HIGH SCHOOL EDITION
Journal of Student Research
Volume 11 Issue 3 (2022)

Zebrafish Demystify Human Skin Color Variation and Develop a Basis for Pigmentation

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ABSTRACT

Human skin color was demystified due to zebrafish and their genes. The paper focuses on three main aspects of the study: the methods and experiments scientists designed with zebrafish and humans, the impacts of the results, and the current level of understanding by a general audience. The paper relies on secondary sources, photographs, and a survey. Secondary data and examples are evaluated using the following criteria: information on the gene and its function, information on its relation to humans, and a larger picture analysis. The paper follows the sequence of the experiment. Photographs are taken to study and compare the pigmentations of two types of zebrafish, and how they were utilized in the experiment. A survey is circulated to a general audience to gauge the current level of knowledge surrounding reasons behind pigmentation in humans. The findings explain the methods scientists used to identify significant genes in zebrafish and humans. Through the identification and study of these genes, scientists developed an evolutionary and genetic basis behind human skin color. The survey shows that the majority of respondents were unfamiliar with the experiments and the scientific community's insight into human skin color. This study raises awareness to the general public about the basis for human skin color. This experiment can be applied to further study other organisms or investigate different aspects of humans.

Introduction

For decades, the reasons why humans of African descent have darker skin color than humans of European descent have been a genetic mystery. Dr. Keith Cheng (employed at Pennsylvania State University) worked on research revealing an answer. This paper investigates the reasons behind human skin color variation through studying zebrafish (*Danio rerio)* and their genes. By studying zebrafish, their genes, and their genetic structure, scientists can build the foundation of human skin color variation. While scientists previously understood that human skin color is influenced by melanin production, the genetic foundation for skin color variation was obscure. Through observing pigmentation differences in zebrafish and studying their genes, scientists drew conclusions in human genes. The genetic grounds for human skin color have eluded scientists for years - previous studies have pointed to over 100 different genes involved in the production of melanin (Biello, 2005). Through the discovery of a special gene in zebrafish, scientists demystified the genetic basis of diversity in human skin color.

A zebrafish is a freshwater fish and is a common model to study vertebrates (Lajis, 2018). There are two main types of zebrafish utilized in this study; the "golden" fish, which has a lighter striped pigmentation due to the SLC24A5 gene, and the wild-type fish, which has a darker striped pigmentation (Robison & Blumenrath, 2020). Orthologs are similar genes in two different species that evolved through speciation events, or occurrences leading to the creation of a new species (Fang et al., 2010). Hypopigmentation is a condition in which skin color is lighter than normal due to a shortage of melanin production in skin cells ("Hypopigmentation", n.d.). Threonine and alanine are both amino acids used to build proteins in the body during the translation process (Feyer et al., 2008). A gene is the basic physical and functional unit of heredity; made up of DNA, their expression is regulated by proteins (Flatley, 2021). An organism's DNA is made up of genomes, which are an organism's complete set of genetic instructions. Each genome contains all the necessary information for the organism to grow and develop (Goldman & Landweber,

2016). A selective sweep is an occurrence in which a gene variant presents a benefit and is therefore selected (Pritchard et al., 2010). One example of a pigmentation cell is a melanophore, which contains melanin and was thoroughly studied when understanding pigmentation in zebrafish and humans (Salim & Ali, 2012). Haplotype Map is an online database with the published human genome and is often used to identify human genes during scientific experiments ("A haplotype map of the human genome", 2005). Melanin is a type of pigment that absorbs harmful ultraviolet rays and gives color to the eyes, skin, and hair of an organism (DiLonardo, 2021). Candidate genes are genes believed to be related to a particular trait, such as a disease. Because of its location or known function, the gene is suspected to play a role, making it a candidate for additional study ("Candidate Gene", n.d.).

Scientists have utilized zebrafish as vertebrate models in research since the 1960s. The first reason is due to the zebrafishes' short developmental stages. Zebrafish are fully developed within 3 months of their birth, whereas most species require years to fully develop. Second, they produce hundreds of offspring weekly, providing scientists with an ample supply of embryos to study. Third, the complete genome sequence of zebrafish is mapped out and was published in 2013. Fourth, they have a genetic structure similar to humans. Zebrafish and humans share 70% of genes, and 84% of genes associated with human diseases have a zebrafish counterpart, so they are frequently utilized to study diseases and illnesses in humans (YourGenome, 2020). Lastly, zebrafish are transparent during development, so their early development can be easily observed (Tonelli et al., 2020).

Through studying pigmentation in zebrafish, scientists pinpointed reasons behind light pigmentation in the golden zebrafish and dark pigmentation in the wild-type zebrafish, and consequently, the reasons behind varying human pigmentations. Scientists could then test the gene within groups of humans with differing skin colors to confirm its influence. The study explains 25-38% of skin pigmentation differences between those of African and European ancestry (Robison & Blumenrath, 2020). Using zebrafish to locate the genes responsible for pigmentation, scientists have identified an experimentation strategy, creating a basis for the evolution of pigmentation. This may contribute to a deeper understanding of the genetic reasons behind variations in human skin color. The key questions are: How did scientists locate the golden gene in zebrafish and the SLC24A5 gene in humans? What are the impacts of the experiment's results?

Taking all the sources into account, the research highlights zebrafish importance in determining reasons behind human skin color differences. There are several competing methods to understanding skin color variation, such as melanocyte activity and carotene leveling. However, analysis of zebrafish and their genes is currently the most successful experiment run to determine genes underlying human pigmentation and skin color variation (Howe et al., 2013).

Skin color is one of the most striking examples of human phenotypic diversity (Deng & Xu, 2018). Discovering the genetic foundation of human skin color has applications in human evolution and medicine and is critical to society's understanding of the human race. The experiment can also provide insight and lay the groundwork for future research on the pigmentation of other organisms, such as plants and fungi. Using zebrafish and their genes, scientists now understand the reasons behind the spectrum of skin colors within the human species.

Methods

Included research used qualitative and quantitative data and focused on both secondary and primary sources. The present research used primary data gathered through a survey conducted, direct observation, and photographs.

Secondary Sources

This research used three main methods of analysis. First, textual analysis allowed for connections and synthesis across sources. Sources used included academic journals, in-depth studies, and schematic news articles, which provided secondary data. The sources cover the processes scientists developed to locate the golden gene responsible for

pigmentation in zebrafish, as well as the larger impacts of the basis for human skin pigmentation and diversity. The photographs and diagrams in the sources assisted in a thorough understanding of the material. Textual analysis focused on the identification of key methods used to locate the golden gene in zebrafish. The second method traced key scientists in the experiment and explored their contributions to the research and advancements, centering on head scientist Dr. Keith Cheng and his team at Pennsylvania State University. The third method of analysis involved searching for recurring terms and concepts in the research to draw connections and similarities across sources. Altogether, by studying and evaluating the sources in these three ways, findings developed from analyzed information and informed the primary and structure of the survey.

Photographs

Photographs taken at Johns Hopkins University's Finzcenter Zebrafish Core Center in Baltimore, Maryland served as a primary source in research and data collection. The wild-type zebrafish and the leopard zebrafish were photographed at the laboratory. The wild-type zebrafish is the standard zebrafish with blue stripes and the leopard zebrafish has a spotted pigmentation due to a genetic mutation. Observations relating to the two zebrafish types and resulting pigmentations enabled comparative analysis. Photographs were taken of the zebrafish larvae and observations were made through utilizing microscopes. The observations served as a vehicle to understand zebrafishes' rapid developmental stages, providing a foundation and backbone on zebrafish growth for the pigmentation research. No direct manipulation took place with the fish, and these photographs and observations follow the ethical considerations set forth by the Finzcenter Zebrafish Core Center laboratory. Findings contextualized the photographs taken of zebrafish at Johns Hopkins University.

Survey

The survey consisted of five multiple-choice questions with one long answer question. The survey included participants with different ages, races, locations, and careers to gauge a general audience's familiarity with pigmentation variation. The participants included students in middle schools and high schools, adults of varying careers, and elders. Participants were given 7 days to complete the survey anonymously, and 201 people responded. Consequently, 201 survey results were included in the analysis. The survey gauges a general public's familiarity with the experiments and research.

Between the utilization of secondary sources, photographs, and the survey, the research includes a holistic view of the experimentation and its contextualization to form the findings and results.

Findings

In his experiment, Dr. Keith Cheng used zebrafish as models to study pigmentation in humans. Scientists identified and located the golden gene responsible for the light pigmentation and phenotype in golden zebrafish. Dr. Cheng's team found that the golden phenotype, characterized by abnormally light pigmentation, results from delayed and reduced development of melanin production. Transmission electron microscopy (TEM) determined the cellular basis of hypopigmentation in the melanophores of the wild-type and the golden type. This technology gave scientists deeper insight as they narrowed down their pool of candidate genes. The microscopy technology revealed that the melanophores in the golden fish were thinner with fewer melanosomes than the melanophores in the wild-type fish. The golden fish melanosomes were smaller, irregularly shaped, and less electron dense than the wild-type melanosomes (Lamason & Cheng, 2005).

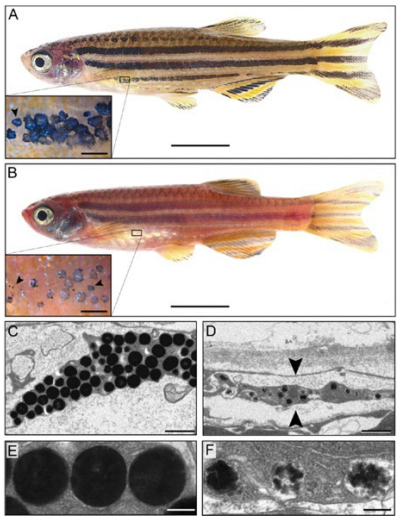

Figure 1. Comparative Visual Analysis between Wild-Type and Golden Zebrafish

Note. The image was created from analysis with a microscope to allow Dr. Keith Cheng and his team to observe the pigmentation at the cellular level. Phenotype of golden zebrafish. Lateral views of adult wild-type (A) and golden (B) zebrafish. Golden fish mutants have melanophores that are, on average, smaller, more pale, and transparent. Transmission electron micrographs of skin melanophores from wild-type (C and E) and golden fish (D and F) larvae. Golden melanophores are thinner and contain fewer melanosomes than do those of wild-type. Melanosomes of golden fish larvae are fewer in number, smaller, less-pigmented, and irregular compared with wild-type (https://www.scienceintheclassroom.org/research-papers/golden-fish-reveals-pigmentation-loss-europeans. Lamason & Cheng, 2005).

A nucleotide transversion is a mutation in which the A or G nucleotide is exchanged for a C or T nucleotide in a DNA sequence (Carr, 2021). Transcription is the process of making an RNA copy in the gene sequence ("Transcription", 2019). A stop codon is a sequence of three amino acids in a DNA sequence that signals for the termination of protein synthesis ("Stop Codon", n.d.). Truncation refers to the shortening or removal of a gene or polymer (Wilson, 2022). To identify the golden gene responsible for the golden phenotype in zebrafish, scientists tested candidate genes. Through positional cloning, morpholino knockdown, and gene expression analysis, scientists located the golden gene. (Lamason & Cheng, 2005). Scientists then found a mutation in a gene variant that led to a golden mutant zebrafish line. To identify the mutation, Dr. Cheng compared complementary DNA and genome sequences from the wild-type and mutated gene variants. Scientists identified a nucleotide transversion that converted a protein into a stop codon, so the transcription process ended early in the mutated gene. This nonsense mutation predicts the truncation of the golden polymer to 40% of its normal size (Biello, 2005). The truncation includes the loss of the central hydrophilic loop and the transmembrane domains. These components serve as vital proteins, as they carry out enzyme analysis, transport substances across membranes, convert signals as receptors of hormones and growth factors, and transfer energy in ATP synthesis (Biello, 2005). The hydrophilic loop and the transmembrane domains are essential to the production of melanin, so without them, the golden zebrafish pigmentation appears lighter than the standard wild-type zebrafish. When scientists added the normal length protein from the wild-type zebrafish into the golden zebrafish, the pigmentation returned to a darker color. After Dr. Cheng's team confirmed the reason behind the golden mutation in zebrafish, they compared the gene to humans. Using International Haplotype Map, an online database that maps out the human genome, scientists identified the human counterpart to the zebrafish golden gene (Lamason & Cheng, 2005).

By comparing the genome sequences of zebrafish and humans, scientists concluded that the golden gene in zebrafish and its genetic equivalent in humans, SLC24A5, were orthologs. Also significantly, injecting SLC24A5, the

human pigmentation gene, into golden zebrafish embryos restored the darker coloration in zebrafish (Biello, 2005). Dr. Cheng then began working with Pennsylvania State University anthropologist Mark Shriver to understand the evolutionary genetics of human skin color. Using the International Haplotype Map, the researchers found out that SLC24A5 has two genetic variations. Nearly all humans of European descent have a version of the gene with one type of amino acid, threonine; nearly everyone else has another, alanine. Scientists measured the effect of the gene in 308 individuals of mixed African and European heritage. They determined that those who carried the threonine variant were of the lightest pigmentation while those who carried the alanine variant were of darker pigmentation. The subjects that contained both variants of threonine and alanine had pigmentation in the middle of the spectrum. The researchers concluded that SLC24A5 accounts for 25-38% of the skin color difference between Europeans and Africans (Biello, 2005).

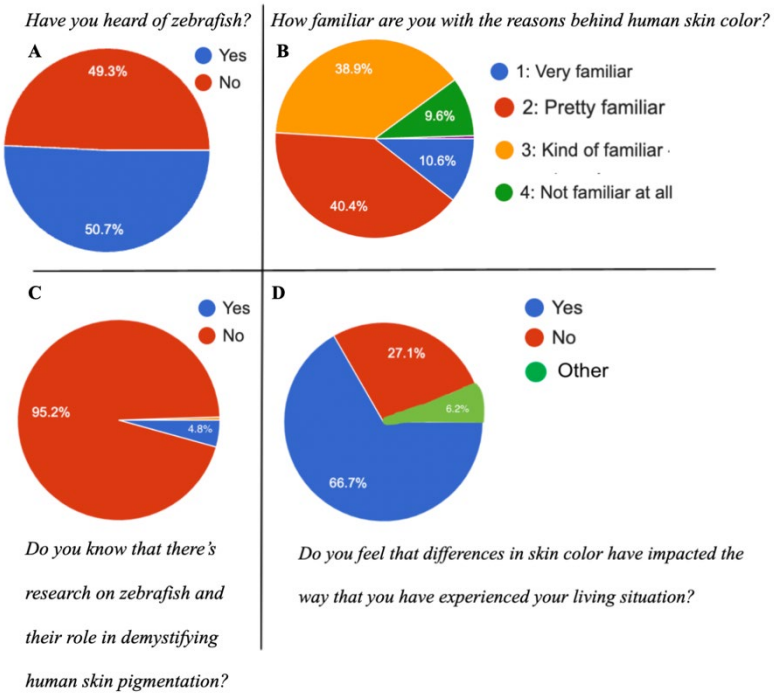

Figure 2. Survey conducted in February of 2022 with 201 respondents. Participants lived in the United States, India, and Canada. 53 respondents were ages 61 or older. 49 respondents were ages 41-60. 24 respondents were 21-40. 66 respondents were ages 13-19. 9 respondents were ages 7-12.

Survey

When asked about familiarity with reasons behind human skin color variation, 81 participants responded that they are pretty familiar, and 78 participants responded that they are partly familiar (Fig. 2). 99 respondents reported that they had not heard of zebrafish until the survey circulated and 191 respondents reported that they did not know research on zebrafish existed (Fig. 2). 29 of the 106 respondents who had heard of zebrafish were 61 or older (Fig. 2). 134 respondents reported that their skin color impacts their living situation (Fig. 2). 60 respondents between ages 13-40 found that differences in skin color impacts the way they experience their living situation (Fig. 2). 5 of the 9 respondents in the 7-12 category experience differences in their living situation because of their skin color (Fig. 2). 62 of the respondents who were unfamiliar with zebrafishes' role in demystifying human pigmentation were ages 13-19 (Fig. 2).

Photographs

Photographs taken at the Finzcenter Zebrafish Core Center at Johns Hopkins University identify the pigmentations in two main types of zebrafish: the wild-type zebrafish and the leopard zebrafish. Photographs were also taken of the zebrafish larvae.

Figure 3. Zebrafish Larvae. Wild-type zebrafish larvae observed 7 days after birth. Prakash, T (2022). [Picture of two types of zebrafish] [Photograph]. Johns Hopkins University, Finzcenter Zebrafish Core Center.

Within 3 months, zebrafish develop from a fertilized egg to an adult fish (Fig. 3). The fish grow at an extremely fast rate, developing as much in a day as a human embryo develops in one month (YourGenome, 2020). Zebrafishes' rapid growth is a key reason why scientists chose to use zebrafish as models in this experiment.

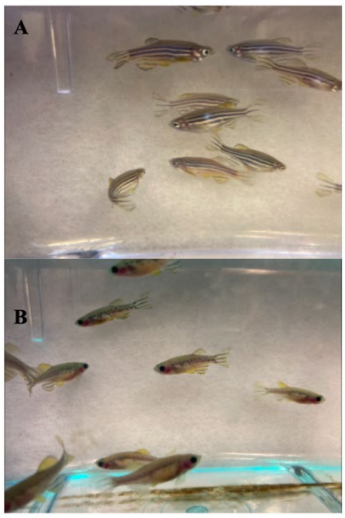

Figure 4. Adult Zebrafish Comparative Pigmentation Analysis. Phenotype of golden zebrafish. Lateral views of adult wild-type (A) and leopard (B) zebrafish. Wild-type fish contain dark blue stripes which show underlying melanophores that are rich with melanin. This pigmentation represents the standard pigmentation. Leopard zebrafish contain dark spots instead of stripes and represent a common mutation line in zebrafish pigmentation. (https://www.scienceintheclassroom.org/research-papers/golden-fish-reveals-pigmentation-loss-europeans). Prakash, T (2022). [Picture of two types of zebrafish] [Photograph]. Johns Hopkins University, Finzcenter Zebrafish Core Center.

The wild-type zebrafish have a blue-and-gold striped pigmentation and grow to be roughly 1-inch long (Fig. 4). The leopard zebrafish have a dotted pigmentation with a blue-and-yellow striped tail and also develop to be roughly 1-inch long (Fig. 4). The abnormal pigmentation on the leopard zebrafish is the result of a common mutation line that leads to a spotted skin pattern instead of a striped skin pattern (Fig. 4). Consequently, leopard zebrafish serve as models for the study of skin patterning and allow for comparative analysis with the wild-type zebrafish due to the differentiated pigmentations (Fig. 4). These photos led to a deeper understanding of the abnormality of zebrafish pigmentation, the fluctuation of the genes underlying pigmentation, and the importance and role of zebrafish in identifying the basis for skin color in humans.

Discussion

Sources

For many years, the general public has believed that skin color variation is a result of different amounts of exposure to the sun. A leading theory is that skin color adapts to sun radiation to provide partial protection against the harsh rays. A newer theory, constructed by Dr. Keith Cheng and his team, explores the role of a special gene in zebrafish in allowing scientists to identify and study the corresponding gene in humans. Studies fully support the findings, and no inconsistencies with Dr. Cheng's theory were identified in the sources used (Biello, 2005). Data that derives in findings is consistent with the data and information in additional literature reviewed.

Results from the survey confirmed that 190 of the 210 respondents are unfamiliar with reasons behind skin color. Previous studies have pointed to over 100 different genes involved in pigmentation (Biello, 2005). Through the discovery of a special gene in zebrafish, scientists demystified the genetic diversity in human skin color. Key to unlocking this mystery is a special gene in zebrafish, the golden gene. Dr. Keith Cheng and his team (2005) heavily utilized and experimented on the golden gene throughout the experiment. Scientists studied the golden gene in hopes that those observations could assist in studying the corresponding human pigmentation gene. During analysis of the mutated gene, scientists identified a truncation, the main reason behind light pigmentation in zebrafish. This observation led to further studies of the human gene counterpart, SLC24A5, and its two variations. Knowing that, scientists identified the different amino acids in each version of the gene, so zebrafish proved to be crucial in this process (Lamason & Cheng, 2005). The golden gene served as a guide to where the human equivalent gene could be, so identifying the location of the golden gene was critical in locating the human pigmentation gene.

Overview of Findings

Scientists used positional cloning, gene expression analysis, and morpholino knockdown to locate the golden gene in zebrafish. These processes provide insight into the relationship between studies on zebrafish and knowledge on skin color differentiation in humans, which the study explored with a survey.

Once Dr. Cheng's team located the gene, they found a mutation in an allele that led to a golden mutant zebrafish line. With this came the discovery of a truncated golden polymer. The shortened polymer leaves out proteins that are essential to the production of melanin. Without this melanin, the resulting pigmentation of the zebrafish is lighter (Lamason & Cheng, 2005). This breakthrough was pivotal to the experiment, as it allowed scientists to identify the reason for light pigmentation in zebrafish, which further led scientists to establish a genetic and evolutionary basis for human skin color variation. When Dr. Cheng's team added the normal length protein from the wild-type zebrafish into the golden zebrafish, the pigmentation returned to a darker color, proving the scientists' hypothesis that the normal length protein was responsible for darker pigmentation.

These processes led scientists to find the differentiation in zebrafish pigmentation between the golden and wild-type zebrafish, which further allowed for the analysis and identification of SLC24A5, the human pigmentation

gene. Scientists used Haplotype Map to identify the corresponding gene to the golden gene in humans (Lamason & Cheng, 2005). The usage of Haplotype Map allowed for scientists to locate the gene in humans and eventually develop the groundwork for human skin color variation. Haplotype Map serves as the only platform that fully maps out the human genome, so it was crucial in locating the SLC24A5 gene in humans. To test the hypothesis that the truncated golden gene led to a lighter pigmentation, scientists injected SLC24A5 into golden zebrafish embryos. SLC24A5 restored the darker coloration in zebrafish, proving the scientists' theory. This result was pivotal to the experiment as it proved the role of SLC24A5 in pigmentation, so scientists could focus on SLC24A5 at the cellular level, identifying the amino acid make-up of each variation (Balter, 2005). If the SLC24A5 gene did not impact or affect the golden zebrafish pigmentation, scientists would need to continue searching for human genes that correspond to the zebrafish golden gene.

Nearly all humans of European descent have a version of the gene with one type of amino acid, threonine; nearly everyone else has another, alanine. Evolutionarily, this could suggest that a selective sweep took place among European ancestors, leading to their version of the gene containing threonine (Kane, 2010). To test this hypothesis, scientists measured the effect of the gene in 308 individuals of mixed African and European heritage. The threonine in the European version leads to a lighter skin color, whereas the alanine in other ethnic versions leads to a darker skin color. People with both variants of threonine and alanine had pigmentation in the middle, reflecting the wide array of human skin tones. While these findings do not address why the threonine variant was selected for Europeans in the first place, it could serve as a helpful foundation for skin cancer treatments and other skin-related diseases in the future.

Methods to Identify Golden Gene in Zebrafish

All three of the methods allowed for the identification of the golden gene in zebrafish, which further led to the identification of the SLC24A5 gene in humans and the development of an evolutionary foundation for human skin color. Positional cloning, used in conjunction with linkage analysis, was the first method. With positional cloning and linkage analysis, scientists isolated overlapping DNA segments along the chromosome of the candidate gene. Dr. Cheng then assessed how the resulting isolation of candidate genes affected the melanin production in zebrafish (Biello, 2005). Positional cloning gave scientists insight into melanin's influence in pigmentation, which was further explored when studying the SLC24A5 gene in humans. Scientists established an initial understanding of melanin and its role during positional cloning. Because locating the golden gene served as an essential step in the experiment, scientists utilized these methods collectively in order to locate the golden gene and correctly eliminate the other candidate genes.

Dr. Cheng's team also used morpholino knockdown to test and locate the gene. Morpholinos are molecules of 25 nucleotides, and in morpholino knockdown, the morpholinos bound and blocked the translation complex within the messenger RNA sequences. Scientists then studied the impact the blocking had on the rest of the cells to evaluate the role of each candidate gene on the rest of the body. Through morpholino knockdown, the specific candidate genes were tested with temporary blocking (Biello, 2005). Morpholino knockdown allowed scientists to observe the candidate genes in zebrafish at the cellular level. Because of this, Dr. Cheng's team formed an understanding of how zebrafish genes were structured and translated that knowledge to the human genome structure when studying SLC24A5 at the cellular level.

The last method scientists used to find a candidate gene was expression analysis. During gene expression analysis, Dr. Cheng's team studied the way genes were transcribed into proteins to synthesize gene products to identify the proteins coded from each candidate gene (Lamason & Cheng, 2005). This method allowed scientists to familiarize themselves with how genes transcribed into proteins, which they further studied when analyzing the SLC24A5 gene in humans.

These methods used jointly led to the identification of the golden gene in zebrafish, which laid the foundation for the discovery of the equivalent gene in humans (Biello, 2005). From there, scientists identified variations of SLC24A5, which formed the evolutionary and genetic basis of human skin color variation.

Survey

These findings include a survey with 201 respondents. The survey gathered data from those outside of the scientific community. Familiarity with the experiment, age, and the way in which human skin color impacted respondents' daily life served as criteria for analyzing the data.

The study initially assumed that the respondents were familiar with research regarding zebrafish and pigmentation, but the survey found that 190 out of the 201 of the participants were completely unfamiliar with the research. While this experiment and the resulting groundwork for human skin color were established years ago, 95% of respondents are still unfamiliar with the reasons behind human skin color and the experiments. The people who were unfamiliar with the research ranged in age from 7 to 61 and older and were from India, Canada and the United States. Unfamiliarity with the research and these pivotal breakthroughs apply to participants of different ages, locations, and careers and must be noted. The general public deserves to understand the reasons behind human skin color variation because skin color affects the daily life of these people.

132 people reported that human skin color impacts the way they have experienced their living situation, whether that be through the way people act towards them, results on family members, or cognitive bias in peoples' beliefs. The survey shows that participants perceive their living situations to be affected by skin color, which creates a noticeable, observable impact on their life. Common themes were immediate bias and effects on relationships. The respondents who reported that skin color impacted their life ranged in age from 7-61 and older and were from the United States, Canada, and India. Skin color has inevitable impacts on people across countries, ages, and careers, yet the general public is disconnected from the research and advancements in the scientific community. The paper is addressing the pressing gap between the general public and the scientific community.

Implications

The survey conducted reached 201 people of different ages, ethnicities, locations, and careers. Respondents ranged geographically across the United States, India, and Canada. The survey was only distributed in English. 190 of the respondents reported that they were unfamiliar with research utilizing zebrafish to explain pigmentation variation, and 132 people reported that their lives are impacted by their skin color. These results prove that while the scientific community may be familiar with human pigmentation and the evolutionary foundation for it through the usage of zebrafish, the general public is unfamiliar with these results and breakthroughs. This paper is aiming to raise awareness to the public and connect the widening gap between those within the scientific community and those outside of it.

Skin color affects the way people live, yet the general public is unfamiliar with the topics of human skin color variation. A pivotal factor of outcomes for individuals across the world, skin color has often been seen as a social determinant of health inaccessibility (Hargrove, 2018). The general public has the right to know the genetic reasons behind human skin color in order to fully and properly foster science communication. By exchanging future information and viewpoints about science, greater insight into diverse public views and concerns are gained ("Communicating Science Effectively: A Research Agenda", 2017). If those outside of the scientific community become aware of the established basis for human skin color, it could lessen the impact skin tone has. A future study could address people living in all continents to get more diversity in responses. A prior study only addressed 100 respondents from solely the United States. The survey results from this paper are significant since they survey a wider range of respondents across the United States, Canada, and India.

Limitations

The study could not mirror the experiment performing primary research on zebrafish and human pigmentation genes due to a lack of resources. For example, there were no accessible resources to perform morpholino knockdown, gene

expression analysis, or positional cloning to locate the gene. The human pigmentation gene in other organisms, such as plants, fungi, and other groups of animals, could not be tested on due to the lack of resources. There was also a lack of technology or resources to inject SLC24A5 into those organisms. The visit to the laboratory at the Finzcenter Zebrafish Core Center at Johns Hopkins University was limited to 30 minutes, so there was a lack of time to thoroughly photograph and observe the zebrafish and their conditions. The photographs were taken with an iPhone SE camera. The phone features a 1.8 aperture and a maximum resolution of 4k (3840x2160). The study lacked access to a microscope, so zebrafish could not be enlarged or magnified for photographs.

Improvements

The survey can be more thoroughly done by considering a larger body and increasing the range of people addressed. It can include additional questions that further take into account respondent opinions and their current levels of knowledge. Research can also be extended to other animals and organisms - the golden gene can be injected into a range of organisms to evaluate pigmentation in them. Additionally, social and policy issues can be further explored in a future paper. The photographs can be taken with a higher quality camera to clearly capture the pigmentation of the wild-type and leopard zebrafish and the zebrafish larvae.

Alternative Explanations

The research with zebrafish explains 25-38% of the reason behind differentiation of human skin color (Lamason & Cheng, 2005). The remaining factors for variations in human skin color are still unknown. While research with zebrafish pigmentation clarified differentiation of human skin color, there may be alternative ways of understanding reasons behind human skin color variation. Nina Jablonski, anthropologist at Pennsylvania State University, hypothesizes that darker skin color had evolved in early humans to prevent skin cancer from developing in the sun (Jablonski, 2009). Another hypothesis that could be further studied is the genomes of Anatolian Neolithic farmers in Western Europe. These farmers may be the source population of the first European farmers (Feldman, 2019). However, the current experiment utilizing zebrafish is the most reliable study and develops a solid evolutionary foundation for human skin color.

Social Context of Research

The Finzcenter Zebrafish Core Center at Johns Hopkins University frequently utilizes zebrafish in studies and conducts pigmentation analysis experiments on them. Research centers at the National Institutes of Health use zebrafish as models to study hyperpigmentation. Current policies and programs connect predominantly with scientists and remain within the scientific community. These programs have yet to inform the public about advancements and breakthroughs. Findings from the paper could help to reshape the current programs and policies in place by creating a bridge between science and the general public so a general public can understand and stay informed with scientific advancements. This paper is aiming to inform the public about the reasons behind human skin color variation as it could impact social issues. This understanding can lead to a more connected world with less racism and discrimination. The variation in skin color between an individual of African descent and an individual of European descent simply comes down to a difference in the amino acid sequence within the two variations of SLC24A5.

Hopefully, the general public will develop an understanding of skin color variation. This paper could give reason to create new programs or policies focused on conveying scientific research in an accessible way to the general public. Racism occurs across a spectrum and lives within people and institutions. As children grow, messages of race come from all corners: news media, teachers, community interactions, and families. It has become increasingly important to teach the value of diversity at a young age, and awareness is the first step (Weir, 2021). This paper

establishes a foundation for human diversity, which can further be used to raise awareness and fuel conversations to combat prejudice and racism.

Future Studies

The findings explain how scientists located the golden gene in zebrafish, with gene expression analysis, morpholino knockdown, and positional cloning. Included research describes the utilization of Haplotype Map to locate the SLC24A5 gene in humans. Due to the genetic similarities to humans and the published map of the zebrafish genome, scientists chose zebrafish to study and utilize in the experiments. This study connects the people within the scientific community and those outside of it.

Research could focus now on invertebrates, other vertebrates, plants or fungi. Studies focusing on animals similar to chordates could provide more insight into humans and their pigmentation, demystifying other genetic and evolutionary mysteries about the species. Hair and eye color, in addition to the preexisting research on skin color, could be further explored and investigated. Zebrafish were pivotal to the foundation of human skin color variation. Skin color impacts society's daily life in many ways, yet there has been minimal communication between the scientific community and the general public on the breakthroughs the research has made. This paper hopes to bridge the gap between the scientific world and the lay audience so everyone can become informed on advancements in research and literate with scientific research and breakthroughs.

Conclusion

This research bridges the gap between the general public and the scientific community. It introduces the concepts behind Dr. Cheng's 2005 experiment on zebrafish and the way in which the experiment informs our understanding of human skin color.

However, it is clear through the survey conducted in this study that the scientific community has failed to connect with the general public. Science has limited value if it is not understood and acted upon. With science specializing at a rapid rate, it has become harder for a general audience to access the developments. As the scientific community cultivates a better understanding of the natural world, it is equally important to translate this knowledge for a wider audience ("Communicating Science Effectively: A Research Agenda", 2017). Without proper science communication, the general public may be misinformed. Misinformation can lead to the spread of dangerous or damaging falsehoods, which likely will impact the public's behavior. Especially now, with technology being so accessible and easily manipulated publicly, science communication is especially vital to the wellbeing of society. This study serves as a bridge connecting people outside of the scientific community to a scientific development that has failed to circulate. Previous studies have shown that skin color perception plays a massive role in the way humans live their daily lives (Noe-Bustamante et al., 2021). This survey was consistent with prior studies but also showed that respondents who reported skin color as regularly affecting their living experience did not possess knowledge regarding the genetic grounds for skin color variation. While people do not understand the basis for human skin color, it affects them and serves as a major influence on their lives. Understanding the foundation for skin color is one step toward understanding the impact of race on daily lives.

Future research could explore the role that knowledge of skin color variation plays in potentially addressing the impact of racial constructs on daily experiences. Potential applications of the experiment and its resulting conclusions could be considered when establishing social programs and policies. The experiment predicts the way in which these future organisms may reveal up to 62% of the remaining mystery of human skin pigmentation. Dr. Cheng's research model could help scientists evaluate the role specific genes play. For example, the MFSD12 gene can be explored further in a future study, as it is a human gene correlated with hyperpigmentation and hypopigmentation

conditions. Information and data on the golden gene derived from the experiment could serve as a foundation for these future studies.

Acknowledgements

I want to show my deepest gratitude to Rebecca Rose, a research specialist at Johns Hopkins University, who allowed me to observe and photograph the zebrafish at her lab. I would also like to express my gratitude to Melanie Fields, a former high school science teacher, who carefully reviewed my paper and provided feedback. It was this feedback that allowed me to strengthen each section of the paper.

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