Using a Modified Ames Test and Drosophila melanogaster to Determine the Possible Mutagenic Effects of Low-Frequency Radiation on Living Systems.

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Abstract:

Cell phones and radar emit low-frequency radiation. This has driven some to question whether these items cause adverse effects such as cancer, given the amount of time people are exposed to them. Using *Drosophila melanogaster* (DM) and an *E. coli* variation of the Ames test, these living systems were exposed to both cell phone and radar low-frequency radiation. The DM were exposed to their respective devices for a 20 day duration of exposure (1, 2, and 8 hours), an active cell phone call, monitoring temperature and humidity more frequently. They were then monitored at the 10, 20, and 30 day mark for mutation and population. The mutation rate across all groups and all exposure times was 0%. The fruit fly culture tubes followed the same trend over the three generations, thus showing that exposure to both cell phone and radar low frequency radiation yielded no effect on the birthrate of DM. For the modified Ames test with *E. coli*, the results showed a coloration that was defined as being non-toxic. In conclusion, both tests support the theory that cell phones and radar do not increase mutation rates.

Introduction - General:

Radar first emerged in the mid 1940s as a tool for militaries, and cellular phones first emerged in 1973. Cell phones have become widely popular, being used for both work and entertainment. Radar has been used in a series of applications, such as air traffic control, and more recently becoming standard equipment in newer automobiles. The ubiquity of radar and cell phones, both of which produce microwaves, has led to a series of articles which proclaim that phone use is potentially dangerous. (NIH 2018, WHO 2014, Davis 1993) These articles have accused these items of causing terminal illnesses such as cancer. Other articles have stated that these devices do not present any potential harm. (Leszczynski 2010)

Another form of potentially hazardous radiation comes from car radar emitters. Car manufacturers have started placing radar emitters in the sides, front, and back of cars to decrease the likelihood of accidents. These radar emitters are used in safety features, such as blindspot protection, or for automatic braking. Six cases of testicular cancer were detected in 340 state troopers after having radar guns sitting in their laps from 1979-1991, and the incidence was found to be statistically significant. The study concluded that the radar gun within their laps was the only connection between all of these cases, and suggests that further research should be conducted. (Davis 1993).

In the event that these devices do cause adverse health effects, as the average person spends an average of 3.25 to 3.5 hours a day on their cell phone, with the top 20% going above 4.5 hours, depending on which source you view. (Matei 2019, Molla 2020) The average American spends around an hour a day driving (Volpe 2017). The amount of time that people spend on their phones has only been increased by the COVID-19 pandemic, as people have been required to attend meetings and do work from home. However, the amount that the average person drives has decreased due to the COVID-19 pandemic for the same reasoning that people now no longer need to go outside of their own home for their work.

Introduction - Past Research:

According to an NIH study in 2018, cell phones produce non-ionizing radiation, a form of radiation that is considered too weak for exposure of it to be considered dangerous (NIH 2018). Other studies have produced inconclusive evidence about whether cell phones generate harmful radiation. There are multiple reasons for the inconclusive data, such as the length of time that it takes illnesses such as cancer to develop.

These studies have tried different methods. Many studies use human trials, which presents volunteer bias. It was discovered that during the events of one study, that volunteers underwent the nocebo effect, where negative perceptions cause experiments to have a more negative outcome. The effect

caused the results to become inconclusive. (Leszczynski 2010) Many studies that have proven side effects failed to replicate their results in a double-blind scenario. (Roosil 2008)

While there are limited studies which show any effect of cell phones and radar on cancer, conclusive results have come out regarding other potential side effects. A study stated that there was a slight, but statistically significant increase in DNA fragmentation (Focke et.al 2010). The breakdown of DNA could affect a cell's ability to function properly, thus leading to other side effects mainly related to reproduction in humans. However, DNA fragmenation's cancer risk has only ever been in children born from sperm that underwent DNA fragmentation. (Henkel 2012) Another study assessed cell phones' effects on the brain-blood barrier, which prevents blood from passing into the fluid where neurons reside in the brain. The study investigated if radio waves causing an increase of 1-2 degrees Celsius could denature these proteins, but the results were inconclusive. One of the few studies that has conclusive results was a study conducted by a high schooler, where the mutation rate in *Drosophila melanogaster* increased from 1.5% in the control group to 5% in the experimental group of *Drosophila melanogaster*. Although this study showed increased mutation rates, very few details were included with this study to validate or to address the applicability to my study.

Introduction - This Research:

While new generations of iPhones and Androids have reportedly required less energy than those of previous generations. This experiment reports on investigations of the mutagenic effects of low-frequency radiation from cell phones and radar guns on both bacteria and *Drosophila melanogaster*, as both of these species have fast generation times and are frequent test subjects in genetic research. The Ames test was the original methodology that was to be used. The Ames test assesses the mutagenicity of a source. Given that cancer results from a mutation in cells, assessing whether a substance is mutagenic could also mean that a substance is carcinogenic.

Variations in the tested organisms should be noted. In Trial A, Wild Type *Drosophila melanogaster* were used. Wild Type *Drosophila melanogaster* have red eyes, wings, and dark grey bodies. These are the traits that were monitored. In Trials 1-4, a species known as Tiffany's Golden Delicious *Drosophila melanogaster* was used. This is because the Golden Delicious species has no wings, white eyes, and a light body. All of these genes are recessive, and thus were looked for, as any change in these 3 traits must be the result of a mutation. The variation of the Ames test switches the bacteria being used from *Salmonella* (Biosafety Level 2) to *E. coli* (Biosafety Level 1), in accordance to what I was able to conduct in my high school lab.

Methodology:

Note: The cell phone used in all of these trials was an Apple iPhone 7, and a Radar gun (Bushnell Velocity Speed Gun)

This methodology must be divided into two parts for the two facets of this study.

I. Usage of Fruit Fly (*Drosophila melanogaste*r) Culture Tubes

Preparation started with gathering culture tubes, and adding 2 tablespoons of Drosophila media (from Carolina) to the test tube. Approximately 10mL of tap water was then added and mixed with media. After allowing the media to set for 10-15 seconds, small pieces of straw were added for the *Drosophila melanogaster* to climb on. Afterwards, 4-6 fruit flies were added to each tube, and promptly sealed with a foam stopper. Only 4-6 flies were added due to their maturity, as they were all adults and would start reproducing. Each tube was then labelled in Sharpie: Letter(Either Control(C), cell phone(P), or radar(R)) - the number of the tube (1-10) - and then time it was exposed for (1 Hour - No Denotation, 2 Hours - 2H, or 8 Hours - 8H). There were 5 Trials conducted: Trial A, 1, 2, 3, and 4.

Trial A was conducted with few control factors. After preparation, the cell phone was placed inside the Tupperware container of the P group, and the radar gun would be turned on and placed next to the container of the R group. The time exposed was recorded, and at the end of each time exposed temperature and humidity were recorded. The *Drosophila melanogaster* used in this trial were not Tiffany's Golden Delicious, rather Wild Type *Drosophila melanogaster*. After 21 days, the fruit flies were observed and their traits were recorded. The traits looked for in these flies were red eyes vs. white eyes, and Wings vs. Wingless; they were sorted based on whether they'd been a control, exposed to a cell phone, or exposed to radar.

Trials 1-4 were conducted using these procedures, but with different variations of time exposed groups. After preparations, tubes were monitored daily, with temperature and humidity being recorded at 8am, 12pm, 4pm, and 8pm (all EST). The setting for this experiment was the second floor of my home, due to quarantine from the COVID-19 pandemic. The cell phone group was moved to a back area, and the radar group was moved to a bathtub. This way they would be separated by a minimum of 15 feet(4.57m), and they would each be at least 6 feet(1.82m) from the control group. The cell phone would be called, and the radar gun would be turned on, and the trigger was held down with a rubber band. While being exposed to their device, the flies were exposed to artificial LED light, but at all other times were exposed to the sun through a window. Ten days into each trial, the culture tubes were taken outside, and all adults were taken out of the tubes and counted. The tubes were shaken in order to ensure that as many adults would be removed as possible. They were shaken onto a white sheet (I was limited to in-home materials), and counted by hand. The DM were then observed for mutations. The original, as received adults, at 10 days were then discarded. Similar steps occurred at 20 and 30 days, but instead of being discarded, the DM

were bagged and labeled according to the tube, cell phone or radar, and Generation. Generation 2 identifies those bagged on day 20, and Generation 3 identifies those bagged on day 30. Generation 3 were not exposed to an active cell phone or radar. Exposure time for Trials 3 and 4 were extended beyond 20 days to achieve exposure times closer to the expected goal. Therefore, the range of days exposed are 7/31-8/23 for Trial 3, and 9/3-9/26 for Trial 4. These actions were taken to ensure that the second and third generations of fruit flies were allowed the potential to mutate, as simply exposing the first generation would not yield sufficient potential for a mutation.

II. Usage of the Ames Test with *E.coli*

The *E. coli* variation of the Ames Test took place over 3 days at Princeton High School, and Personal Protective Equipment (PPE) was worn during all preparation and testing. All solutions were refrigerated before preparation, and were refrigerated when not needed.

The *E. coli* variation of the modified Ames test was performed using a SOS-Chromoplate Environmental Testing Kit acquired from Environmental BioDetection Products, Inc, Burlington, Ontario. The kit contained the following materials:

- Growth Medium for the SOS-Chromotest Bacterial Strain (A)
- *E. Coli* SOS-Chromotest Freeze Dried Bacteria (B)
- 10% DMSO in Saline; the SOS-Chromotest Diluent (C)
- Standard containing 10ug/ml 4-Nitro-Quinoline-Oxide (4NQO) in 10% DMSO Saline (D)
- Blue Chromogen Solution (F)
- General Equipment: Microwell Plates, Covers, and Tubes

The procedure outlined in the following paragraphs is based on the one provided in the testing kit. It is described here for completeness, and to detail the methodology used in testing. The kit came from Environmental BioDetection Products, Inc., and is specifically their Geno-Lab Kit.

Day 1: Two jars of Growth Media (A) and two jars of SOS Bacteria (B) were taken out of the refrigerator. The SOS Bacteria is *E.coli*, and the Growth Media helps it develop. The jars were opened, and funnels were placed into the jars of B, and then one jar of A was poured into each jar of B to create a 1-to-1 ratio of A to B. This solution is designated AB. Both jars of AB were then closed and mixed by inverting them for one minute. The jars were then placed into an incubator at 37 ºC for 17 hours and 26 minutes.

Day 2: The jars of AB were taken out of the incubator and exposed to the cell phone (labelled P) and radar (labelled R) in the same way that the fruit flies were exposed for 4 hours. Once they were completed, they were moved under the hood, with two well plates, one for each solution, and labelled based on which solution is used in the welling process (P and R). The plate had columns numbered 1-12, and rows lettered A through H. Solutions AB, saline (C), and 4-NQO (nitroquinoline-1-oxide) (D) were used in this welling. In column 1, 50µL of solution C were added to each well in rows A through H. Then in well 1-A, 20µL of solution D, and engage in serial dilutions, extracting 10µL of mixed solution for each well A through H and placing it in the next well sequentially, discarding the last 10µL from well H. This section was completed by Mr. Mark Eastburn, the adult mentor of my project. While this was being conducted, solution AB was poured from their jars into test tubes to see if the 10mL of solution had been created, which was. In columns, 2, 4, 6, 8, and 10, 50µL of solution C was added to each well. Then in well 1-A, another 10µL of solution C was added as well as 100µL of solution AB. The same serial dilution process of extracting 10µL of mixed solution and placing it in the next well in the column was conducted. This was repeated for both the Phone plate and Radar plate.

Once the welling was completed, they were left at room temperature for approximately 20 hours, however the kit used the term 'overnight'.

Day 3: Both plates were retrieved and 100µL of chromogen were added to each well, and after 20 minutes of letting color develop, photos were taken and analyzed.

Results:

Drosophila Melanogaster Trial A:

For Trial A, the wild type *Drosophila melanogaster* test data is provided in Figures 1 and 2. As described in the methodology, temperature and humidity were taken at the end of the time exposed. This data helps establish a series of variables that ensures that the fruit flies were in a consistent, favorable environment. It also allows the time exposed to be recorded, as a method of determining how much time it takes to cause mutations.

Date	Amount of time of exposure(nearest minute)	Temperature (Fahrenheit)	Humidity (%)	Amount of light exposure (minutes)
3/9	25 minutes	74	42	Unknown
3/10	45 minutes	78	58	Unknown

3/11	45 minutes	70	49	Unknown
3/12	40 minutes	68	76	Unknown
3/16	1 hour	65	54	1:16
3/18	1 hour	67	55	2:09
3/23	1 hour	63	50	1:02
3/24	1:15 hour	62	51	1:17
3/25	1 hour	62	49	1:02
3/26	1 hour	61	51	1:08
3/27	1 hour	61	60	1:40
3/28	1 hour	61	58	1:07
3/29	1 hour	60	57	1:04
3/30	1 hour	63	60	2:37

Figure 1: The monitoring factors for Trial A. Little light exposure, and consistent temperature and humidity are demonstrated through these data. Days were missed due to school and shifting venues.'

The wild type Drosophila *melanogaster* used for Trial A are red eyed and winged. For Trial A, the wild type *Drosophila melanogasters*' initial attributes were not inspected and recorded. *Drosophila melanogaster* that had died were also assessed in these calculations. All of these facets were then compiled into the figure below.

After 21 Days	RE/W	RE/NW	WE/W	WE/NW	Dead	Death Rate	Mutation rate
Control	380	188	0	0	153	26.94%	33.10%
Cell Phone	342	171	0	0	144	22.66%	25.73%
Radar	211	132	0	0	137	39.94%	38.48%

Figure 2: The Drosophila melanogaster assessed in Trial A. RE = Red Eyes; WE = White Eyes; W = Winged; NW = No Wings.

Mutation rate was determined by placing the number of *Drosophila melanogaster* who were not in the red eyed/winged (RE/W) category over the total number of *Drosophila melanogaster* in the 10 culture tubes in the group. The death rate was assessed in a similar manner. This data yields an average death rate of 29.84% and an average mutation rate of 32.44% of all specimens. One may interpret this data as radar having a higher death rate of 39.9% and mutation rate of 38.5% and thus being more dangerous.

It should be noted that the first few days (3/9/2020-3/12/2020) were done in Princeton High School's Research Classroom during a class period. This provides the reason as to why the temperatures were much higher, the amount of light exposed unknown, and the inconsistency in time exposed. Due to COVID-19 forcing students to stay home, I was required to move everything to my home, where the rest of the trials would be conducted.

In conclusion, lessons learned from this trial were incorporated into future trials, and this data was not considered in the final conclusion.

Trials 1-4:

It is important to first establish the variables that the *Drosophila melanogaster* lived in as to ensure that they were in a comfortable environment. Trial 1 was conducted from 5/26-6/24, Trial 2 from 7/1-7/30, Trial 3 from 7/31-8/29, and Trial 4 from 9/3-10/3.

Trial Number	Temp at 8AM (Mean, σ)	Temp at 12PM (Mean, σ)	Temp at 4PM (Mean, σ)	Temp at 8PM (Mean, σ)
1	74.8, 2.32	77.45, 2.95	78.05, 1.28	77.1, 0.83
2	77, 1.26	77.75, 0.96	77.95, 0.86	77.35, 0.79
3	74.3, 2.33	76.35, 2.12	78.15, 1.49	76.85, 1.28
4	72.65, 1.55	76.8, 1.48	77.65, 0.91	76.95, 2.21

Figure 3: Average and Standard Deviation of Daily Temperature at the given times, during Trials 1-4.

Trial Number	Humidity at 8AM (Mean, σ)	Humidity at 12PM (Mean, σ)	Humidity at 4PM (Mean, σ)	Humidity at 8PM (Mean, σ)
1(5/26-6/14)	54.55, 3.46	55.05, 3.54	55.45, 3.64	54.05, 3.31

2(7/1-7/20)	55.6, 2.83	57.1, 2.55	57.3, 2.12	59.5, 3.17
3(7/31-8/19)	50.75, 2.79	53.3, 3.05	55.35, 4.15	54.25, 3.69
4(9/3-9/23)	53.25, 3.04	54.45, 3.39	54.7, 2.96	53.95, 2.68

Figure 4: Average and Standard Deviation of Daily Humidity at the given times, during Trials 1-4.

Next, it is important to understand how much time the *Drosophila melanogaster* were actually exposed. This can only be accurately done for the cell phone group, as it was possible to access the phone records for this information; it is not possible to get this accurate information from the radar gun. In general, the batteries were replaced in the radar gun every few days to ensure operation. Both devices dropped due to either

	Trial 1	Trial 2	Trial 3	Trial 4
Expected number of minutes exposed	3600	13200	13200	9600
Actual number of minutes exposed	3306(91.8%)	12418(94.1%)	12275(93%)* 10595(20 days)	6598(68.7%)* 5246(20 days)

Figure 5: The total number of minutes that the Drosophila melanogaster were exposed in Trials 1-4, along with the percentage of the expected time.

These data shows that while the *Drosophila melanogaster* weren't exposed for the entire expected time, the Trials 1-3 were fairly consistent in their exposure times. Trial 4 has a lower percentage of exposed times due to the significant increase in times that the cell phone call dropped. This did not change the dates that the fruit flies were counted, observed, and released to ensure that they were approximately at the same point in the cycle of fruit flies. The number of minutes that the *Drosophila melanogaster* were exposed to up to the 20 days point, being 8/19 for Trial 3 and 9/23 for Trial 4, are denoted by the (20 days) label in Figure 5.

The phone calls did not end and restart between time groups. Therefore, it is assumed that the exposure percentages are applicable to all time groups. For the following tables: C = control, P = exposed to cell phone, R = exposed to radar, and the time lengths follow the denotations above.

	C Group	P Group	P-2H Group	R Group	R-2H Group
Generation 1	149	125	165	163	54
Generation 2	492	270	774	505	751
Generation 3	50	21	225	64	367

Figure 6: The total number of fruit flies at each generation, as being defined by the number of adults which were removed from the culture tube at 10, 20, and 30 days during Trial 1.

	C	P	P-2H	P-8H	R	R-2H	R-8H
Generation 1	124	127	77	176	169	157	58
Generation 2	664	521	590	698	541	773	734
Generation 3	236	244	209	158	674	351	264

Figure 7: The total number of fruit flies at each generation, defined by the number of adults which were removed from the culture tube at 10, 20, and 30 days during Trial 2.

	C	P	P-2H	P-8H	R	R-2H	R-8H
Generation 1	168	257	193	218	162	268	242
Generation 2	411	441	550	618	204	234	382
Generation 3	354	240	307	488	91	324	300

Figure 8: The total number of fruit flies at each generation, as being defined by the number of adults which were removed from the culture tube at 10, 20, and 30 days during Trial 3.

	C	P-8H	R-8H
Generation 1	100	127	42
Generation 2	303	557	485

Generation 3	366	429	218

Figure 9: The total number of fruit flies at each generation, as being defined by the number of adults which were removed from the culture tube at 10, 20, and 30 days during Trial 4.

It should be noted that across all of these generations across all the tubes of all types and whether they were exposed to cell phone, radar, or received no exposure, there were no visible mutations of any kind for Trials 1-4. Above it was noted that *Drosophila melanogaster*, which had experienced any mutations other than the ones listed above would be recorded. No such mutations occurred across any group during any of the 4 trials, in addition to any of the mutations that were considered to be "normal" traits of wild type *Drosophila melanogaster*: having red eyes, wings, and a dark body. Therefore, we can say that this study resulted in a 0% mutation rate, regardless of exposure to low-frequency radiation.

In addition, the birth rate across all from Generation 1 to 2 and Generation 2 to 3 was calculated. It was calculated by the number of flies counted in the generation divided by the number of flies in the previous generation. It was then multiplied by 100 to get the birth rate percent.

	C	P	P-2H	R	R-2H
Generation 1-2	330.2	216	469.1	309.8	1390.7
Generation 2-3	10.2	7.8	29.1	12.7	48.9

Figure 10: The percentage birth rate by generation for Trial 1, which denotes the population in the tube as a percentage of the previous generation.

	C	P	P-2H	P-8H	R	R-2H	R-8H
Generation 1-2	535.5	410.2	766.2	396.5	320.1	492.4	1265.5
Generation 2-3	35.5	46.8	35.4	22.6	124.6	45.4	36

Figure 11: The percentage birth rate by generation for Trial 2, which denotes the population in the tube as a percentage of the previous generation.

	C	P	P-2H	P-8H	R	R-2H	R-8H
Generation 1-2	244.6	171.6	285.0	283.5	125.9	87.1	157.9

Generation 2-3	86.1	54.4	55.8	78.9	44.6	138.4	78.5

Figure 12: The percentage birth rate by generation for Trial 3, which denotes the population in the tube as a percentage of the previous generation.

	C	P-8H	R-8H
Generation 1-2	303	438.6	115.5
Generation 2-3	120.8	77	44.9

Figure 13: The percentage birth rate by generation for Trial 4, which denotes the change in population as a percentage of the previous generation.

<u>*E. coli* Arrays:</u>

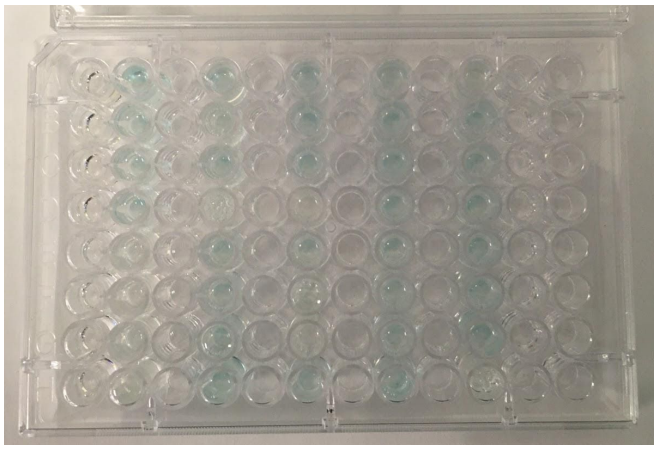

Figure 14: Serial Dilution Array of E. coli after being exposed to Radar. The chemical 4-NQO is in column 1 on the left (clear), exposed E.coli & saline solution is in columns 2, 4, 6, 8, 10. Taken 20 minutes after chromogen was added.

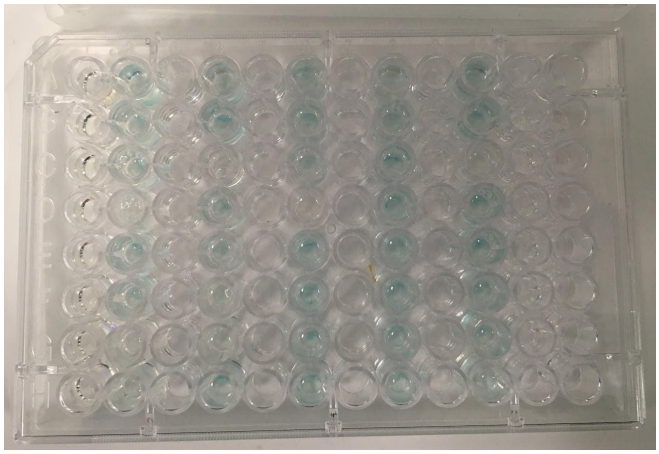

Figure 15: Serial Dilution Array of E. coli after being exposed to Cell Phone. The chemical 4-NQO is in column 1 on the left (clear), exposed E.coli & saline solution is in columns 2, 4, 6, 8, 10. Taken 20 minutes after chromogen was added.

This information gathered has a series of interesting points. Namely that most of the wells containing exposed *E.coli* had started to develop a light blue color. Due to time constraints, I did not have time to observe the continued development of color. Clear signifies that the solution is acutely toxic, and blue signifies that the solution is not toxic. Therefore from this, we can conclude that cell phones and radar are not toxic. This may have yielded slightly different results in some tubes. However, when observed at 20 minutes, the wells containing solution of 4-NQO is entirely clear, whereas the majority of the wells containing solutions *E. coli* are or are developing a light blue color.

Conclusion and Discussion:

Even with the series of controlled variables that were established, there were still several limitations with this experiment. This was mainly due to the onset of COVID-19 which forced me to move my experiment to my home. This presented several challenges and benefits. The main challenge being that I was forced to adapt to a new setting with fewer scientific resources. However, it also allowed me to reexamine my methodology after Trial A and prepare for Trials 1-4.

Given the results of this study, which show no mutations in the *Drosophila melanogaster* and lack of toxicity in the *E. coli* test, we can say that cell phones and radar do not present an increased risk for mutations. One may rationalize that the 0% mutation rate may be highly unlikely. It should be noted that this mutation rate was for the variables looked for in the study, being winged vs. wingless, red eyes vs. white eyes, and light body vs. dark body. This may mean that there were other mutations that the *Drosophila melanogaster* experienced that were not in this percentage. This fact was taken note of, and thus any observable mutation would have been recorded. It is also possible that there were mutations that

were not visible that occurred due to their exposure to radiation. In those cases I could not observe them due to my technical limitations.

In addition, the birth rate was assessed. The general trend across all trials was a dramatic increase in the population from generation 1 to generation 2, and then a decrease in population from generation 2 to generation 3. Given that this trend occurred for all groups, regardless of exposure to a device or not, it is safe to say that exposure to low-frequency radiation had no effect on the birth rate. Given that temperature and humidity remained constant, and there was no outside influence other than the removal of flies at 10 and 20 days, it is highly unlikely that something external influenced this change consistently. The two primary reasons for this trend are that in the beginning there is a lot of space and food, so the population explodes, but then these resources disappear and the population cannot be sustained. Moreover, several internal factors may have caused this change. *Drosophila melanogaster* submerge their eggs into the media, and need to burrow their way into the media to do so. This causes a potential issue of flies being caught in the media when being removed from the tube. This could be prevented by removing the media and extracting the flies, but that would damage the eggs and larvae of the next generation. Another shift in between the second and third generation is the lack of/change in media. Several instances of dried out or moldy media caused serval tubes to present little to no flies, probably as a result of this. However, given that there were several hundred flies that were alive across all generations and across all trials, data still applies.

Now, to highlight Trials 3 and 4. These trials showed a much lower time exposed than what was planned. As stated above, there were a series of issues with connectivity. While this did affect all 4 trials, the amount of time the cell phone was not active had increased during trials 3 and 4. Therefore, it is important to note that this data is potentially less reliable than Trials 1 and 2, but should not be ignored.

Figure 5 shows the number of minutes that each of the trials were exposed. Given the amount of data that my phone provider would give to me, I could not assess when the phone dropped, only have the total number of minutes called per day. Thus, I cannot attribute time being lost at any specific point during testing. I can only get this data for the cell phone, and given that the radar gun and cell phone were checked at the same times, it can be assumed that the time of exposure is similar.

This study was most similar to the one referenced in the introduction, which had an increase of a mutation rate of 1.5% in the control and 5% in the experimental cell phone group. However, there are a few key differences in this study and the study that I conducted. The study that was conducted by Thomas has no indication of whether Wild Type or Golden Delicious *Drosophila melanogaster* are used or how much time the *Drosophila melanogaster* were exposed. However, the study conducted by Thomas went over 5 generations of *Drosophila melanogaster*, whereas my study went over 3 generations of *Drosophila melanogaster*, as there was similar potential for genetic mutations to develop from each generation.

In addition, the *E. coli* showed very little change as it went down the array in comparison to the control. This would suggest that the cell phone and radar gun's exposure to the plates had no adverse effect on them. However, given the lack of replication of this experiment, I am not sure as to how verifiable this method is. One possible improvement in the methodology of this experiment would be repeating this experiment with multiple plates. Waiting additional time for the chromogen to form color is also a potential improvement. Repeating this experiment and/or increasing times was not possible due to limited access to labs due to COVID. All-in-all, the data points towards cell phones and radar being non-toxic.

Putting the data in the remaining context of the literature described in the introduction shows a definitive conclusion in the direction of cell phones not causing adverse effects. However due to the differences between *Drosophila melanogaster* and humans, it would be advisable to limit exposure until definitive human trials have been conducted. Definitive human trials would allow for the public to be properly informed about the effects of cell phones and radar. This could be limited by using the Apple Screen Time or other similar features.

In conclusion, after an assessment of the possible effects on the mutagenicity of cell phones and radar, it is probable that these items do not show mutagenicity in *Drosophila melanogaster* after being exposed for 20 days and across 3 generations. There was a 0% mutation rate across all trials, regardless of what group they have been in or their exposure time. In addition, the birthrate across all of the groups follows the same general trend. In the *E. coli* test, mutagenicity appears to show similar results after being exposed for only four hours.

Sources/References:

Davis, R L, and F K Mostofi. "Cluster of Testicular Cancer in Police Officers Exposed to Hand-Held Radar." American Journal of Industrial Medicine, U.S. National Library of Medicine, Aug. 1993, pubmed.ncbi.nlm.nih.gov/8213849/.

Fanelli, D. "How many Scientists Fabricate and Falsify Research? A Systematic Review and Meta-Analysis of Survey Data" *Plos*, 29 May 2009 https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0005738

Focke, F. Schuerman, D. Kuster, N. Schar, P. Z "DNA fragmentation in human fibroblasts under extremely low frequency electromagnetic field exposure." *National Library of Medicine*, 5 Jan 2010, https://www.ncbi.nlm.nih.gov/pubmed/19896957

Henkel, Ralf R, D. Franken. *Sperm DNA Fragmentation: Origin and Impact on Human Reproduction*. 2012, journals.sagepub.com/doi/pdf/10.1177/205891581100200204#:~:text=In%20cases%20where%20the%20oocyte,numerous%20diseases%20including%20childhood%20cancer.

Leszczynski, Darius. Xu, Zhengping. "Mobile phone radiation health risk controversy: the reliability and sufficiency of science behind the safety standards." *National Library of Medicine* 27 Jan 2010, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2825185/

Matei, Adrienne. "Shock! Horror! Do You Know How Much Time You Spend on Your Phone?" *The Guardian*, Guardian News and Media, 21 Aug. 2019, www.theguardian.com/lifeandstyle/2019/aug/21/cellphone-screen-time-average-habits.

Meena, Jitendra Kumar. Verma, Anjana. Kohli, Charu. Ingle, Gopal Krishna. "Mobile phone use and possible cancer risk: Current perspectives in India." *National Library of Medicine* Jan-Apr 2016, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4922278/

Molla, Rani. "Tech Companies Tried to Help Us Spend Less Time on Our Phones. It Didn't Work." *Vox*, Vox, 6 Jan. 2020, www.vox.com/recode/2020/1/6/21048116/tech-companies-time-well-spent-mobile-phone-usage-data.

Nirwane, Abhijit. Sridar, Vinay. Majumdar, Anuradha. "Neurobehavioral Changes and Brain Oxidative Stress Induced by Acute Exposure to GMS900 Mobile Phone Radiations in Zebrafish (*Danio rerio*)." *National Library of Medicine* , 30 April 2016, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4843974/#idm139956689829584title

Roosil, M. "Radiofrequency electromagnetic field exposure and non-specific symptoms of ill health: a systematic review." *National Library of Medicine*, 21 Mar 2008 https://www.ncbi.nlm.nih.gov/pubmed/18359015

Stam, Rianne. "Electromagnetic Fields and the Blood–Brain Barrier." *NeuroImage*, Academic Press, 1 June 2010, www.sciencedirect.com/science/article/pii/S0165017310000718?via%3Dihub.

Schooler, J. “Metascience could rescue the ‘replication crisis’” *Nature*, 04 Nov 2014 https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0005738

Thomas, Danna. “Permanent Mutations in Fruit Flies by Cell Phone Radiation.” *EMFacts Consultancy*, 13 May 2005, www.emfacts.com/2005/05/permanent-mutations-in-fruit-flies-by-cell-phone-radiation/.

“Electromagnetic fields and public health: Cell Phones” *World Health Organization* 8 Oct 2014 https://www.who.int/news-room/fact-sheets/detail/electromagnetic-fields-and-public-health-mobile-phones

“Cell Phones and Cancer Risk.” *Cell Phone Fact Sheet*, National Cancer Institute, 1 Nov. 2018, www.cancer.gov/about-cancer/causes-prevention/risk/radiation/cell-phones-fact-sheet.

“How Much Time Do Americans Spend Behind the Wheel?” *How Much Time Do Americans Spend Behind the Wheel? | Volpe National Transportation Systems Center*, 11 Dec. 2017, www.volpe.dot.gov/news/how-much-time-do-americans-spend-behind-wheel.