HOW SWIMMING AFFECTS CARDIOVASCULAR FUNCTION AMONGST INDIVIDUALS WITH DOWN SYNDROME VS TYPICALLY DEVELOPING INDIVIDUALS

By

NOAH THOMAS WEAVER

____

A Thesis Submitted to The W.A. Franke Honors College
In Partial Fulfillment of the Bachelor's degree
With Honors in
Physiology and Medical Sciences
THE UNIVERSITY OF ARIZONA
MAY 2024

Approved by:

____

Dr. MATT GRILLI
Department of Psychology

Abstract:

Cardiovascular differences in Down syndrome (DS), the most common chromosomal disorder, mark a key difference between this population and typically developing (TD) individuals. This study, conducted by the Memory Development & Disorders Lab at the University of Arizona, investigated how swimming affects cardiovascular function amongst participants with DS compared to their TD peers. Previous studies have used treadmill tests, in which children and young adults with and without DS would have their heart rates recorded continuously while on a treadmill for a set number of minutes (Bahiraei et al., 2023). However, very few studies have been conducted using more accessible forms of exercise, such as swimming. Through a generous donation from a family in Tucson, support from the Lejeune Foundation, and a partnership with the UA Campus Recreation Center, participants with DS and TD participants engaged in 8 free 30-minute swimming lessons over 2 weeks. Prior to these 2-week swim lessons, individuals attended a session in the lab and collected baseline heart rate data over a 60-minute sedentary time period. This study also evaluated memory and executive functioning prior to and during swimming, but this thesis will focus on the cardiovascular results. 23 participants with DS, ages 5-26, and 25 TD mentally-age-matched peers, ages 5-12, participated in the study. The mode of collection for heart rate was continuous using MotionWatch goggle clips. At the beginning, middle, and end of the lesson, Finger-tip Pulse Oximeter measures were collected for all participants as well. Results indicated that maximum, average, and percentage maximum heart rate significantly increased as a result of swimming in both groups, suggesting that swimming is an effective form of cardiovascular exercise in this sample. Secondly, TD participants had significantly higher maximum, average, and percentage

maximum heart rates than DS participants while swimming but not at baseline, suggesting differences in heart rate between the two groups in response to swimming.

Introduction:

The study of Down syndrome (DS), a chromosomal disorder, has been an emerging field of research since it was first discovered as a medical condition in the late 1850s (Ataman et al., 2012). When thinking about the topic of DS, it is first important to understand the various types of DS that currently exist. The most common type of DS has been coined as Trisomy 21, coming from the chromosomal defect that is present. Trisomy 21 accounts for approximately 95% of total DS cases worldwide, according to the CDC (2023). Generally, each cell within the human genome holds 2 copies of chromosome 21; however, a person who has Trisomy 21 has 3 copies of chromosome 21 within each cell. Another type of Down syndrome, much less common at around 3% of total cases, is called translocation DS, occurs when the extra third chromosome 21 is present and is also translocated, meaning the position of the chromosome is “trans-located” to another chromosome (CDC, 2023). The final type of DS that has been discovered is called Mosaic Down syndrome, meaning a mixture of either 2 or 3 chromosomes 21, depending on the cell. This means that some cells in the human body have the normal 2 chromosome 21, while other cells have the abnormal amount of 3 chromosome 21 (Stanford Medicine, 2023).

Currently, in the United States, DS is the most common chromosomal condition, accounting for nearly 6,000 babies each year being diagnosed with Down syndrome. In other words, about 1 in every 700 babies born will have DS (CDC, 2023). Physical differences associated with DS can be seen as follows: A flattened face, almond-shaped eyes that slant up, a short neck, a small ear, a tongue that tends to stick out of the mouth, tiny white spots on the iris (colored part) of the eye, small hands and feet, a single line across the palm of the hand (palmar crease), small pinky fingers that sometimes curve toward the thumb, poor muscle tone or loose joints, and shorter in height as children and adults.

Another critical factor to understand about DS is the causes and risk factors associated with this chromosomal condition. One of the most common risk factors for having a child with DS is the age of the mother. Generally, mothers who conceive at an age over 35 years have an increased risk for DS (Olsen et al., 1996). This is a major reason why many Pediatric and Neonatal physicians advise prospective parents about having children too late in life, as health risks and diagnoses see a great chance of occurring on a macro scale (Bull, 2011). Additionally, it is well known that having one child with DS can increase the risk of having a second child who also is born with DS (Mayo Clinic, 2023). Although there are many families that have had one child and then the next child is born TD, it is important to understand this risk factor for families who have an older mother or have multiple children with DS.

Next, there are a plethora of topics that could be discussed as exercise connects to the cardiovascular system. The current study sought to understand how heart rate range and oxygen saturation change in participants with DS and typically developing (TD) participants as a result of swimming as a mode of exercise. As seen in Table A, there is an example table of normal heart rate for a typically developing individual as they age (Hipp, 2023). Heart rate is the number of beats the heart makes every minute. At rest, an elevated number is generally seen with younger individuals, as the rate of growth in cells is enhanced within a growing individual. As individuals age into older teen and adult years, there is less cell division going on, and the heart does not have to work as hard to grow as it did when individuals were in the age range of 1-3 years old (Gill, 2022).

Age of Individual	Average Heart Rate (Beats per Minute)
Newborns ages 0 to 1 month old	70 to 190 bpm
Infants 1 to 11 months old	80 to 160 bpm
Children 1 to 2 years old	80 to 130 bpm
Children 3 to 4 years old	80 to 120 bpm
Children 5 to 6 years old	75 to 115 bpm
Children 7 to 9 years old	70 to 110 bpm
Children 10 years and older	60 to 100 bpm
Athletes in Top Condition	40 to 60 bpm

Table A: Heart Rate Changes with Age

It is important to understand what happens to the heart when an individual exercises in terms of cardiac output. Cardiac output refers to the amount of blood the heart pumps each minute. This is calculated by multiplying the stroke volume (end-diastolic volume end-systolic volume) by the heart rate (cardiac output = stroke volume x heart rate). When one exercises, the body demands an increased amount of oxygen to allow for the muscle to function properly. Oxygen is carried via the cells within our blood, allowing the organs and muscles to get the nutrients they need to survive and function efficiently with other muscles and organs while exercising. With the increased blood and oxygen needed during exercise, the heart must pump faster and thus see a greater increase in cardiac output (Alberta, 2023). The heart can increase its stroke volume by pumping more forcefully and increasing the amount of blood that fills the left ventricle prior to being pumped out. Additionally, the heart rate can increase, which in turn increases the amount of blood that leaves the heart and travels to the various organs of the body.

Anywhere from 40-60% of individuals with DS have cardiovascular abnormalities (Elmaghraby et al., 2011). According to the NIH, the main purpose of our cardiovascular system is to provide adequate blood circulation throughout the body. Cardiac abnormalities have also been shown to co-occur with abnormalities in pulmonary circulation, a process which helps to provide oxygen to the blood that is delivered to all organs within our body through systemic circulation that allows us to perform simple life actions like walking up the stairs (Chaudhry et al., 2022). Specifically, “The regulation of the cardiovascular system occurs via a myriad of stimuli, including changing blood volume, hormones, electrolytes, and many more" (Chaudhry et al., 2022).

In discussing Down syndrome, the field must understand how cardiovascular function and anatomy are altered in this population. Cardiovascular disease is a leading cause of mortality in individuals with and without DS (Colvin et al., 2017). Congenital heart disease (one or more problems with the heart's structure since birth and a common cardiovascular disease) is the most common cardiovascular condition in this group, present in up to 50% of people with DS and contributing to poor outcomes (Dimopoulos et al., 2023). One specific congenital heart disease is an atrioventricular septal defect (ASVD) (Fernhall et al., 2013). ASVD is the most common type of congenital heart defect that is present in individuals with DS, meaning that blood is able to sneak through areas that it should not be going through as a result of a hole between the left and right side of the heart. This heart defect generally forms during gestation (pregnancy), creating holes between the chambers of the right and left sides of the heart, and the valves that control the flow of blood between these chambers may not be formed correctly (CDC, 2023). In other words, blood can go from the lungs, where it gets oxygen, to the heart, then back to the lungs without taking the oxygen to the rest of the body (National Down Syndrome Society, 2024). This can lead to a variety of heart functionality issues, as the blood may have a lower amount of oxygen or extra blood going back to the lungs, and not enough is being sent to the rest of the body. The extra blood going to the lungs causes an increase in work for the heart and the lungs on a second-to-second basis, which can lead to congestive heart failure (CHF) in the future for the individual. It is crucial to understand that other cardiovascular abnormalities have been discovered in children with Down syndrome, but an AVSD is the most common at this point and time. This is a major reason why individuals with this condition become more easily fatigued as a result of exercise compared to someone without an AVSD. It is also important to consider that not all children with DS have a congenital heart condition and that many other conditions associated with DS could cause their bodies to react differently to mild to moderate exercise. In fact, while many babies with DS are born with a septal defect, many defects heal on their own or are corrected via surgery during their first days of life. *Image 1* shows a human heart and pulmonary circulation. As seen in this image, the heart is made up of four different chambers: the left and right atrium and then the left and right ventricle. Blood enters the right side of the heart and then goes to the lungs to receive its oxygen. It is then spread to the rest of the body after leaving the left atrium. The current study **hypothesized** that heart rate maximum, minimum, and range would differ for children with DS and TD children, and a high rate of AVSD among individuals with DS could be a major contributor.

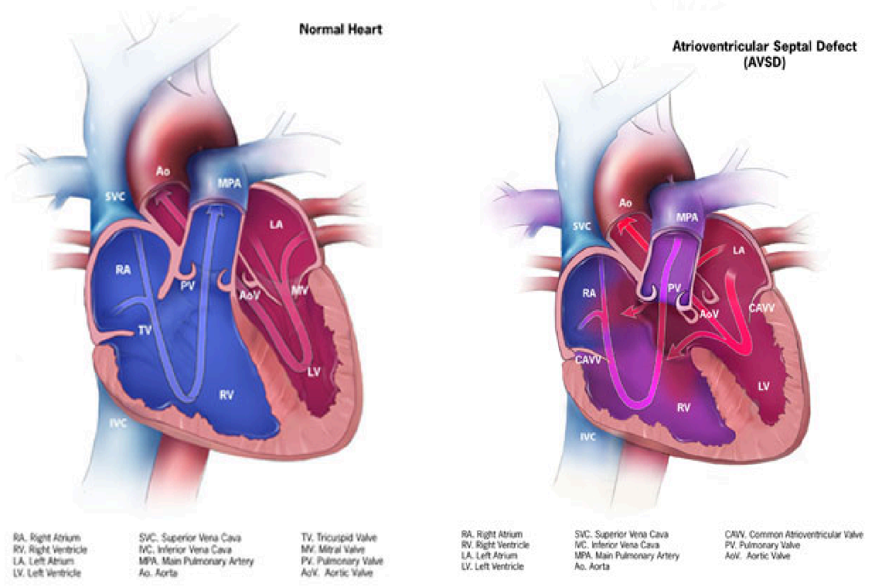


Image 1. Facts about Atrioventricular Septal Defect (AVSD) (CDC, 2023)

It is critically important to understand the biological basis for cardiovascular response to exercise in both children and young adults with and without DS. Evaluating the correlation between exercise and cardiovascular functioning informs how the body maintains homeostasis. When individuals exercise, the body reacts in a plethora of ways to ensure that homeostasis is maintained. One of the biggest factors that affect how a TD individual reacts to exercise is whether the individual is generally sedentary or is a regular exerciser. Sedentary individuals generally have higher resting heart rates, which increase significantly during aerobic or anaerobic exercise. One reason why resting heart rate is generally higher among individuals with DS is the lack of physical exercise individuals with DS are exposed to, providing further evidence that the current swim study is needed and impactful.

Furthermore, blood pressure and cardiac output also increase during both swimming and using a treadmill, two modes of exercise that provide evidence of how exercise can affect cardiovascular function between TD individuals and individuals with DS (Kumaria et al., 2023). Individuals who live a sedentary lifestyle reach their heart rate, cardiac output, and blood pressure limit sooner and need more time to recover after exercising. On the other hand, individuals who exercise regularly have lower resting heart rate values, more controlled responses to heart rate changes, stable blood pressure, and more efficient oxygen delivery to muscles (Kumaria et al., 2023). The last factor, being more efficient in oxygen delivery, is very important to understand and a major reason why exercising regularly is recommended for individuals. The increase in oxygen delivery allows our blood and heart to function properly. It is crucial to understand that components like heart rate and blood pressure for individuals can be affected by various variables, but lifestyle components represent a major contributing factor (Cleveland Clinic, 2023).

Although there are a plethora of topics that could be discussed as exercise connects to the cardiovascular system, the current study sought to understand how heart rate range and oxygen saturation are influenced by participants with DS and typically developing participants when it comes to swimming as a mode of exercise. Heart rate is the number of beats the heart makes every minute. At rest, an elevated number is generally seen with younger individuals, as the rate of growth in cells is enhanced within a growing individual. As individuals age into older teen and adult years, there is less cell division going on, and the heart does not have to work as hard to grow as it did when individuals were in the age range of 1-3 years old (Gill, 2022).

The research question for this project connects to swimming and how it affects the cardiovascular function of individuals with DS compared to typically developing individuals. As a result, it is important to ponder just how crucial exercise is for an individual diagnosed with Down syndrome. Now, of course, it is crucial to understand that many health components could affect rates of youth obesity, such as diabetes. Specifically, a recent 2023 showed that DS have a higher prevalence of overweight and obesity compared to the general youth population (Ptomey et al., 2023). Another study specifically found that between 30-50% of children with DS were obese. For typically developing, it was around 1 in 5 children or 20% (Sthol, 2023). Given that our study mostly included children, this information shows a difference in the two groups studied and a possible factor that could be at play for the exercise and heart rate differences that will be discussed. This is why it is so important for children with DS to find ways to move their bodies on a regular basis and counteract these rates in ways that are accessible for them and their families. This is far easier said than done for individuals and their parents, stemming from the plethora of barriers that currently exist to accessing opportunities for exercise for this specific population. Some of the most common barriers that exist for individuals with DS and their families include time constraints, finances associated, lack of feeling of belonging, and more (Banky, 2023). These barriers are even more prevalent in non-white and economically marginalized individuals. Some of the most important barriers that swimming, as opposed to other exercise methods such as using a treadmill, helps to bridge include increased enjoyment and interest, minimal cost for participants, and reduced need for major gross and motor skills. A recent 2023 study was able to review treadmill testing from the last 25 years, showing the great amounts of research into this field but also providing a glimpse into the fact that the treadmill has been the main mechanism to increase heart rate and compare heart rate differences between the two populations (Kaminska et al., 2023).

Previous research has investigated the use of treadmill exercises for individuals with DS and how that can affect overall heart rate minimum, maximum, and range values, but not many have investigated how swimming, specifically, can affect cardiovascular function amongst individuals with DS compared to typically developing individuals. A recent study performed by researchers at the University School of Physical Education in Poland helps to explain the benefits of swimming for individuals with DS, such as an increase in accessibility and a feeling of belonging. This comprehensive study not only mentions the benefits it yields for overall health but also points to the increased mental health and socialization that can be aided for individuals with DS (Naczk et al., 2021). The current study created a partnership with the UA Campus Recreation Center partner in both the Summer of 2022 and the Summer of 2023 to further understand just how beneficial swimming can play in the lives of individuals with DS and then see how this mode of exercise can affect minimum and maximum heart rate and then the range of overall heart rate.

Individuals with DS tend to exhibit low cardiovascular fitness, as indicated by peak heart rate according to stress tests completed comparing TD individuals and individuals with DS (Pitetti et al., 2013). Furthermore, as previously mentioned, individuals with DS face a variety of barriers to exercising on a regular basis and tend to live a more sedentary lifestyle than their typically developing peers. As a result, their average heart rate and blood pressure tend to be higher and see a similar pattern to a typically developing individual who has experienced a sedentary lifestyle. Additionally, individuals with DS tend to have lower muscle tone compared to TD individuals. A major reason for this decrease in muscle tone could be the higher rates of obesity seen in individuals who have DS, as well as lower rates of physical activity (Foley & Killeen, 2019). Furthermore, individuals with DS tend to have smaller airways within the lungs and overall pulmonary system. This is important to mention, as smaller airways can increase the rates of wheezing overall. Wheezing is classified as a whistling sound that makes it harder to breathe in both the short and the long term (John Hopkins, 2023). Swimming, as described in the current study, could be introduced as an effective way to dive deeper into the way that exercise affects cardiovascular function for the TD and DS population.

One study showed that subjects with DS had a significantly higher mean maximal heart rate (Pastore et al., 2000). Furthermore, the heart rate is overall higher at baseline for individuals with DS compared to typically developing individuals. These test results come from the researchers doing a stress test for participants, in which participants would get on a treadmill for a certain amount of minutes, and researchers would collect data on how much their heart rate changed, as well as pulmonary function and look at the differences between DS and TD (Pastore et al., 2000). Many interventions have been attempted to increase the chance that individuals with disabilities have to exercise, including aquatic practices such as swimming and exercising in the pool through a plethora of other mechanisms (Naczk et al., 2021). This study included a 33-week-long water-based exercise and a swimming program while the control group maintained their normal daily activity. 31 individuals with DS were recruited to participate, similar to the number of individuals with DS. While this study had a similar sample size, the study described by Naczk et al., 2021 mostly sought to understand how swimming could affect BMI, body mass, and body fat and found that swimming is an effective way to decrease those variables. However, it did not dive into how swimming affects heart rate between the DS and TD population, marking a key gap that our research is seeking to fill.

Furthermore, individuals with DS have a different cardiovascular system, and the current heart rate equation (Fox equation) may not totally capture this, which is why the Tanaka equation was created. The difference between the Fox equation and the Tanaka equation relates to the equation that is used for each, as the Tanaka equation has been shown to possibly be more tailored to children. The Tanaka equation can be seen as the following: $208-0.7 \times \text{age}$. An Age-Predicted Maximal Heart Rate in Recreational Marathon Runners study in 2018 sought to use this equation, but few other studies have chosen to use it over the Fox equation (Nikoladis et al., 2018). The current study hypothesized that swimming will be an effective form of exercise in regard to cardiovascular activation. It is also hypothesized that individuals with DS will have lower maximum heart rate compared to TD individuals after swimming.

The importance of exercise for the DS population cannot be understated. As previously mentioned, individuals with DS have metabolic and physiological differences compared to TD individuals. Two major outcomes of these differences can be seen through a decrease in exercise participation and work capacity in the short and long term. The metabolic and physiological differences can be seen in lower peak heart rates and higher rates of obesity (Kawasaki et al., 2010). Environmental factors mark another key reason why exercise is often less common for individuals with DS. On a macro level, there is a lack of inclusive programs that allow this population to feel comfortable exercising with other individuals with DS or TD individuals. Furthermore, there is an increase in family responsibilities that make it hard to exercise, a lack of friends, and also a stigma connected to individuals with any type of physical or intellectual disability (Pitetti et al., 2013).

In summary, it is well established that individuals with DS have less access to viable forms of exercise. Furthermore, previous research on exercise and cardiovascular function amongst children with and without DS has mostly focused on how physical activity can affect cardiovascular function amongst individuals with DS and TD individuals, through treadmill testing. Exercise is important for cardiovascular health, and the body reacts in predictable ways to exercise, which helps the body circulate blood and oxygen to perform best. There are many factors that can impact cardiovascular responses to exercise, such as ASVD or congenital heart disease. Children with DS not only are less active overall, impacting their baseline cardiovascular health but also have additional defects that exacerbate this issue and impact how they react to exercise. Actively increasing heart rate over time through exercise is critical to improving cardiovascular health and an effective way to understand the differences in heart rate between the DS and TD populations. Understanding the differences in how individuals with DS react to exercise can shed valuable light on increasing cardiovascular health for all. Swimming has been shown to effectively engage all individuals in exercise and may be a more accessible intervention for individuals with physical disabilities or differences, heart conditions, low SES, or other demands. As a result, the Memory Development & Disorders Lab sought to design a study that could provide both DS and TD individuals the opportunity to exercise in a more inclusive environment. The current research study capitalizes on a partnership and community funding to propose an accessible intervention to increase exercise engagement and investigate cardiovascular outcomes. It is hypothesized that swimming will effectively increase participants' heart rate, but children with DS will react differently to exercise, reflecting lower overall activation than TD peers.

Aims & Hypotheses:

Aim 1) When participants exercise, their heart rate (HR) increases as a result of an increase in demand for oxygen that is then delivered to muscles and organs within the human body. The current study evaluated heart rate during swimming to evaluate differences in the heart for participants with DS and TD participants, in response to exercise. It was **hypothesized** that swimming would be an effective way to increase heart rate in both groups.

Aim 2) Individuals with DS have lower heart rates than TD individuals at rest and during exercise. The current study evaluated heart rate at baseline in a sedentary setting compared to swimming at the Arizona Recreation Center and compared differences between each. It was **hypothesized** that individuals with DS have lower heart rates at baseline and while swimming than TD peers of a similar age range. The range of HR, the numerical difference from minimum heart rate to maximum heart rate response to exercise, would be less for individuals with Down Syndrome. This ideology greatly comes from a recent 2023, which showed similar results using a treadmill test (Bahiraei et al., 2023).

Methods:

I. Participants

Medical records are obtained as part of verification for diagnosis of individuals with Down syndrome. The exclusion criteria for the swim study will include a plethora of different components, including a diagnosis of ADHD, head injury history, episode of loss of consciousness that lasts longer than five minutes, uncorrected vision impairments, and overall untreated hearing impairments. Given the frequency of comorbid diagnoses of attention-deficit/hyperactivity disorder (ADHD), Autism, and DS and underdiagnosis in the group, screeners for ADHD and Autism were included. The likelihood of Autism or ADHD was controlled for in data analysis. Typically developing (TD) participants who had existing diagnoses of Autism or unmanaged ADHD were not included in the study. Furthermore, as compensation for their participation in the study, The Memory Development & Disorders Lab will give each participant a $40 Target Gift card at the end of the study. This study has been approved by the Institutional Review Board (IRB) at the University of Arizona. Below is a table representing our sample size for the past two years of swim camp in 2022 and 2023. Over the course of the two summers, the lab was able to recruit nearly 50 DS and TD individuals to participate in the swim study. The specifics behind our study population are as follows: DS (N = 23, 16 Male), ages 5-26 years (mean = 13.65) and TD (N = 25, 14 Male) children ages 5-12 years (mean = 8.68) participated in the University of Arizona Campus Recreation Center's swim camp, which can be further seen in Table B.

	Down Syndrome (DS)	Typically Developing (TD)
N	22	25
Age	5.79 -25.21 (Mean=13.65)	5.29 -12.76 (Mean=8.68)

Table B. Sample Size and Age of Participants

Commitment of Memory Development & Disorders Lab to Diversity

Anecdotal reports from parents confirmed the barriers that were previously hypothesized. This shows the universality that exists for thousands of families throughout the United States who have a family member with Down syndrome, showing just how crucial it is that the field of research seeks to work with individuals at both a local and national level to increase the opportunities for individuals with DS to access modes of exercise. It is also important to understand that swimming is not the only mode of exercise that could be used for individuals with Down syndrome, as that may not be available for individuals and families. However, finding a way to exercise is crucial because it could help decrease the rates of the various comorbidities that currently exist for individuals with Down syndrome, including obesity.

The field of research into this topic demands an opportunity for all backgrounds to be included in the research process, which was also paramount for this specific project. One important factor to consider when it connects to inclusivity and diversity is the socioeconomic status of possible participants. The partnership between the Memory Development & Disorders Lab and the University of Arizona Recreation Center, with the help of a sizable donation, made it possible for this project to offer free swim lessons to participants. Furthermore, the lab helped cover the cost of parking passes and offered money for gas if a family and their participant traveled from a long distance. Additionally, each participant was compensated for their time over 2 weeks, which is evident by the $40 gift card that everyone was given. Another component that was considered was the race and ethnicity of our participants. To best represent the total population of Tucson and surrounding communities, the project used a plethora of networks. This includes DS networks and various listservs used in previous research studies completed by the Memory Development & Disorders Lab. One specific example of this is the fact that members of the lab went to various information sessions and meetings of mothers with Hispanic children, ensuring that everyone had the opportunity to learn about the lessons that were to be offered in the summer. With the inclusion of the diverse backgrounds of individuals that the lab was able to recruit, the lab had to ensure that a bilingual staff was present. During both summers, multiple research assistants were hired who could speak Spanish and effectively communicate with parents who only spoke Spanish. All the information on these various factors can be found in Table C.

	DS	TD
N	22	25

Sex	15 (Male) 7 (Female)	14 (Male) 11 (Female)
Ethnicity	-	-
White	12 (54.54%)	14 (56.00%)
Hispanic	5 (22.72%)	5 (20.00%)
Asian – Pacific Islander	0 (0%)	3 (12.00%)
Black	0 (0%)	0 (0%)
Biracial – Multiracial	5 (22.72%)	3 (12.00%)
Income	-	-
Lower	5 (22.72%)	4 (16.00%)
Middle	12 (54.54%)	13 (52.00%)
Upper	5 (22.72%)	7 (28.00%)
Maternal Education	-	-
High School	4 (18.18%)	2 (8.00%)
College	10 (45.45%)	13 (52.00%)

Post-Grad	8 (36.36%)	10 (40.00%)

Table C. Individual Age, Sex, Ethnicity, Income and Maternal Education

II. Design

This study, looking at how heart rate changes as a result of swimming, was part of a larger study within the lab that looked at how sleep and memory also change as a result of swimming. The swim camp was held at the Arizona Campus Recreation Center for two weeks throughout the summers of 2022 and 2023. A total of eight 30-minute sessions in the evening were held for each participant, as they came from Monday to Thursday for the duration of two weeks.

Participants were separated into two groups during their 2-week sessions, allowing them to come at 5:00 PM or 7:00 PM. The main factor used to determine what group each participant was in was based on swimming experience, making it easier for the swim instructors to give the same instruction to all the participants in each group. There were two swim groups per day, one for experienced swimmers and one for inexperienced swimmers. The inexperienced group had 2-4 swimmers per group, and the experienced group had 4-6 swimmers per group. Furthermore, each time, there was a mix of individuals, including DS and TD individuals, allowing participants to interact and have fun with both subgroups of the study. The same swim instructor was used as often as possible to ensure equal exercise engagement across the groups.

There were multiple occasions when the lab had to cancel swim lessons because of lightning storms; in that case, the lab could reschedule participants for either of the two Fridays. This ensured that all participants received at least 7 swim sessions. Swim camp generally started at the end of May and finished near the end of July. Our relationship with the Arizona Campus

Recreation Center is very well established, providing an opportunity for future research studies to use these resources. As seen in *Diagram 1* below, participants came into the lab space a few weeks before the start of swim camp. This allowed for data on heart rate and oxygenation saturation in a sedentary setting and provided an opportunity to compare how these results differed for individuals with DS and TD. During this time, children would play a plethora of memory games and other activities to maintain their baseline (sedentary) heart rate. This within-subjects approach and design of our study allowed investigators to compare levels of activity during the baseline testing to activity during swim camp.

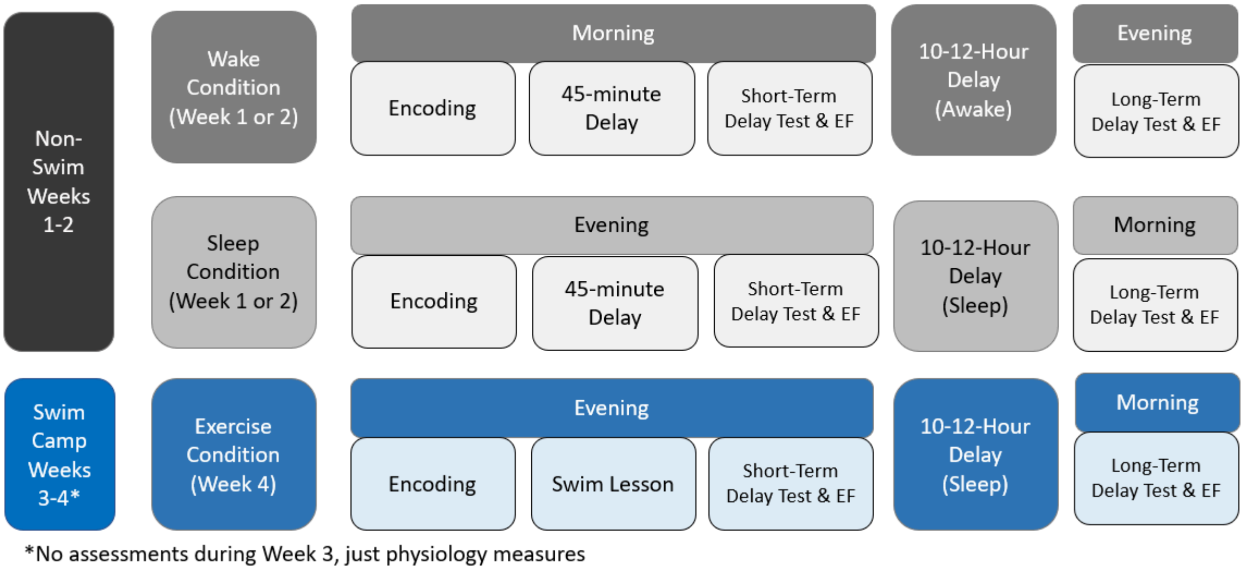


Diagram 1. Intervention Condition Overview and Schedule of Assessments

III. Monitors

Physical activity was measured using three different monitors. To evaluate how heart rate changed throughout the swim lessons, this study used **(1) Polar Goggle Clips**. These devices were then clipped to the goggles of participants, and continuous heart rate was tracked. The devices were connected to a Bluetooth heart rate tracking app, allowing the examiners to continuously monitor data collection. There were a handful of participants who chose not to wear these clips on the goggles due to sensory sensitivities, and as a result, researchers placed the Polar Watch on the tricep and bicep area of participants. This device provides the main outcome variables for the current study (Table E). Heart rate was collected using both Fox (*Equation*) and Tanaka (*Equation*) and later compared. As discussed in the *Introduction*, the Tanaka equation may capture cardiovascular differences better in participants with Down syndrome, but the Fox equation is the Gold Standard.

(2) Oxygen Saturation was measured using the **Masimo Fingertip Pulse Oximeters**.

(3) **CamnTech Motion Watches**, a waterproof Actiwatch, were used to measure day-to-day sleep and activity throughout participation in the study. Future data analyses will use this data to group participants into active and minimally active participants to evaluate how overall activity moderates heart rate changes through exercise.

IV. *Heart Rate Variables*

In previous research studies, the Fox equation has been used to find the maximum heart rate of an individual. This equation can be seen as 220 minus the individual's age (Max heart rate= 220-Age) and has been used as the gold standard for many previous experiments in this field. However, given that this study had many children under the age of 21, the research team thought it could be more beneficial to use the Tanaka equation to better understand how swimming affects heart rate between individuals with DS vs TD individuals. Previous literature has possibly shown that the Tanaka equation is more suitable for younger hearts. Furthermore, individuals with DS have a different cardiovascular system, and the current heart rate equation (Fox equation) may not totally capture this, which is why the Tanaka equation was created. The Tanaka equation can be seen as the following: 208-0.7 × age. An Age-Predicted Maximal Heart Rate in Recreational Marathon Runners study in 2018 sought to use this equation, but few other studies have chosen to use it over the Fox equation (Nikoladis et al., 2018). The difference between the Fox equation and the Tanaka equation relates to the equation that is used for each, as the Tanaka equation has been shown to possibly be more tailored to children. The various variables used can be seen in Table D.

Variable Name	**Variable Description**
Average Heart Rate	Using the motion watches, the average heart rate of the sedentary or active interval
Max Heart Rate	Using the motion watches, the maximum heart rate during the sedentary or active interval
Average Percentage of Estimated Max Heart Rate, Compared to their Average Heart Rate	Using participants' estimated maximum heart rate based on their age, height, and weight, this variable was created to see, on average, what percentage of their estimated max they reached. (e.g.,
Average Percentage of Estimated Max Heart Rate, Compared to their Max Heart Rate	Using participants' estimated maximum heart rate, based on their age, height, and weight,

	this variable was created to see what percentage of their estimated max was reached based on their measured max heart rate.

Table D. Devices Used

Image 1. Polar Goggle Clip Heart Rate Device

V. Oxygenation Saturation

As previously mentioned, the current study collected data on the oxygenation saturation of participants during the in-lab testing sessions and then at the swim camp. This data was collected through the use of a portable pulse oximeter that went on the index finger of participants. In analyzing the data collected over the past two summers, there were no significant conclusions that could be drawn. Previous studies have shown that individuals with DS tend to have abnormal oxygen for a variety of reasons. One of the most common reasons for this connects to the higher rate of sleep apnea that can persist among individuals with DS. Many sleep providers believe that a significant number of children with DS experience some level of sleep-disordered breathing, with obstructive sleep apnea being the most common. The unique physical characteristics associated with Down syndrome, such as differences in airway and facial structure, contribute to a higher prevalence of sleep-related issues in this population (Marcus et al., 1991). As a result, the current study was very intrigued by the possibility of observing if swimming could affect the oxygenation saturation of participants and if there was an overall difference between DS and TD participants.

One major component that affected the vitality of our pulse oximeter readings for participants was the impact that the water had on overall results. Although we took the time to dry the fingers of participants before putting it in the device, the wet residue did affect the overall readings in general. This is evident from the very low readings, such as 65% and 70% for some participants. Furthermore, some of the participants were very young and had tiny fingers. Another factor that speaks to our inability to draw comprehensive conclusions is the fact that it was not collected continuously, which is different from the heart rate data that was collected at a continuous rate. If continuous data had been collected, averages would have been able to be analyzed, and it would have provided an opportunity to understand if previous research saw similarities with the data of our lab. Future research should seek to better understand the differences in oxygen saturation in DS and TD individuals while exercising, allowing for a better understanding of how practicing exercise affects this variable.

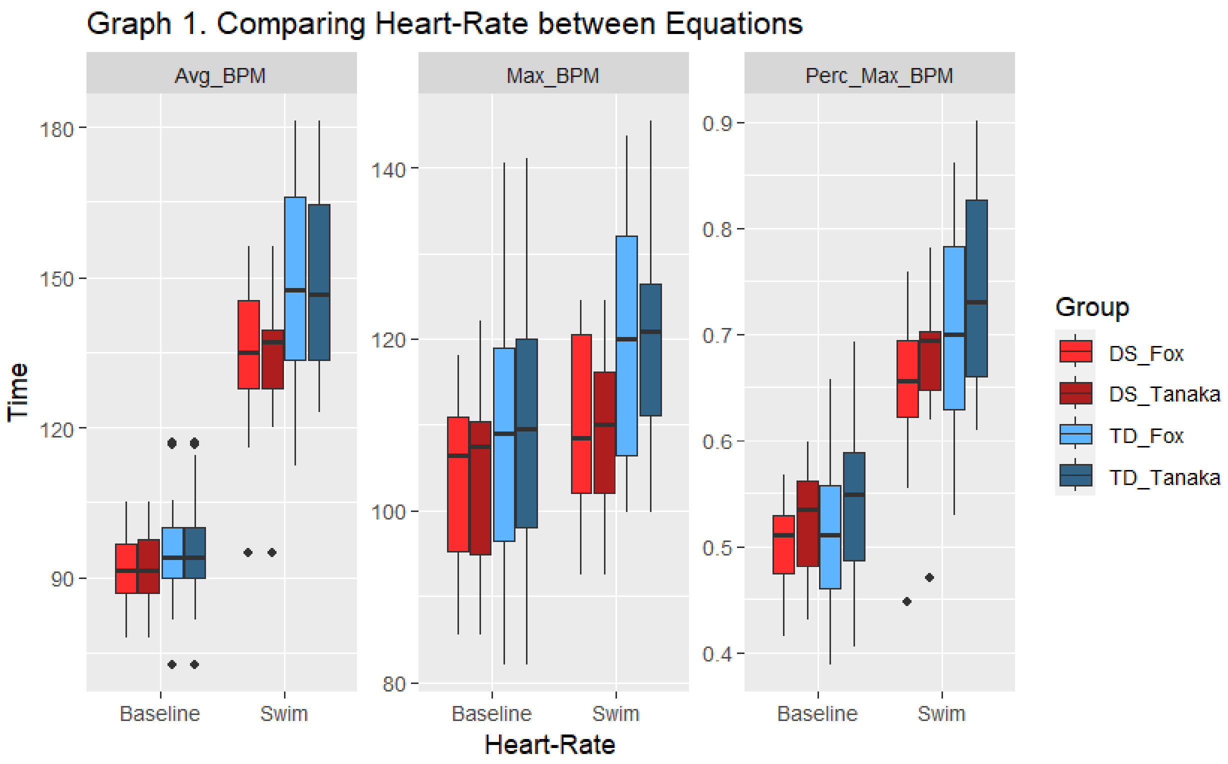
Statistics for this study were collected through various platforms. First, the heart rate data was combined and analyzed using Excel sheets. The three variables compiled on the Excel sheet were average heart rate, maximum heart rate, and percentage maximum heart rate. Next, data was analyzed using R to draw qualitative conclusions. Levene's tests were used to determine the skewness of data. Since no variables were skewed, parametric tests were used. T-tests and ANOVAs assessed within- and between-group differences in heart rate variables before and after swimming. Graphs were created using the ggplot2 package in R.

Results:

Before diving into the results found over the past two years, it is important to understand the difference between Fox and Tanaka as a method to collect data on heart rate. The Fox equation has long been the gold standard when looking at maximum heart rate, which allows you to find the maximum heart rate of an individual based on the equation 220 - Age = maximum heart rate. However, previous literature has pointed to the fact that sometimes, that may be an inaccurate representation of what truly is the maximum heart rate of an individual. As a result, the Tanaka equation was created to provide a possibly more accurate understanding of heart rate. As was previously stated, individuals with DS have different heart functions and structures to a great degree. Therefore, a more accurate heart rate equation is necessary (Shilton, 2023). The Tanaka equation is seen as 208 - 0.7 * age. The formula tends to produce a slightly elevated max heart rate for younger people and underestimate it for older adults. As a result, the current study wanted to compare the two types of heart rate equations to see if there truly is a difference and which one should be used for data collection.

T-tests were used to evaluate the difference between heart rates using the Fox and Tanaka equations during the baseline and swimming conditions. A p-value less than 0.05 shows significance, and anything greater shows that the data points are not significant. Referenced in *Graph 1,* at baseline (sedentary), there was no significant difference between average heart rate (t(18.71)=0.07, p=0.949) or max heart rate (t(16.96)=0.22, p=0.825) in DS. Similarly, in TD participants at Baseline, there was no significant difference between average heart rate (t(23.95)=-0.14, p=0.890) or max heart rate (t(23.90)=-0.38, p=0.709). While swimming, there was no significant difference between the average heart rate (t(18.85)=-0.11, p=0.91) or the max heart rate (t(18.86)=-0.25, p=0.80) for the DS population between the Fox and Tanaka equations. As it pertains to the TD population while swimming, there was no significant difference between the average heart rate (t(23.99)=-0.39, p=0.69) or the max heart rate (t(23.97)=-0.18, p=0.86) between the two equations.

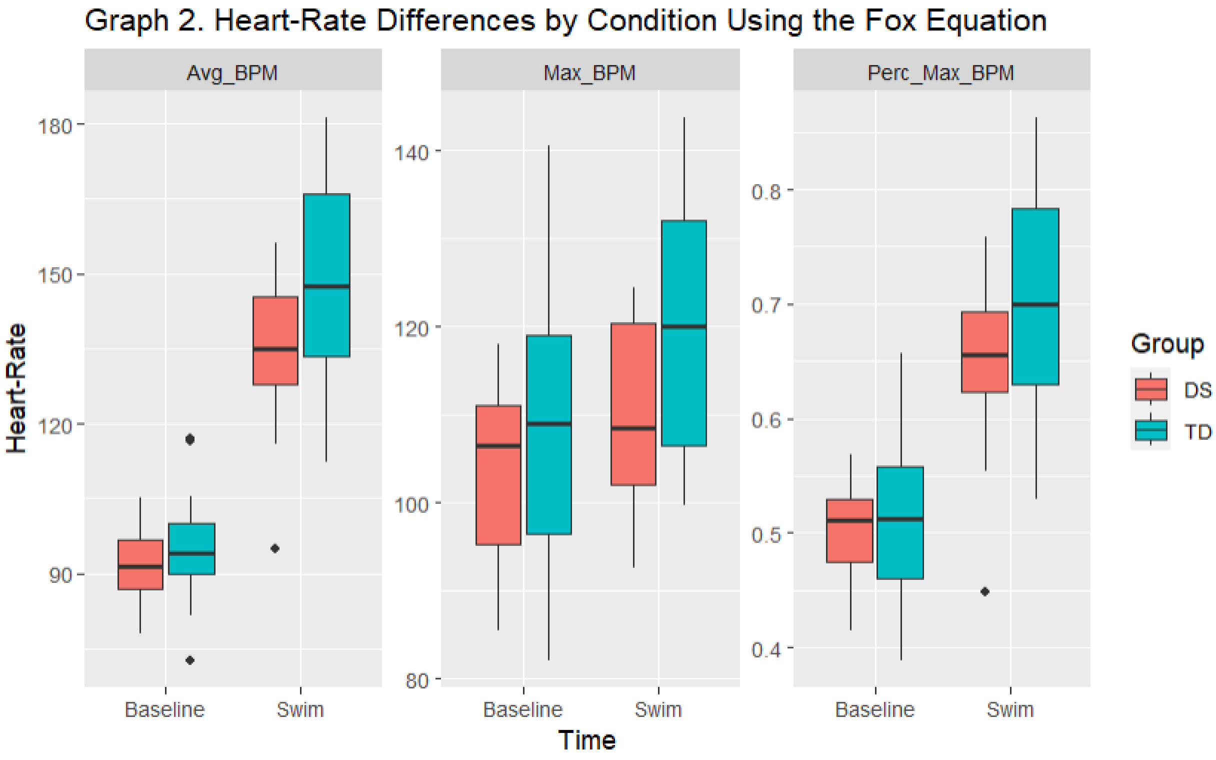
Given that there was no significant difference between the two equations, the research team decided to use the Fox equation because of its use as the gold standard for understanding the max heart rate of individuals. Although there is a little difference between the two equations for each group. Future studies should continue to research the efficacy of each of these equations and gain a more comprehensive understanding of which is most effective in understanding max HR.



Graph 1: Comparing Fox and Tanaka Heart Rate Equations

Aim 1 of this research study sought to understand whether swimming was an effective exercise mechanism for increasing heart rate among participants.

Referenced in *Graph 2*, the results show statistically significant data between baseline heart rate and then heart rate during swimming for both DS and TD participants. For baseline for average heart rate, maximum heart rate, and percentage maximum heart rate for both TD and DS, the results show similar HR do not show significant differences between the two groups studied. However, when looking at the baseline compared to swimming, heart rate differences can be seen. Specifically, for baseline compared to swimming for DS participants, there was a significant increase in average heart rate (t(69.55)=-17.252, p<0.001). Furthermore, participants with DS had significantly higher maximum heart rates after exercising compared to sedentary (t(72.08)=-10.97, p=0.015). Additionally, for baseline vs. swim for DS participants, there was a significant increase in percentage max heart rate (t(72.04)=-10.97, p<0.001) for the DS participants. Next, in looking at the TD population, we see similar results that show that heart rate effectively increases as a result of swimming. Specifically, for baseline vs. swim for TD participants, there was a significant increase in average heart rate (t(96.67)=-18.9, p<0.001). Furthermore, for baseline vs. swim for TD participants, there was a significant increase in max heart rate (t(93.01)=-4.14, p<0.001). Additionally, for baseline vs. swim for TD participants, there was a significant increase in percentage max heart rate (t(96.01)=-11.4, p<0.001) for the TD participants. In summary, during and after swimming, all participants had a significantly higher average maximum and percentage maximum heart rate than at baseline. In addition, swimming was an effective method for heart rate in children with DS and TD.



Graph 2: Heart Rate Data: Fox Equation

Aim 2 of this research study was to investigate the difference between average and maximum heart rate between individuals with DS and TD individuals at baseline and during swimming, respectively. In other words, this aim evaluated cardiovascular differences between TD participants and participants with DS while sedentary and in response to exercise. Referenced in *Graph* 2, At baseline, DS and TD participants did not differ significantly (similar heart rates) between average heart rate (t(85.85)=-1.78, p=0.07). Furthermore, at baseline, when comparing the DS and TD groups, there was no significant difference between maximum heart rate (t(84.70)=-1.54, p=0.12). Lastly, for baseline comparing the DS and TD, there was no significant difference between the percentage maximum heart rate (t(82.36)=-0.61, p=0.53). Given that all three of these baseline values for the DS and TD groups were not statistically significant, it does show that the baseline differences for DS and TD are not present to a significant degree according to the data collected over the last two summers. In other words, these results may not suggest differences in cardiovascular function between TD and DS participants while sedentary. However, the opposite is shown when evaluating the effect that swimming has on the average, maximum, and percentage maximum heart rate. While swimming, comparing the DS and TD, there was a significant increase in average heart rate (t(85.59)=-4.12, p=8.5e-5). TD individuals had a greater increase in average heart rate compared to DS.

Furthermore, comparing the DS and TD when swimming, there was a significant increase in the maximum heart rate (t(86.88)=-4.52, p=1.9e-5). TD individuals had a greater increase in range for maximum heart rate compared to DS. Lastly, comparing the DS and TD when swimming, there was a significant increase in the percentage maximum heart rate (t(85.64)=-2.99, p=0.003). TD individuals had a greater increase in percentage maximum heart rate than DS. In summary, average, maximum, and percentage maximum heart rates in DS vs. TD at baseline were not significantly different. However, while swimming, the average HR, maximum HR, and percentage maximum heart rate were lower for individuals with DS compared to TD individuals. This fulfills the initial hypothesis of the lab at the beginning of the study, which was that the maximum and average heart rate would be lower for individuals with DS than TD participants while exercising. This is a very intriguing finding and shows that swimming is not only an effective mechanism of increasing the heart rate of individuals but also affects heart rate differently among individuals with DS compared to TD individuals.

Discussion:

This study aimed to show the feasibility of swimming as a mechanism of exercise to understand the difference in cardiovascular function between individuals with DS and TD individuals. The primary objective of the research was to evaluate swimming as an effective mechanism to increase heart rate and if there are differences in heart rate average and heart rate maximum in response to swimming in DS compared to TD participants due to cardiovascular differences in their response to exercise. Although treadmill testing has shown ample amounts of evidence regarding differences in heart rate range, maximum HR, and average HR, treadmill testing also comes with some challenges for people with DS. Specifically, individuals with DS face many health differences and accessibility concerns that may prevent them from either participating in the treadmill test, such as physical or mental inhibitions.

The first aim this research study sought to answer was if swimming was an effective mechanism for increasing heart rate in both individuals with DS and TD individuals. The results showed that heart rate increased during swimming for both groups. When someone exercises, their heart contracts faster and increases blood circulation. This, in turn, increases the amount of oxygenated blood in the body, and that oxygenated blood is then able to reach the muscles at a higher rate. When looking at swimming as a way to exercise, the hearts of our participants had to contract faster to keep up with the greater demand for oxygen needed to continue the physical exertion of moving in the water. As previously mentioned, prior research indifferences in cardiovascular function between the two subgroups were mostly isolated to treadmill and other stationary machine testing. From accessibility to physical activity ability, using treadmill testing comes with several barriers, especially for individuals with DS. As a result, the use of swimming could be an effective way to further research this topic in the future. Understanding the differences in cardiovascular function is imperative, providing yet another piece to the puzzle in the overall field of the DS. Further research could also look into just how different the practice of treadmill testing is compared to swimming testing and analyze if the ability to increase heart rate is similar or if one is better than the other. In summary, our study found that swimming effectively increased the heart rate of both TD and DS. Similar results were found with treadmill testing in the past, but the fact that swimming shows similar results is important for the field of exercise within the DS population.

As it pertains to the possible heart rate differences in individuals with DS compared to TD individuals, the action of swimming did provide evidence that maximum, average, and percent max heart rate differences are present. In looking at the results, the heart rate while swimming, but not sedentary, was lower for individuals with DS, confirming the proposed hypotheses. In looking at the data collected, one can see that at baseline, there is no statistical difference in heart rate for individuals with DS and TD individuals, but they were significantly different while swimming. Participants with DS had significantly lower heart rate values compared to TD peers in response to exercise. As a result, seeing that heart rate differences at baseline are not statistically significant is an intriguing finding and demands further research compared to previous research, which found similar results (Gasior et al., 2023). When it comes to the action of swimming, TD individuals were able to increase their heart rate in all three categories present (maximum HR, average HR, and percentage maximum HR) at a higher rate than individuals with DS. There are many reasons for this difference, but one possibility could be the high rate of ventricular septal defects (VSDs) among individuals with DS compared to TD individuals. As mentioned, a VSD is a birth defect of the heart in which a hole in the wall (called a septum) separates the heart's two lower chambers (ventricles). When this happens, the ability for blood to flow as it usually does is altered to a certain degree and could alter the ability for the heart rate to contract as quickly as it usually does. This, in turn, would provide reasoning as to why the maximum HR, average HR, and percentage maximum heart rate vary for the two populations. It is important to understand that not all individuals with DS have a VSD, but it is just a common feature that is seen in individuals who have DS. Other possibilities could connect to BMI differences, metabolic differences, or a variety of other possibilities. Future research should focus on understanding why the differences in these three variables are altered for individuals with DS when they exercise.

Although there are a plethora of components the current study was able to successfully control for, as with every research study, there were a few limitations that are important to point out. The first correlates to the weather factor the current project had to deal with over the past two summers. Given that the study took place outside at the Recreation Center during June and July, there were multiple instances where the swim staff had to cancel the swim lessons for the evening because of impending or current monsoons. In this sense, the current study could not accurately measure cardiovascular change during the swim camp, as the number of days between swim lessons was not consistent. Although this affected our data collection on a macro scale, the saddest part of these cancellations was seeing the kids sad about not being able to swim that evening. One thing the lab did not expect coming into the study was how much joy swim lessons would bring to the participants and the friendships that were made amongst participants and parents. Often, individuals with DS have a difficult time making deep connections with their peers, and these lessons provide an opportunity for them to talk and make true friendships that have lasted long after swim camp. Whenever there was a canceled lesson, the lab tried our best to make up the lesson on a non-scheduled day, allowing us to still collect enough data to draw comprehensive conclusions about how swimming affects cardiovascular function amongst individuals with DS compared to typically developing individuals.

The second limitation that is important to point out is the breakup in Bluetooth connections of the Polar GoggleClips that the research study experienced at times. As seen in the pictures above in the methods section of this Honors Thesis, our Polar Goggle Clips were attached to the temple of each participant via being strapped onto the goggle strap. This allowed us to collect continuous data and see the data in real-time on the iPads that were used. However, there were multiple times throughout where either the goggles would fall off their face, or the device would disconnect if the goggles or arm band was not tight enough, causing an interference of water between the individual and the device and the research study would lose a few minutes of data. Once this happened a few times, the research team became proactive and ensured the watch strap was very secure before the participants entered the water. Furthermore, researchers were able to quickly react and put the device back on the goggles if it fell off. Even though the current study did have these complications, my team and I unequivocally believe that the use of this technology is far better than simply taking the heart rate of our participants three times throughout the lesson, similar to what was done to collect the pulse ox of our 49 participants over the course of two summers.

This brings me to our final limitation, which is connected to the pulse ox data collection. Throughout each swim lesson, the current study used a fingertip pulse oximeter to collect data on the oxygenation saturation 3 times per swim lesson. The first collection of this data was done right before they entered the pool to swim, the second was in the middle of the 30-minute lesson, and the last data collection was when they exited the pool at the end of the lesson. The first aspect of this limitation can be seen in the initial data collection for the day. Many participants had to walk a long distance from their cars to the testing room or pool in the high-temperature days of June and July, which increased their heart rates significantly, meaning their initial baseline pulse ox readings were affected to some degree. Furthermore, after 15 minutes of the lesson, researchers collected the data of our participants on the side of the pool. Given that the water could have made their fingers colder than usual and wrinkled their skin, oxygen saturation readings were hard to establish on young children with small fingers as the device could not accurately read their saturation levels.

This once again brings back the credibility of our heart rate data collection method through the use of the Polar Goggle Clip, as this data was collected continuously for each participant over the course of the 30 minute less. Future research should focus on ensuring fingers are completely dry, especially for children who are young and have small fingers or use fingertip pulse oximeters designed for very small children with cross-validation with oximeters for older individuals. Furthermore, future studies should emphasize waiting a few minutes after participants have arrived to record their oxygen saturation level. The field of research concerning DS is ever-growing and demands a better understanding of this topic, in addition to how cardiovascular function is affected. The current study possessed several strengths in study design and participant inclusion. The use of swimming as a mechanism provides a more inclusive environment and a more joyful experience for participants. Heart rate data is just a small aspect of the overall research project that was conducted, as memory and sleep were also important data points that were collected by the research team. The commitment to diversity and an inclusive environment was a critical component of the overall goal of this research project, a goal that was reached at a very high rate as a result of the research design and the ability of participants to swim at the University of Arizona Recreational Center for a total of 8 sessions. Through the use of objective measures to collect heart rate data at baseline and swim for both subgroups, the research team was able to collect data and further understand the hypotheses that were created at the beginning of the research project.

Another strength that is important to point out is the ability of the research to collect data on heart rate via the use of small, accessible. During the baseline testing in the lab, there could have been a variety of other modes of technology to collect data on HR, such as collecting data at the beginning, middle, and end of swim lessons as we did with the pulse oxygenation data. However, during the swimming portion of the lab, it was critical that technology could be used to continually collect data on heart rate while in the pool. Using iPads to continuously monitor the devices allowed the average, maximum, and percentage of maximum heart rate to be analyzed for both individuals with DS and TD individuals. Out of the 22 participants with DS, only one participant refused to wear the device, which is a much higher success rate than other objective devices. This is very important in research studies like this, allowing our research team to feel confident in the conclusions that are drawn for this population.

Additionally, the research project was able to recruit a diverse pool of participants. A common challenge in human subjects research, especially in DS, is that most participants are white, middle-class, and highly educated. Our sample's wide range of diversity closely represents the Southern Arizona community and arguably the whole country in general, providing more evidence for ecological validity. Furthermore, the fact that our study was completely free of cost for participants bridged the gap for families of low SES status. This diversity component is crucial because it allows for conclusive conclusions to be drawn and pave the way for future studies to do the same.

From a design point of view, previous treadmill studies showed that some individuals with DS struggle with increasing their heart rate effectively while on a treadmill. The chance to participate in our swim study was still a mode of exercise for participants but also enjoyed a fun activity like swimming. The final strength that our research team would like to bring attention to is connected to results that were found, specifically how swimming affects heart rate differently for individuals with DS compared to TD. At baseline, the results showed no significant difference in heart rate between the two groups. However, swimming provided a difference and showed that the cardiovascular response to exercise varied for the two groups studied in this research study. Future research should further look into why swimming leads to these heart rate differences because our research lab and this two-year comprehensive study shed light on the idea that exercise alters heart rate in different ways as it pertains to individuals with DS compared to TD individuals.

Conclusion:

In summary, the results of this two-year-long summer research study suggest that swimming is an effective method of exercise to increase the cardiovascular function of an individual with Down syndrome and a typically developing individual. Furthermore, our results show a varied increase in cardiovascular function (heart rate) variables when the current study looked at the two sub-groups of individuals. The specific reasons that could explain why the increase of heart rate for individuals with DS is less than typically developing individuals demand further research. Although there have been a few reasons discussed throughout this Honors Thesis, I call on other individuals in this field to gain a better picture of the underlying reasons behind this variation. Additionally, further research should investigate how oxygen saturation is altered through the activity of swimming and if this change is consistent across individuals with DS and typically developing individuals. Evaluating oxygen saturation changes could help shed light on the benefits of exercise on other organs, such as the brain. Pulse oxygenation is very closely related to heart rate changes during exercise, which is why it is important to research pulse oxygenation in the coming years. Future research studies into this topic should also continue with the use of swimming and PolarWatches to collect data on this topic, as swimming introduces a mode of exercise that is far more accessible and inclusive than previously used methods such as treadmill tests. Lastly, the results that we found are very important to the DS community, as the results showed that swimming is an inclusive physical activity that can help individuals with DS to become more active and increase their heart rate at a healthy rate.

Acknowledgments:

I would first like to thank the families that took time out of their busy schedules to allow us to collect meaningful data. This study would not have been possible without their dedication, so myself and the whole lab are very grateful. Next, I would like to give a major thanks to the University of Arizona Recreation Center for their constant support of this study and their unwavering commitment to giving both DS and TD individuals the chance to learn how to swim and have fun. Additionally, I was able to complete the 2023 Frontera/Blaiser Summer Internship with this research project as well. I would also like to thank the W.A. Franke Honors College for their commitment to my education, as they have funded multiple trips where I have been able to present this work and similar work. Specifically, the Honors College helped to fund my trip to

Kansas City in 2023 for the Gatlinburg Conference, where I was able to take part in poster sessions and share my work with leaders in the field of intellectual and developmental disabilities. I would also like to thank my PI and mentor, Dr. Jamie Edgin, as well as my Ph.D. candidate advisor, Alison Luongo, for their help throughout this Honors Thesis project and for giving me the opportunity to be part of such a special and transformative research lab since April 2022. Furthermore, I would also like to thank Dr. Matt Grilli for stepping and becoming my official mentor for this Honors Thesis after Dr. Jamie Edgin took a job at Virginia Tech in Summer 2023. I would also like to thank Brenden Barness and Ken Bottrill for their guidance during my two years as a member of the DS Research Group. Being part of this research project for the last two years has been such an amazing blessing. It has further cemented by passion for Pediatrics and working with underserved populations to better understand pressing health disparities. Furthermore, it has provided a unique opportunity to better understand how important swimming and overall exercise can be to enhance the overall health benefits of individuals with Down syndrome. This research lab and the W.A. Franke Honors College has allowed me to grow beyond my wildest dreams and am forever grateful and blessed for the experiences I have had as a wildcat here in Tucson. Bear Down, Go Cats, forever, and I hope everyone has a great rest of their day!

References

Anwar, A. J., et al. “Type 1 Diabetes Mellitus and Down’s Syndrome: Prevalence, Management and Diabetic Complications.” *Diabetic Medicine: A Journal of the British Diabetic Association*, vol. 15, no. 2, Feb. 1998, pp. 160–63. *PubMed*, https://doi.org/10.1002/(SICI)1096-9136(199802)15:2<160::AID-DIA537>3.0.CO;2-J.

Ataman, Ahmet Doğan, et al. “Medicine in Stamps: History of Down Syndrome through Philately.” *Journal of the Turkish German Gynecological Association*, vol. 13, no. 4, Dec. 2012, pp. 267–69. *PubMed Central*, https://doi.org/10.5152/jtgga.2012.43.

Bahiraei, Saeid, et al. “Effects of Exercise Programs on Cardiovascular Responses in Individuals with down Syndrome: A Systematic Review and Meta-Analysis.” *Preventive Medicine Reports*, vol. 36, Dec. 2023, p. 102521. *ScienceDirect*, https://doi.org/10.1016/j.pmedr.2023.102521.

Bull, Marilyn J. and Committee on Genetics. “Health Supervision for Children with Down Syndrome.” *Pediatrics*, vol. 128, no. 2, Aug. 2011, pp. 393–406. *PubMed*, https://doi.org/10.1542/peds.2011-1605.

Centers for Disease Control and Prevention. (2023, February 2). *Congenital heart defects - facts about atrioventricular septal defect*. Centers for Disease Control and Prevention. https://www.cdc.gov/ncbddd/heartdefects/avsd.html

CDC. “Facts about Down Syndrome | CDC.” *Centers for Disease Control and Prevention*, 10 Oct. 2023, https://www.cdc.gov/ncbddd/birthdefects/downsyndrome.html.

CDC. “Congenital Heart Defects - Facts about Atrioventricular Septal Defect.” *Centers for Disease Control and Prevention*, 20 Nov. 2019, https://www.cdc.gov/ncbddd/heartdefects/avsd.html.

Chaudhry, Raheel, et al. “Physiology, Cardiovascular.” *StatPearls*, StatPearls Publishing, 2024. *PubMed*, http://www.ncbi.nlm.nih.gov/books/NBK493197/.

Colvin, Kelley L., and Michael E. Yeager. “What People with Down Syndrome Can Teach Us about Cardiopulmonary Disease.” *European Respiratory Review*, vol. 26, no. 143, Mar. 2017. *err.ersjournals.com*, https://doi.org/10.1183/16000617.0098-2016.

“Down Syndrome - Symptoms and Causes.” Mayo Clinic, https://www.mayoclinic.org/diseases-conditions/down-syndrome/symptoms-causes/syc-20355977. Accessed 25 Mar. 2024.

Ehrenwald, Michal, et al. “Exercise Capacity and Body Mass Index - Important Predictors of Change in Resting Heart Rate.” *BMC Cardiovascular Disorders*, vol. 19, no. 1, Dec. 2019, p. 307. *BioMed Central*, https://doi.org/10.1186/s12872-019-01286-2.

Elmagrpy, Z., et al. “Down Syndrome and Congenital Heart Disease: Why the Regional Difference as Observed in the Libyan Experience?” *Cardiovascular Journal of Africa*, vol. 22, no. 6, Nov. 2011, pp. 306–09. *PubMed Central*, https://doi.org/10.5830/CVJA-2010-072.

Fernhall, Bo, et al. “Reduced Work Capacity in Individuals with Down Syndrome: A Consequence of Autonomic Dysfunction?” *Exercise and Sport Sciences Reviews*, vol. 41, no. 3, July 2013, pp. 138–47. *PubMed*, https://doi.org/10.1097/JES.0b013e318292f408.

Foley, Charlene, and Orla G. Killeen. “Musculoskeletal Anomalies in Children with Down Syndrome: An Observational Study.” *Archives of Disease in Childhood*, vol. 104, no. 5, May 2019, pp. 482–87. *PubMed Central*, https://doi.org/10.1136/archdischild-2018-315751.

Gąsior, J. S., Zamunér, A. R., Madeyska, M., Tomik, A., Niszczota, C., Williams, C. A., & Werner, B. (2023, January 4). *Heart rate variability in individuals with Down Syndrome: A scoping review with methodological considerations*. International journal of environmental research and public health. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9859252/#:~:text=Individuals%20with%20Down%20syndrome%20(DS,which%20indicates%20reduced%20vagal%20regulation.

"Heart Arrhythmia in Newborns: Diagnosis, Treatment, and Outlook." *Healthline*, 9 June 2022, https://www.healthline.com/health/baby/heart-arrhythmia-in-newborns.

"Heart Rate and Kids: How High Is Too High?" *Cleveland Clinic*, https://health.clevelandclinic.org/pushing-childs-heart-rate-high. Accessed 25 Mar. 2024.

Kamińska, K., Ciołek, M., Krysta, K., & Krzystanek, M. (2023, May 16). *Benefits of treadmill training for patients with Down Syndrome: A systematic review*. Brain sciences. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC10216428/

Kawasaki, Tatsuya, et al. "Chronotropic Incompetence and Autonomic Dysfunction in Patients without Structural Heart Disease." *Europace: European Pacing, Arrhythmias, and Cardiac Electrophysiology: Journal of the Working Groups on Cardiac Pacing, Arrhythmias, and Cardiac Cellular Electrophysiology of the European Society of Cardiology*, vol. 12, no. 4, Apr. 2010, pp. 561–66. *PubMed*, https://doi.org/10.1093/europace/eup433.

Kumari, Anita, et al. “Comparison of Cardiovascular Response to Lower Body and Whole Body Exercise Among Sedentary Young Adults.” *Cureus*, vol. 15, no. 9, p. e45880. *PubMed Central*, https://doi.org/10.7759/cureus.45880. Accessed 25 Mar. 2024.

Marcus, C. L., et al. “Obstructive Sleep Apnea in Children with Down Syndrome.” *Pediatrics*, vol. 88, no. 1, July 1991, pp. 132–39.

Mosaic Down Syndrome. https://www.stanfordchildrens.org/en/topic/default?id=mosaic-down-syndrome-90-P02133. Accessed 25 Mar. 2024.

Olsen, C. L., et al. “The Effects of Prenatal Diagnosis, Population Ageing, and Changing Fertility Rates on the Live Birth Prevalence of Down Syndrome in New York State, 1983-1992.” *Prenatal Diagnosis*, vol. 16, no. 11, Nov. 1996, pp. 991–1002. *PubMed*, https://doi.org/10.1002/(SICI)1097-0223(199611)16:11<991::AID-PD977>3.0.CO;2-5.

Naczk, Alicja, et al. “Effectiveness of Swimming Program in Adolescents with Down Syndrome.” *International Journal of Environmental Research and Public Health*, vol. 18, no. 14, July 2021, p. 7441. *PubMed Central*, https://doi.org/10.3390/ijerph18147441.

Nikolaidis, Pantelis T., et al. “Age-Predicted Maximal Heart Rate in Recreational Marathon Runners: A Cross-Sectional Study on Fox’s and Tanaka’s Equations.” *Frontiers in Physiology*, vol. 9, 2018, p. 226. *PubMed*, https://doi.org/10.3389/fphys.2018.00226.

Pastore, Enrica, et al. “Clinical and Cardiorespiratory Assessment in Children With Down Syndrome Without Congenital Heart Disease.” *Archives of Pediatrics & Adolescent Medicine*, vol. 154, no. 4, Apr. 2000, pp. 408–10. *Silverchair*, https://doi.org/10.1001/archpedi.154.4.408.

Pérez, Carlos Ayán, et al. "Water-Based Exercise for Adults with Down Syndrome: Findings from a Preliminary Study." *International Journal of Therapy and Rehabilitation*, vol. 25, no. 1, Jan. 2018, pp. 20–28. *DOI.org (Crossref)*, https://doi.org/10.12968/ijtr.2018.25.1.20.

Pitetti, Ken, et al. "Children and Adolescents with Down Syndrome, Physical Fitness and Physical Activity." *Journal of Sport and Health Science*, vol. 2, no. 1, Mar. 2013, pp. 47–57. *ScienceDirect*, https://doi.org/10.1016/j.jshs.2012.10.004.

Ptomey, Lauren T., et al. "Weight Management Recommendations for Youth with Down Syndrome: Expert Recommendations." *Frontiers in Pediatrics*, vol. 10, Feb. 2023, p. 1064108. *PubMed Central*, https://doi.org/10.3389/fped.2022.1064108.

Signs of Respiratory Distress. 19 Nov. 2019, https://www.hopkinsmedicine.org/health/conditions-and-diseases/signs-of-respiratory-distress.

"Title: Heart | Structure, Function, Diagram, Anatomy, & Facts | Britannica." *Www.Google.Com*, https://www.google.com/imgres?imgurl=https://cdn.britannica.com/88/22488-050-8AAD90B0/conduction-heart-individuals-sinoatrial-node-pacemaker-cells.jpg&tbnid=AMXXnobBrPr8YM&vet=12ahUKEwiDnoeun9GDAxVPh-4BHY5rDCoQMygGegUIARCAAQ..i&imgrefurl=https://www.britannica.com/science/heart&docid=tpsqifiqhDDhiM&w=1743&h=1600&q=heart&ved=2ahUKEwiDnoeun9GDAxVPh-4BHY5rDCoQMygGegUIARCAAQ&sfr=vfe&source=sh/x/im/can/1. Accessed 25 Mar. 2024.

The Heart & Down Syndrome | National Down Syndrome Society (NDSS). https://ndss.org/resources/the-heart-down-syndrome. Accessed 25 Mar. 2024.