

Hreish Ramzi

San Marcos Unified School District, San Marcos, USA
Email: rhreish06@yahoo.com

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Abstract

Lofi, or low-fidelity music, is an emerging music genre in the modern age. Most studies previously done outlining connections between music and concentration have primarily focused on classical music and binaural beats, while little attention has been paid to alternative music. Hence, this study aims to address an imbalance by providing insight into another kind of music and its impact on concentration-lofi. How effective is lofi in comparison to classical music when it comes to promoting concentration? 26 participants took part in a study carried out through experimental design which sought to compare the relationships between music—both lofi and classical music—and test performance. The assumption was made that test performance was correlated with concentration, and methods were aimed to establish such. Overall, lofi improved test scores substantially, though to slightly inferior levels to classical music, suggesting a potential alternative for the use of classical music or binaural beats when aiming to promote concentration.

Keywords

Music, Classical, Lofi, Concentration

1. Literature Review

Many researchers claim that listening to music provides benefits in a working environment: clinical psychologist Francis Cholle explained one may want to create an emotional connection to a piece of music in order to improve their intuition [1] and E. Schellenberg and Teresa Lesiuk concluded that music enhances spatial abilities [2] and mindfulness [3]. However, different kinds of music impact concentration in varying degrees—one study, for example, found classical music was more effective than rock in promoting cognitive benefits such as attention and memory [4]. Thus, this paper sought to explore the kinds of music that best promote concentration before introducing a new genre of music into the conversation.

1.1. Classical Music

The idea that classical music, specifically that written by Mozart, can be used to improve human cognition is dubbed "The Mozart Effect" [5]. Tested within a wide range of parameters, its consistency is rather appealing. First off, Sara Bottiroli, from the National Neurological Institute in Italy, and her research team focused on the effects of classical music relating to adults. By having given them a list of vocabulary words to memorize and then having tested them on their memory and application of these words—all while listening to classical music, white noise, or nothing—they found that "memory performance increased when classical music played in the background compared to white noise and no music conditions" [6]. While the study affirmed the presence of the Mozart Effect, it raised the question of whether this phenomenon was consistent on a wider spectrum. Luckily, there have been many studies that looked at the Mozart Effect on unique groups. For one, a professor in the Department of Psychology and manager of the Music & Cognition Lab Experiments at the University of Toronto, Glenn Schellenberg found "[classical] music groups had larger increase across the four main areas of intellectual ability measured" when having tested the impacts of listening to classical music among children under the age of twelve [2]. Furthermore, Badrie Mohammad and two others found that students with intellectual disabilities also experience the Mozart Effect, having increased their calmness, concentration spans, and performance skills while listening to classical music and having taken SAT practice tests [7]. Jenkins even conducted a study in which mice listened to classical music and raced against mice who did not. Interestingly, the mice listening to classical music finished the maze much faster. This not only served in helping Jenkins draw the conclusion that classical music has a universal reach in the improvement of cognitive ability, but the research also served to dispute the misconception that cognitive improvements from classical music, or music in general, are only associated with whether or not a participant enjoys the music—"enjoyment and musical appreciation [was] unlikely to [have] been the basis of the improvement" [5]. In sum, several research projects done on the effectiveness of the Mozart Effect have all corroborated its presence, each having done so among different pools of participants. Thus, the Mozart Effect was observed to be a universal phenomenon that improves concentration.

The first explanation for the cognitive effects of classical music came in the form of the "cognitive-capacity hypothesis (CCH)", an idea presented by Sara Bottiroli and her crew; it is the idea that everyone has a limited pool of resources—essentially energy—available for them to be able to process things through their brains [2]. Attention cannot be spread too thin among multiple demanding sounds and thoughts. This hypothesis explained two separate conclusions reached by William Ford Thompson, chair of the Department of Psychology at Macquarie University, and Devarajan Sridharan, Associate Professor for the Indian Institute of Science: Thompson observed listening to background

music was most likely to "disrupt reading comprehension" when played louder, and more likely to "allow for continuous and spontaneous recovery from acoustic interference" when played quieter [4]. In other words, he believed louder music inputs more information into the mind in comparison to quieter music, a theory that aligned well with the reasoning behind the CCH; quieter music requires less energy to process. Next, Devarajan Sridharan observed the brains of multiple people as they listened to music at different speeds, all with similar volumes. It was concluded that music with generally slower transitions (changes in the music) is more easily processed, especially among non-professional musicians [8]. Minds were better able to focus on the work at hand instead of having to constantly react to musical elements such as beat drops, bridges, or melodies, once more aligning with the CCH. Moreover, one of 22 studies on psychology and neurology published by Yi-Nuo Shih found music with lyrics—something extremely rare within the classical genre—is "likely to reduce worker attention and performance", an idea which also corroborates the CCH in that lyrics provide more inputs to the brain which must be actively responded to, taking up space [9]. Thus, the cognitive capacity hypothesis provided an informative and corroborated explanation for the increase in cognitive function observed when listening to classical music.

The CCH, however, was not the only explanation for the Mozart Effect; classical music had also been shown to activate parts of the brain highly associated with attention and other cognitive benefits. For example, Sridharan's study also concluded that the detection of musical transitions stimulates the ventral and dorsal networks—these networks are crucially responsible for attention [8]. Similarly, Jenkins conducted an experiment in which he observed and compared the activated segments of the mind during puzzle-solving and listening to Mozart (each was done separately). The result? Jenkins concluded listening to Mozart "primes the activation of [the] areas of the brain… concerned with spatial reasoning and puzzle solving" [5]. Clearly, then, it can be stated classical music activates parts of the mind extremely supplemental to attention and reasoning. Thus, classical music is not only lowly demanding of the mind's cognitive capacity, but it also makes great use of the space it takes up, increasing cognition and helping to enjoy the process.

In sum, classical music proved its ability to promote increased cognitive performance among a wide variety of people—even animals. This was shown to be a result of its low cognitive demand and high stimulation of valuable brain systems.

1.2. Binaural Beats

The second type of music proven to be competitive classical music is binaural beats. Binaural beats are more of an audio than a music genre, but they still serve the same purpose—to increase cognition.

Some of the first studies looking deep into the effects of binaural beats included one done by Dale S. Foster, who is the founder and President of Memphis Integral Neurofeedback Institute. He found that binaural beats increase relaxa-

tion levels among listeners; when someone is relaxed, they are better at focusing on more difficult tasks [10]. This relaxation also explained the result of a study done a few years later by Susan Kennel, who found "Parents and adolescents stated homework problems due to inattention improved during [a] 3-week study" in which students with impairments such as autism and ADHD were asked to listen to binaural beats whenever they were to have done homework [11]. It seemed that because the children were not as relaxed, they tended to take their attention away from their work before the study—but when they were introduced to binaural beats, this inattention sharply decreased because they felt more tranquil [11]. Thus, binaural beats were proven to be effective at improving cognition. But to see just how effective, the science behind them must be understood.

Firstly, music with binaural beats has many similarities with classical music that contribute to their cognitive benefits, including lack of lyrics and soft, quiet tendencies, meaning they took up less cognitive power in accordance with the CCH. However, they did not appear to have the same impacts on the mind as classical music. No studies were found, for example, demonstrating dopamine output or activation of the dorsal or ventral networks when listening to binaural beats. Binaural beats change brain waves instead.

The idea behind binaural beats is to play one frequency in one ear and one in the other which are slightly offset. As Thomas DeLauer explained in his video essay from 2019, the slight offset of these frequencies confuses the mind, producing a final frequency equivalent to the difference between the two initial frequencies [12]. By combining two frequencies with a difference between eight to thirteen hertz, for example, the listener can change the state of their brainwaves, entering the alpha state. This phenomenon is called brainwave entrainment, or BWE [12].

For most people, beta waves are most common in day-to-day life. Sandro Aparecido-Kanzler provided an in-depth explanation of the differences between beta waves and alpha waves—alpha waves being the main goal when listening to binaural beats. Examples of being in a beta state included being in conversation, arguing, or being, generally, in more intense and mentally demanding situations. Unfortunately, spending too much time in this state leads to heightened levels of anxiety and stress [13]. Alpha waves, on the other hand, were associated with "relaxation, visualization, [the creative processes]…, and memory optimization", all extremely useful for cognitive performance [13]. By way of binaural beats "altering attentional focus, and [levels] of awareness, *i.e.*, the elements of consciousness itself", it was indeed possible to use BWE to entrain someone's mind to exhibit the typical mannerisms associated with alpha waves, which—as stated by Aparecido-Kanzler—can vastly improve levels of concentration [14]. Better yet, he claimed that alpha waves do not seem to have a time limit before they hold negative impacts, unlike beta waves.

Altogether, the impacts of binaural beats are like the Mozart Effect in that the music itself is quiet, absent of lyrics, and slowed in both circumstances. Howev-

er, the uniqueness of binaural beats lies in their ability to entrain the mind to fit into a desired brainwave state to replicate the effects of such a state.

1.3. Gap

The Mozart Effect and binaural beats, while different, share similarities regarding their impacts on cognitive ability, specifically that of concentration. However, there are still many genres of music that share similar traits without much research in the modern day. One such genre is lofi. Lofi—or low fidelity beats—incorporates, in general, slow tempos, predictable transitions, limited lyrics, and soft tones. Many lofi playlists on YouTube and Spotify claim that it can improve things like focus and that it is beneficial to listen to when studying [15]. Due to these insights and in combination with the lack of research in the area, it seemed interesting whether listening to lofi yields lesser, similar, or greater benefits when compared to classical music.

2. Methodology

To test the effectiveness of lofi music in promoting concentration, it was compared to both classical music and silence by use of experimental design. Silence acted as a control, while classical music was used as a benchmark to measure the effectiveness of lofi music.

Lofi was not compared to binaural beats. Though binaural beads do promote concentration, they are more of a concept than a specific genre of music. It was difficult to compare a musical element to a musical genre due to there being no way to directly sample binaural beats. To test them, one would have needed to, for example, have students listen to ambient music—its own genre—and songs within the genre with binaural beats. This made it difficult to separate the effects of binaural beats from ambient music. While evaluating their impact was applicable to the research, it would have sharply decreased the practicality of this study. Performing a separate study to identify the benefits of binaural beats was not only complex but also held little additional merit, considering classical music is already a well-supported music genre in the field relating music to concentration. Despite this, binaural beats still provided critical insight into the hypothesis, which will be expanded upon later.

2.1. Experimental Design

Experimental design was used to carry out the experiment. This required an identification and understanding of control, non-control variables, independent, and dependent variables. Following this, an informed hypothesis was made as to the outcome of the study.

Experimental design was chosen as the methodology due to the simplicity of comparing quantitative data in a science-focused study. A qualitative study of this phenomenon may have resulted in bias if questions such as "to what extent, on a scale from one to ten, did you feel yourself concentrating while listening to

this music" were asked based on whether participants enjoyed the music, possibly creating a sort of placebo effect. Not only would there be little guarantee that participants were responding precisely, but earlier studies have shown the irrelevance of emotions when it comes to identifying the relationship between music and concentration; there are countless reasons, including the CCH and neural activation, which provide more significant insight into the impacts of classical music through statistical means rather than opinion-based ones.

2.2. Variable Control

There were three allotted test days in which 26 juniors (aged 15 to 17) from a southern Californian high school assembled in one classroom to take a 20-minute assessment while listening to either nothing, classical music, or lofi, and the kind of music changed each day. The participants were sampled randomly from a pool of 208 juniors from the same Californian high school. Similar to those in Mohammad's study, the tests were sampled from Khan Academy's SAT practice tests [7]. This was done because the SAT requires exposure to algebra and geometry for the math section, both of which are taken in some form before reaching junior year at this high school [15]. Students first read an article and answered a subsequent set of eight comprehension questions followed by another eight questions drawn from the math section (no calculator was allowed). In accordance with the SAT timing structure, the time limit set for all students taking the test was 20 minutes. This way, students were scored based on questions of similar difficulty and all were given an equal opportunity to perform well. If students did not finish in the allotted time, each unfinished question would be marked as a zero.

There were several variables that were meant to remain unchanged between test days; in a vacuum, the music listened to by students should be the only alteration. Thus, it was important to keep track of these variables and note which ones were harder to keep consistent in comparison to others. To prevent fatigue, each test was given on a different day, and to minimize variation, they were each given at the same time each day, with the same time limit, and the same question difficulty. The only variable difficult to control was the changing levels of educational stress or tiredness students experienced from test day to test day. Because of this, students who felt particularly fatigued were asked to come back and take their test another day to minimize fatigue. If any students were caught cheating, their scores were removed from the data set (none were). To prevent cheating, the room was actively monitored before and during the tests up until everyone was finished.

To measure the dependent variable of test performance, both the mean scores of each test, as well as their respective standard deviations, were observed to determine effectiveness and reliability based on distribution.

2.3. Hypothesis

The effectiveness of both classical and lofi was measured by finding the mean

scores and standard deviation for each of the three tests and comparing the improvement between silence and classical music to that between silence and lofi; I hypothesized that the improvement between lofi and silence would be slightly less than that between silence and classical music, though still significant: lofi scores would be within 3% of the average classical music test score.

Such a prediction was made because lofi has many similar attributes to classical music. For one, the average beats per minute (bpm) of Mozart and Laffey, the most streamed lofi producer, are only eight bpm apart. Moreover, Mozart's music is only written in 432 hertz. Luckily, lofi music is also commonly written in 432 hertz, with hundreds of playlists dedicated to music only tuned to that frequency—the playlist used for lofi testing was at such. Additionally, the piano and violin are used in the vast majority of both lofi and classical music, the main difference being lofi typically has an overlapping drum beat to go along with these instruments. In regards to the CCH, this means lofi provides the brain with enough capacity to function well, just as classical music does with its moderate tempo and calming frequency and instruments. However, it should be noted that lofi music sometimes consists of unique, inconsistent beats.

As for binaural beats—more specifically brainwave entertainment—countless experts, including Sabrina Cruz, have cited similarities between the impacts of lofi and binaural beats. In her video essay titled The Science Behind Lofi Music, Cruz explained how lofi results in a "general increase in sensations such as increased relaxation and entering into a meditative state", almost the exact traits of someone listening to alpha binaural beats [16]. As previously expressed, this state is most optimal when trying to achieve relaxation and focus, with little to no consequences.

Collectively, prior research on lofi led to the conclusion that lofi would promote similar levels of concentration to classical music because it exhibits similar musical elements to classical music and promotes a mental state similarly associated with alpha brain waves. However, the slightly unpredictable nature of some lofi beats may—in reference to the CCH—marginally decreased my prediction regarding its impact on concentration.

3. Analysis

The purpose of the data was to conclude whether or not lofi music compares to classical music when it came to improving concentration based on which genre improved test results in comparison to a baseline score, derived from taking a test in silence.

3.1. Results

When test-taking without music (silence), the average score for all 26 students was 10.18 out of 16, or 63.63%. When test-taking with classical music, the average score was 75.38%. When test-taking with lofi, the average score was 72.63%. The standard deviation of students listening to silence was 1.9, while it was 1.4

for classical music and lofi.

3.2. Analysis and Recommendations

It was hypothesized that classical music would surpass the effects of lofi music by no greater than three percent, which was true. Although lofi music did not score higher than classical music, the scores of lofi test taking were indeed closer to those of classical music than silence and the standard deviation of lofi scores was identical to that of classical music. Thus, the conclusion was drawn that low-fidelity music improves concentration as hypothesized, doing so at slightly lower levels than classical music—shown through the average test scores. Its reliability to repeat this outcome is demonstrated through standard deviation.

This raised a few other questions. Firstly, were the benefits of lofi in accordance with the hypothesized reasoning—the idea that lofi is similar to classical music and alpha binaural beats and will thus yield similar effects—or were there other reasons which could have led to its success in promoting concentration? And if lofi was beneficial for reasons not associated with classical music or the CCH, then were there any other kinds of music that include the musical elements that separate lofi from classical music? They too could be just as effective at promoting concentration.

These questions, particularly the former, would require extensive and expensive future research, likely requiring access to brain imaging, whereby researchers could analyze the brain's behavior when exposed to lofi in opposition to classical music, possibly comparing lofi brain imaging to the results of Jenkins (previously mentioned) who wrote about the impact of classical music on the mind based off actual brain scans. Seeing if they act similarly or not, researchers may need to look deeper into the parts of the brain that lofi interacts with and classical music does not, and vice versa. This process could either affirm the hypothesis of similarities or spawn an entirely new theory regarding music and its impact on concentration.

3.3. Limitations

The main limitation of the research was the absence of repetition; though there were several participants in the study, each only took each quiz once. Thus, the results of the study may have varied slightly if it were to be repeated a few more times. Having students take three or even five different tests listening to each kind of music is recommended for future research, as it would improve the integrity of the study by decreasing margins of error and outliers in things like question difficulty, participant effort, and so on. The more participants there are in the future, the more significant this statement becomes. In sum, the methodology of my study held up well, but the reach and frequency of the study itself should be expanded upon to obtain more concrete results.

Another limitation was in the weaker statistical analysis of the results. While means and standard deviation provided decent insight into the context of the

results, having calculated p values and other statistical relationships between data may have been better to improve the integrity of the study. Such is certainly recommended for future quantitative studies surrounding lofi and concentration.

3.4. Implications

The knowledge that lofi promotes concentration at levels slightly below classical music—the most well-researched and best-proven music genre when it comes to concentration—can make more practical many different aspects of modern learning. Though classical music still seems to be the better option by a slight margin, lofi can serve as a substitute when needed in order to help keep things from feeling repetitive.

Students and workers, firstly, can introduce lofi into their working sessions as a viable substitute for classical music or binaural beats if they are intent on increasing their focus while doing everyday tasks that require higher levels of concentration. Though lofi may not promote concentration to the exact levels of classical music, it can offer a new kind of background for those who may have gotten bored of whatever they have been listening to in the past. Even if that's not the case, if people know about the promise of lofi music in the working area and are more intrigued by it than classical music or binaural beats, then they may choose to set aside their podcasts and rap playlists which—though enjoyable—are genres which would be to be terrible for focus in accordance to the CCH. Additionally, teachers can use this study to promote the use of lofi in their classrooms. If the class collective would rather do so, then listening to lofi while doing classwork will still be able to replicate, to a similar degree, the effects of classical music. This can help to create a more flexible learning environment, in which students have the option to listen to what they want when they want, and not have to be subjected to just classical tunes when it comes time to write an essay or take a math test. In sum, with millions of lofi tracks on Spotify alone, teachers, students, and workers can continue to reap the benefits of listening to concentration-promoting music while doing work, while also broadening their spectrum of choice.

Lastly, the more information is uncovered on the relationship between music and concentration, the more applicable these implications become. There may very well be an uncovered genre of music that promotes concentration far better than what has been currently observed, classical music or otherwise.

4. Conclusion

In conclusion, the similarities between classical music, binaural beats, and lofi inspired a study done through experimental design which sought to identify the relative impacts of listening to music and concentration, shining light on a more modern genre of music. In the future, a similar attempt should be taken to measure either lofi or a new genre of music but should also be done on a larger scale, sampling from more schools, taking more tests, increasing participants, and so on.

Likely because of similarities between lofi and classical music and binaural beats, lofi music spawned benefits at levels comparable to classical music—certainly more comparable than silence—suggesting that it can and should serve as a viable alternative to classical music or binaural beats if needed.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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Appendix

Subject of Appendix

This appendix contains the exact questions sampled from Khan Academy's SAT prep course which were used in this study.

Appendix

Exam A.

At last, Old Widow Lau was done haggling with the driver and we stepped inside Father's shop. It was north-facing, quite dim inside, and perhaps this was why Father did not see us at first. He was busy with a customer, a man who was distinguished-looking, like the scholars of two decades before. The two men were bent over a glass case, discussing the different qualities of inksticks. Big Uncle welcomed us and invited us to be seated. From his formal tone, I knew he did not recognize who we were. So I called his name in a shy voice. And he squinted at me, then laughed and announced our arrival to Little Uncle, who apologized many times for not rushing over sooner to greet us. They rushed us to be seated at one of two tea tables for customers. Old Widow Lau refused their invitation three times, exclaiming that my father and uncles must be too busy for visitors. She made weak efforts to leave. On the fourth insistence, we finally sat. Then Little Uncle brought us hot tea and sweet oranges, as well as bamboo latticework fans with which to cool ourselves.

I tried to notice everything so I could later tell GaoLing what I had seen, and tease out her envy. The floors of the shop were of dark wood, polished and clean, no dirty footprints, even though this was during the dustiest part of the summer. And along the walls were display cases made of wood and glass. The glass was very shiny and not one pane was broken. Within those glass cases were our silkwrapped boxes, all our hard work. They looked so much nicer than they had in the ink-making studio at Immortal Heart village.

I saw that Father had opened several of the boxes. He set sticks and cakes and other shapes on a silk cloth covering a glass case that served as a table on which he and the customer leaned. First he pointed to a stick with a top shaped like a fairy boat and said with graceful importance, "your writing will flow as smoothly as a keel cutting through a glassy lake". He picked up a bird shape: "Your mind will soar into the clouds of higher thought." He waved toward a row of ink cakes embellished with designs of peonies and bamboo: "Your ledgers will blossom into abundance while bamboo surrounds your quiet mind."

As he said this, Precious Auntie came back into mind. I was remembering how she taught me that everything, even ink, had a purpose and a meaning: Good ink cannot be the quick kind, ready to pour out of a bottle. You can never be an artist if your work comes without effort. That is the problem of modern ink from a bottle. You do not have to think. You simply write what is swimming on the top of your brain. And the top is nothing but pond scum, dead leaves, and mosquito spawn. But when you push an inkstick along an inkstone, you take the

first step to cleansing your mind and your heart. You push and you ask yourself, What are my intentions? What is in my heart that matches my mind?

I remembered this, and yet that day in the ink shop, I listened to what Father was saying, and his words became far more important than anything Precious Auntie had thought. "Look here," Father said to his customer, and I looked. He held up an inkstick and rotated it in the light. "See? It's the right hue, purple-black, not brown or gray like the cheap brands you might find down the street. And listen to this." And I heard a sound as clean and pure as a small silver bell. "The high-pitched tone tells you that the soot is very fine, as smooth as the sliding banks of old rivers. And the scent—can you smell the balance of strength and delicacy, the musical notes of the ink's perfume? Expensive, and everyone who sees you using it will know that it was well worth the high price."

I was very proud to hear Father speak of our family's ink this way.

Exam B.

Beginning of reading passage.

Anyone watching the autumn sky knows that migrating birds fly in a V formation, but scientists have long debated why. A new study of ibises finds that these big-winged birds carefully position their wingtips and sync their flapping, presumably to catch the preceding bird's updraft—and save energy during flight.

There are two reasons birds might fly in a V formation: it may make flight easier, or they're simply following the leader. Squadrons of planes can save fuel by flying in a V formation, and many scientists suspect that migrating birds do the same. Models that treated flapping birds like fixed-wing airplanes estimate that they save energy by drafting off each other, but currents created by airplanes are far more stable than the oscillating eddies coming off of a bird. "Air gets pretty unpredictable behind a flapping wing," says James Usherwood, a locomotor biomechanist at the Royal Veterinary College at the University of London in Hatfield, where the research took place.

The study, published in Nature, took advantage of an existing project to reintroduce endangered northern bald ibises (Geronticus eremita) to Europe. Scientists used a microlight plane to show hand-raised birds their ancestral migration route from Austria to Italy. A flock of 14 juveniles carried data loggers specially built by Usherwood and his lab. The device's GPS determined each bird's flight position to within 30 cm, and an accelerometer showed the timing of the wing flaps.

Just as aerodynamic estimates would predict, the birds positioned themselves to fly just behind and to the side of the bird in front, timing their wing beats to catch the uplifting eddies. When a bird flew directly behind another, the timing of the flapping reversed so that it could minimize the effects of the downdraft coming off the back of the bird's body. "We didn't think this was possible," Usherwood says, considering that the feat requires careful flight and incredible awareness of one's neighbors. Perhaps these big V formation birds can be thought of quite like an airplane with wings that go up and down.

The findings likely apply to other long-winged birds, such as pelicans, storks,

and geese, Usherwood says. Smaller birds create more complex wakes that would make drafting too difficult. The researchers did not attempt to calculate the bird's energy savings because the necessary physiological measurements would be too invasive for an endangered species. Previous studies estimate that birds can use 20 percent to 30 percent less energy while flying in a V.

"From a behavioral perspective it's really a breakthrough," says David Lentink, a mechanical engineer at Stanford University in Palo Alto, California, who was not involved in the work. "Showing that birds care about syncing their wing beats is definitely an important insight that we didn't have before."

Scientists do not know how the birds find that aerodynamic sweet spot, but they suspect that the animals align themselves either by sight or by sensing air currents through their feathers. Alternatively, they may move around until they find the location with the least resistance. In future studies, the researchers will switch to more common birds, such as pigeons or geese. They plan to investigate how the animals decide who sets the course and the pace, and whether a mistake made by the leader can ripple through the rest of the flock to cause traffic jams.

"It's a pretty impressive piece of work as it is, but it does suggest that there's a lot more to learn," says Ty Hedrick, a biologist at the University of North Carolina, Chapel Hill, who studies flight aerodynamics in birds and insects. However they do it, he says, "birds are awfully good hang-glider pilots."

The main purpose of the passage is to

A. describe how squadrons of planes can save fuel by flying in a V formation

B. discuss the effects of downdrafts on birds and airplanes

C. illustrate how birds sense air currents through their feathers

D. explain research conducted to study why some birds fly in a V formation

The author includes the quotation "air gets pretty unpredictable behind a flapping wing" (paragraph 2) to

A. stress the amount of control exerted by birds in a flying V formation

B. explain that the current created by a bird differs from that of an airplane

C. indicate that wind movement is continuously changing

D. emphasize that the flapping of a bird's wing is powerful

What can be reasonably inferred about the reason Usherwood used nothern bald ibises as the subjects of his study?

A. The ibises were well acquainted with their migration route

B. The ibises were easily accessible for Usherwood and his team to track and observe

C. The ibises have a body design that is similar to that of a modern airplane

D. Usherwood knew the ibises were familiar with carrying data loggers during migration due to prior experimentation

What is the most likely reason the author includes the 30cm measurement at the end of paragraph 3?

A. To demonstrate the accuracy with which the data loggers collected the data

B. To present recorded data about how far an ibis flies between successive wing flaps

C. To provide the wingspan length of a juvenile ibis

D. To show how far behind the microlight plane each ibis is

What does the author imply about pelicans, storks, and geese flying in a V formation?

A. They create a similar wake to that of ibises

B. They communicate with each other in the same way as do ibises

C. They have the same migration routes as those of ibises

D. They expend more energy than do ibises

What is the main idea of the seventh paragraph?

A. Different types of hierarchies exist in each flock of birds

B. Future research will help scientists better understand V formations

C. Mistakes can happen when long-winged birds create a V formation

D. Long-winged birds watch the lead bird closely to keep a V formation

The author uses the phrase "aerodynamic sweet spot" in the beginning of the seventh paragraph most likely to

A. describe how the proper structural design of an airplane helps save fuel

B. show that flying can be an exhilarating experience

C. suggest that a certain position in a V formation has the least amount of wind resistan

D. describe the birds' synchronized wing movement

As used at the end of the seventh paragraph, "ripple" most nearly means

A. Fluctuate

B. Wake

C. Spread

D. Undulate

$x + y = 75$

The equation above relates the number of minutes, x, Maria spends running each day and the number of minutes, y, she spends biking each day. In the equation, what does the number 75 represent?

A. The number of minutes spent running a day

B. The total number of minutes spent running and biking each day

C. The number of minutes spent biking each minute spent running

D. The number of minutes spent biking each day

Which of the following is equivalent to $3(x + 5) - 6$

A. $3x + 9$

B. $3x - 1$

C. $3x - 3$

D. $15x - 6$

$x = y - 3$

$(x/2) + 2y = 6$

Which ordered pair (x,y) satisfies the system of equations shown above?

A. (3, 0)

B. (6, −3)

C. (36, 6)

D. (0, 3)

A company that makes wildlife videos purchases camera equipment for $32,400. The equipment depreciates in value at a constant rate for 12 years, after which it is considered to have no monetary value. How much is the camera equipment worth 4 years after it is purchased?

A. 10,800

B. 16,200

C. 29,700

D. 21,600

$x^2 + 6x + 4$

Which of the following is equivalent to the expression above?

A. $(x + 3)^2 - 5$

B. $(x + 3)^2 + 5$

C. $(x - 3)^2 + 5$

D. $(x - 3)^2 - 5$

Ken is working this summer as part of a crew on a farm. He earned $8 per hour for the first 10 hours he worked this week. Because of his performance, his crew leader raised his salary to $10 per hour for the rest of the week. Ken saves 90% of his earnings from each week. What is the least number of hours he must work the rest of the week to save at least $270 for the week?

A. 38

B. 33

C. 22

D. 16

The function f is defined by $f(x) = (x + 3)(x + 1)$. The graph of f in the xy-plane is a parabola. Which of the following intervals contains the x-coordinate of the vertex of the graph of f?

A. $-4 < x < -3$

B. $1 < x < 3$

C. $1 < x < 3$

D. $3 < x < 4$

If $2x + 8 = 16$, what is the value of $x + 4$?

A. −4

B. 0

C. 8

D. 4

Exam C.

Please read and answer the following questions:

Texas gourd vines unfurl their large, flared blossoms in the dim hours before sunrise. Until they close at noon, their yellow petals and mild, squashy aroma attract bees that gather nectar and shuttle pollen from flower to flower. But "when you advertise [to pollinators], you advertise in an open communication network," says chemical ecologist Ian Baldwin of the Max Planck Institute for

Chemical Ecology in Germany. "You attract not just the good guys, but you also attract the bad guys." For a Texas gourd plant, striped cucumber beetles are among the very bad guys. They chew up pollen and petals, defecate in the flowers and transmit the dreaded bacterial wilt disease, an infection that can reduce an entire plant to a heap of collapsed tissue in mere days.

In one recent study, Nina Theis and Lynn Adler took on the specific problem of the Texas gourd—how to attract enough pollinators but not too many beetles. The Texas gourd vine's main pollinators are honey bees and specialized squash bees, which respond to its floral scent. The aroma includes 10 compounds, but the most abundant—and the only one that lures squash bees into traps—is 1,4-dimethoxybenzene.

Intuition suggests that more of that aroma should be even more appealing to bees. "We have this assumption that a really fragrant flower is going to attract a lot of pollinators," says Theis, a chemical ecologist at Elms College in Chicopee, Massachusetts. But, she adds, that idea hasn't really been tested—and extra scent could well call in more beetles, too. To find out, she and Adler planted 168 Texas gourd vines in an Iowa field and, throughout the August flowering season, made half the plants more fragrant by tucking dimethoxybenzene-treated swabs deep inside their flowers. Each treated flower emitted about 45 times more fragrance than a normal one; the other half of the plants got swabs without fragrance.

The researchers also wanted to know whether extra beetles would impose a double cost by both damaging flowers and deterring bees, which might not bother to visit (and pollinate) a flower laden with other insects and their feces. So every half hour throughout the experiments, the team plucked all the beetles off of half the fragrance-enhanced flowers and half the control flowers, allowing bees to respond to the blossoms with and without interference by beetles.

Finally, they pollinated by hand half of the female flowers in each of the four combinations of fragrance and beetles. Hand-pollinated flowers should develop into fruits with the maximum number of seeds, providing a benchmark to see whether the fragrance-related activities of bees and beetles resulted in reduced pollination.

"It was very labor intensive," says Theis. "We would be out there at four in the morning, three in the morning, to try and set up before these flowers open." As soon as they did, the team spent the next several hours walking from flower to flower, observing each for two-minute intervals "and writing down everything we saw".

What they saw was double the normal number of beetles on fragrance-enhanced blossoms. Pollinators, to their surprise, did not prefer the highly scented flowers. Squash bees were indifferent, and honey bees visited enhanced flowers less often than normal ones. Theis thinks the bees were repelled not by the fragrance itself, but by the abundance of beetles: the data showed that the more beetles on a flower, the less likely a honey bee was to visit it.

That added up to less reproduction for fragrance-enhanced flowers. Gourds that developed from those blossoms weighed 9 percent less and had, on average,

20 fewer seeds than those from normal flowers. Hand pollination didn't rescue the seed set, indicating that beetles damaged flowers directly—regardless of whether they also repelled pollinators. (Hand pollination did rescue fruit weight, a hard-to-interpret result that suggests that lost bee visits did somehow harm fruit development.)

The new results provide a reason that Texas gourd plants never evolved to produce a stronger scent: "If you really ramp up the odor, you don't get more pollinators, but you can really get ripped apart by your enemies," says Rob Raguso, a chemical ecologist at Cornell University who was not involved in the Texas gourd study.

The main purpose of the passage is to

A. discuss the assumptions and reasoning behind a theory

B. present and analyze conflicting data about a phenomenon

C. show the innovative nature of a procedure used in a study

D. describe the aim, method, and results of an expiriment

As presented in the passage, Theis and Adler's research primarily relied on which type of evidence?

A. Historical data

B. Expert testimony

C. Random sampling

D. None of the above

Which statement about striped cucumber beetles can most reasonably be inferred rom the passage

A. They feed primarily on Texas gourd plants

B. They are attracted to the same compound in Texas gourd scent that squash bees are

C. They experience only minor negative effects as a result of carrying bacterial wilt disease

D. They are less attracted to dimethoxybenzene than honey bees are

The author indicates that it seems initially plausible that Texas gourd plants could attract more pollinators if they

A. increased their floral scent

B. emitted more varied fragrant compounds

C. targeted insects other than bees

D. did not have aromatic flowers

What did Theis and Adler do as a part of their study that most directly allowed Theis to reason that "bees were repelled not by the fragrance itself" (paragraph 6)

A. They gave bees a chance to choose between beetle-free enhanced flowers and beetle-free normal flowers

B. They compared the gourds that developed from naturally pollinated flowers to the gourds that developed from hand pollinated flowers

C. They increased the presence of 1,4-dimethoxybenzene only during the August flowering season

D. They observed the behavior of bees and beetles both before and after the flowers opened in the morning

The primary function of the seventh and eighth paragraphs is to

A. explain Theis and Adler's reasoning

B. summarize Theis and Adler's findings

C. describe Theis and Adler's hypotheses

D. illustrate Theis and Adler's methods

In describing squash bees as "indifferent" (paragraph 7), the author most likely means that they

A. could not distinguish enhanced flowers from normal flowers

B. largely preferred normal flowers to enhanced flowers

C. visited enhanced flowers and normal flowers at an equal rate

D. were as likely to visit beetle-infested enhanced flowers as to visit beetle-free enhanced flowers

According to the passage, Theis and Adler's research offers an answer to which of the following questions?

A. How can Texas gourd plants increase the number of visits they receive from pollinators?

B. Why does hand pollination rescue the fruit weight of beetle-infested Texas gourd plants?

C. Why is there an upper limit on the intensity of the aroma emitted by Texas gourd plants?

D. Why do Texas gourd plants stop producing fragrance attractive to pollinators when beetles are present?

If $x = (2/3)y$ and $y = 18$, what is the value of $2x - 3$?

A. 1

B. 21

C. 12

D. 10

Which of the following is equal to $(4x^2 + 6x)/(4x + 2)$

A. $x + 1 - 2/(4x + 2)$

B. X + 4

C. X

D. $x - 2/(4x + 2)$

$2x^2 - 4x = t$,

In the equation above, t is a constant. If the equation has no real solutions, which of the following could be the value of t

A. −1

B. 1

C. 3

D. −1

$(2/3)t = 5/2$

What value of t is the solution of the equation above?

A. 4/15

B. 15/4

C. 1.84

D. 0

$3x + x + x + x - 3 - 2 = 7 + x + x$

What is the value of x?

A. 3

B. −5/7

C. 1

D. 12/7

The width of a rectangular dance floor is w feet. The length of the floor is 6 feet longer than its width. Which of the following expresses the perimeter, in feet, of the dance floor in terms of w?

A. $2w + 6$

B. $w^2 + 6$

C. $4w + 12$

D. $w^2 + 6w$

$y > 2x - 1$

$2x > 5$

Which of the following consists of the y-coordinates of all the points that satisfy the system of inequalities above?

A. $y > 6$

B. $y > 5/2$

C. $y > 4$

D. $y > 3/2$

A group of 202 people went on an overnight camping trip, taking 60 tents with them. Some of the tents held 2 people each, and the rest held 4 people each. Assuming all the tents were filled to capacity and every person got to sleep in a tent, exactly how many of the tents were 2-person tents?

A. 30

B. 20

C. 19

D. 18