Exploring the Role of Genetics in Self Control: A Replication and Extension Study

Jennie Van, Ria Tao, Genesis Luna, Sara Hui, Izba Haq, Pearl Bhatnagar

Undergraduate Student Mentor: Jane Lee

Graduate Student Mentor: Midori Pierce

Cognitive Science and Psychology ULAB

University of California, Berkeley

Abstract

It has been long debated whether nature or nurture has causative effects on the physiological and psychological profiles of an individual. However, there is a growing body of evidence that suggests that nature and nurture often work in tandem to influence such profiles, namely behavior. Of the many behaviors, this paper specifically aims to focus on self control, which is the ability to control one's instinctual impulses when confronted with certain temptations or challenging situations. There are many twin studies that suggest a genetic influence on the heritability of self control, and this paper details a replication of a meta-analysis study that attempts to determine the heritability estimates of self control in monozygotic (MZ) and dizygotic (DZ) twins. The replication consists of data-processing of 31 papers using RStudio and conducting a multi-level meta-analysis in order to calculate the heritability estimates between MZ and DZ twins, univariate moderators, and multiple moderators. Our results had very similar heritability estimates for MZ and DZ twins for all the univariate and multiple moderators. For the extension, we attempted to do a meta-analysis on the heritability of control in MZ and DZ twins that have ADHD or anxiety. We predicted that there would be a discrepancy in heritability estimates and univariate moderators between MZ and DZ twins with these disorders. We found that the MZ correlations were higher than the DZ correlations for the overall heritability estimates as well as the various univariate moderators.

Keywords: self control, heritability, twin studies, genetics, meta-analysis

1. Introduction

Self control is the ability to control one's instinctual impulses when confronted with certain temptations or challenging situations. Many factors influence self control, such as gender. One study that compares self-control between males and females is a meta-analysis of studies that measured self-control in various domains, including impulsivity, delay of gratification, and emotion regulation (Cross, Copping, and Campbell, 2011). The researchers found studies on impulsivity and sex differences, and identified a total of 775 studies that met their criteria such that 1) studies investigated the relationship between sex and impulsivity, 2) studies had to use validated measures of impulsivity, and 3) data has to report effect sizes for the sex difference in impulsivity. The authors found that, on average, women had slightly higher self-control than men. Larger sex differences were found on measures of sensation-seeking and risk-taking compared to measures of delay discounting and response inhibition. This suggests that gender can be an important moderator in affecting self control.

Throughout history, researchers have argued the nature versus nurture discourse, which debates whether certain behaviors are inherited from parents or developed through being in an environment. For example, language acquisition is one of the main applications of this debate. Noam Chomsky, a well known linguist, stands with the nature side of the debate as he believes that humans were born with universal language. A piece of evidence favoring nature is the localization of language in the brain. Performing lesions to the Broca's area results in the loss of the ability to produce correct grammatical structures when producing speech, which serves as an example of how language is innate within humans (Lenneberg, 1964). On the other hand, the critical period for language acquisition serves as evidence for the nurture side of the argument. Friedmann and Sztermann conducted a study with children that had hearing impairment and

focused on their ability to comprehend and produce sentences. They found that children with hearing impairment struggled to produce and understand sentences, especially given a hearing device long after they were born. They concluded that a child must have a hearing device before 8 months in order to comprehend and produce speech (Friedmann and Rusou, 2015).

Currently, the stance is that human behaviors stem from both nature and nurture. However, it is difficult to decouple the relationship between genetic and environmental influences. The most common way researchers attempt to understand the effect of genetic versus environmental influences on a particular trait or behavior is through observing twins, whether monozygotic or dizygotic, or twins that were separated from a young age and grew up in different environments. A meta-analysis studying the heritability of human traits, such as social interactions and nutritional habits, using fifty years of twin studies that followed the first study method revealed that the heritability across all traits is 49% (Polderman et al., 2015). However, this number changes based on the particular trait; for 69% of the traits, the similarity between twins is mostly due to the genes they share, and not their environment or upbringing (Polderman et al., 2015).

Despite how genetics has a considerable influence on the expression of specific traits, the effect of the environment must also be considered and explored. According to psychologist David Moore, modern-day epigenetics research, which studies the effect of the environment on how genes are expressed, can provide insight into the nature versus nurture debate. One way this can be done is to study particular animals, such as rats, observe an aspect of their behavior, then breed them and control the environment they are raised in to observe the effect of different environments on their behavior. The most prominent study which provides support for the science of epigenetics involves rats; after noticing that rats with mothers who groomed them

more were less stressed when placed in stressful situations and vice versa, Meaney and Szyf cross-fostered the rats, placing rats who born to mothers who did not lick their babies to be raised by a mother rat who did. They found that those rats raised by high licking and grooming mothers, despite not being born from mothers with those traits, were less stressed in stressful situations, and vice versa, when their environment was changed. After further investigation, they found that the grooming by mothers activated a particular gene that enabled building of specific proteins which moderated stress. Therefore, the environment had an effect on which genes were expressed, thus impacting specific traits (Meaney and Szyf, 2015). Thus, the present-day stance of this nature vs nurture debate is that both aspects influence the development of particular traits, and specifically, our environment affects which genes are expressed.

Moreover, according to Mayo Clinic, anxiety disorder is described as experiencing persistent fear surrounding everyday situations and often involves panic attacks in the form of sudden feelings of severe anxiety and fear. There were many studies done between twins with anxiety disorders which are valuable to gain insight from. A twin study regarding the heritability of anxiety sensitivity measured scores on the Anxiety Sensitivity Index by assessing 179 monozygotic and 159 dizygotic twin pairs. The results indicated that additive genetic effects, the mechanism by which the combined effects of alleles at multiple loci are the same as the combination of their individual effects, and environmental effects, or physical, psychological, and social environmental concerns, are strongly correlated with anxiety sensitivity– ultimately concluding that anxiety disorder likely has a heritable component. (Stein et al., 1999). For another study concerning the attentional control of an adolescent sample with symptoms of anxiety, an anxiety assessment of over 400 twin pairs was conducted through “self-report” and “mother reports.” The results of this study indicated that attentional control is a genetic risk

factor for anxiety in early adolescence, with risk level contingent on symptomatology (Gagne, 2017). The findings of these studies support the correlation between genetic and environmental factors and the heritability of anxiety in twin pairs.

In addition to anxiety, our meta-analysis also looks into the effects of Attention-deficit hyperactivity disorder (ADHD), one of the most common mental disorders in children, on self-control. Symptoms of ADHD as described by the American Psychiatric Association include "hyperactivity, impulsivity, organization, and/or inattention". Statistics on ADHD sourced from the Center for Disease Control and Prevention imply a correlation between genetic and environmental factors, with ADHD diagnosis varying between geographies, ages, races, and gender (CDC, 2022). Furthermore, there have been hundreds of studies conducted on the effects of environmental factors on ADHD diagnosis with twin studies being most helpful in untangling the interplay between genetics, environment and ADHD. One such twin study conducted in the UK features the genetic overlap between ADHD and hyperactivity-impulsivity. After following up with 5,500 pairs of twins from the original sample, through a DSM-IV based rating scale the study found a 0.55 genetic correlation indicating hyperactivity and inattention are influenced by the same genes, with around 70% heritability for both traits (Greven et al., 2011). This high of a heritability estimate is not uncommon among ADHD twin studies, with "20 extant twin studies, which estimate the heritability of ADHD to be .76" (Faraone et al., 2005). Another relevant study is The Colorado Twin Study of Reading Disabilities and ADHD involving 473 twin pairs found that environmental factors such as prenatal smoking, birth weight can modify genetic risk for ADHD and associated reading disabilities. The major takeaway from both studies is the importance of considering both genetic and environmental factors in analyzing the etiology of ADHD.

Understanding the genetic influences on self control is very important because self control is a crucial predictor of many important domains in society such as health, public safety, finances, work, etc. For instance, one study suggests that self control is predictive of many outcomes, from positive and negative adolescent behavior to career outcomes (Converse et al., 2014). Although environmental factors such as finances, upbringing, and social life cannot be overlooked when examining differential manifestations of self control within individuals, there are many physiological and psychological disorders that can make an individual more genetically predisposed to developing poor self control, such as ADHD. However, poor self control is usually addressed by interventions that disproportionately focus on environmental features such as altering one's cognition and behaviors. For instance, interventions such as "Self-control and Aggression Replacement Training (ART) aim to improve self-control through the use of anger control and problem-solving skills training" and their efficacy suggest that "improvements in self-control are related to reductions in disruptive behavior" (Nijhof et al., 2021). All of these programs and behavioral interventions rest on the assumption that self control is an individual behavioral issue. However, this is a one-dimensional, incomplete assumption to determine the causality of poor self control as there are many other contributing factors such as neuroadaptations involved in affecting self-control. As much as environmental factors are important to consider, genetic factors are equally important to investigate to gain better insight regarding the heritability of self control.

Out of the many avenues in which self control is studied, this paper attempts to further explore the influence that genetic heritability has on self control in individuals. A study done by Willems et al. focused on the heritability of self control in monozygotic (MZ) and dizygotic (DZ) twins. MZ twins are conceived with a single egg and sperm but have split off into two cellular

entities whereas DZ twins are each conceived with their respective sperm and egg. Hence, MZ twins have almost, if not completely, identical genetic makeup as opposed to their DZ counterparts. The paper attempts to do this by doing a multi-level meta-analyses, a type of statistical method that accounts for the between- and within-cluster heterogeneity and hence the intracluster (or intraclass) correlation in the true effects (Viechtbauer, 2021). Hence, our research aims to revalidate Willem et al.'s data analysis on the heritability estimates of self control, the univariate moderator effects, and the multiple moderator effects on MZ and DZ correlations. This replication intends to analyze and run their data again to test the validity and replicability of their findings. This can help further support the growing attention genetic factors deserve when exploring self control itself.

2. Methods

To analyze the heritability of self control, the authors examined twin studies that involved monozygotic twins and dizygotic twins. One assumption is that these twins grew up in the same environment, which allows for any differences between them to be accounted for by their genetics. Standardized heritability estimates (a scale from 0-1 where a lower number indicates environmental factors playing a large role in behavior) were also taken into account. The authors found relevant articles through three online databases: PubMed, PsycINFO, and Web of Science. The following search terms were used: twin, heritability, genetics, self control, self-regulation, effortful control, and self-discipline (Willems et al., 2019). Through this protocol, 6375 papers were yielded in the initial search.

Among those articles, the screening phase was administered with their inclusion criteria. First, the studies had to have twin correlations or standardized heritability estimates of some sort. Second, the study had to assess self control or its adjacent concepts such as self-regulation, self

discipline, etc. Third, the papers had to have been published in English and in peer-reviewed journals. Lastly, there could not be any participants suffering from clinical psychological or physiological disorders (Willems et al., 2019). Of the 6375 papers, 6,204 papers were excluded from this initial screening process because they failed to meet some/all the criteria. After the screening phase, the authors advanced to the eligibility stage where these studies were selected for in-depth reading. Among the 171 papers selected, 140 were excluded because they either did not include a twin sample, a self control measure, and/or twin correlations/heritability estimates of self control. In the end, this filtering left the researchers with 31 papers to use for their meta-analysis. Within the 31 papers, there were a total of 107 studies that were used in the meta-analysis, as many papers had multiple studies.

With these 31 papers, the authors pre-processed their raw data and information in a format that would make it readily available to run through the code that they constructed. This 7-step code was built to extract, visualize, and analyze all descriptive data (authors, article title, journal, year of publication), sample data (country, cohort, sample size, age), methodological data (self control measurement, informant of the measure), and heritability estimates (MZ correlations, DZ correlations, standardized heritability estimate of the overall model if provided, and otherwise estimates of the best fitting model). In Step 1, they installed the metafor package, a free and open-source R add-on for conducting meta-analyses (Viechtbauer, 2021). Then in Step 2, data was read by pasting an Excel file path so that R can read and load the data into memory. In Step 3, the overall effect was estimated in order to calculate and visualize the overall MZ and DZ estimated effects of heritability. Steps 4 through 6 involved testing univariate moderators which are gender, age, and informant, respectively. The goal of this analysis was to determine whether the variables gender, age, and informant influenced the amplitude of the MZ or DZ

correlations. Step 7 consisted of evaluating multiple moderators within a single model. To accommodate for this reliance, they utilized multivariate models that incorporated both age and informant into the same model (Willems et al., 2019).

Many studies that were analyzed had reported multiple effect sizes, such as reporting twin correlations for different age groups or self control measures they used. There are also multiple studies that used data from the same MZ and DZ cohort. These two observations indicate that these subset of studies will have more similar effect sizes than other different studies. In order to take this observed dependency between studies into account and include all the effect sizes for each study, the researchers concluded that utilizing multi-level meta-analyses was the best statistical method to take these conditions into consideration. This method not only can increase statistical power, but it can also provide maximum information for the data they collect (Willem et al., 2019). Hence, they applied the multi-level meta-analyses that accounts for the sampling variance, variance between effect sizes from same samples, and variance between studies in general.

The researchers carried out this analysis in several stages. In the first stage, they had to determine which effect size to meta-analyze. There were studies that allowed for the determining the heritability estimates of self control through MZ and DZ correlations or standardized genetic variance. Since many studies only presented their best fitting model, the researchers admitted that biased perspectives of heritability estimates of self control can be introduced since these models are very sensitive to sample size (Willems et al., 2019). Hence, the standardized genetic variance is less favorable to analyze because standardizing all these studies considerably overlooks the intricate differences between the models the papers use, thereby risking the

introduction of biased estimations of the genetic influence on self control. Hence, it was decided to meta-analyze the MZ and DZ correlations instead.

In the second stage, the MZ correlations (r_{mz}) and DZ correlations (r_{dz}) were normalized so the mean effect size estimates are more accurate and the tests of statistical significance remain unbiased (Willems et al., 2019). To normalize the data, researchers transformed the MZ and DZ correlations into Fisher Z scores (ES_Z), ES_{Zmz} and ES_{Zdz}, respectively. All the studies using the same sample were given the same identification number to account for the dependency between the effect sizes of these studies. With this, they examined the effects that univariate moderators (age, gender, informant) and multiple moderators had on ES_{Zmz} and ES_{Zdz}. They converted the Z scores back into MZ and DZ correlations to calculate the heritability of self control using the Falconer's formula, an equation used in twin studies to predict the contribution of genetics versus environment in specific trait differences between twins (Chow, 2015).

3. Replication

3.1. Methods and Materials

3.1.1. Meta-Analysis Replication

The raw data set was downloaded through Mendeley Data, which is a communal repository that allows for the storage of public data (Willems et al., 2019). This data was originally organized in an Excel sheet which required no additional preparation since it could be directly uploaded to RStudio and its format was fully compatible with the R-script the authors provided. The R-script was copied into a new RStudio file and the file was run continuously until redirected to a new tab titled "dataset_h," referring to the name of the raw data that was saved in R. Then, the remaining lines of the R-Script were run.

To further understand the code, here is a brief explanation of its general logic. It first installs the metafor package. Then, it reads the data from excel into R using the library function which is used to load packages into RStudio. After loading the data, the code estimated the overall effect of the study by creating a 95% confidence interval for the distribution of monozygotic (MZ) and dizygotic (DZ) samples and producing their respective confidence interval plots. To interpret these plots from the normalized data, the code converted Fisher Z correlation, which assumes there is no point at which the results become significant, to Pearson correlation, which allows a decision to be made based on the results. This was done in order to determine the significance of the overall MZ and DZ correlations. After installing all necessary add-ons and laying the basis for comparison, the multistep stage, "testing moderators" was run. The next three steps in the code tested univariate moderators, such as gender, age, and informant. The first step determined the intercepts for females and males in order to determine if gender moderates MZ and DZ correlations. The next step used several references as a baseline to test if age was a moderator for self control. The third step involved testing the univariate informant moderators and utilized steps similar to the previous step. Finally, the last step involved testing the various multiple moderators in a singular model.

After running the whole code, the console output displayed the heritability estimates of self control for both MZ and DZ twins, two confidence interval plots for such estimates, and the univariate moderator and multiple moderator statistics that are found in Tables 2 and 3 of the paper, respectively (Appendix A). Then, a mass cross-comparison of all of the acquired data was conducted to determine the replicability of this paper and determine if the results could be verified. As far as statistical analysis goes, we did not utilize any statistical methods that were not used in the original study. However, we operationally defined our own α-value, the threshold

for statistical significance, as 0.05. This was necessary because the original paper did not state the α-value they used, making it impossible to determine whether the results bore any statistical significance.

3.1.2. Figure 2 Replication

Figure 2 in Willems et al. shows the MZ correlations per sample and DZ correlations per sample. To reproduce Figure 2, the following 4 columns were used to create a scatterplot: MZ sample individuals, DZ sample individuals, MZ correlation (rMZ), and DZ correlation (rDZ). Through this, Excel generated the two scatterplots, and no outliers were omitted. Although the scatterplot for rMZ per sample ranges from 0 to 1, the scatterplot for rDZ per sample ranges from -0.2 to 0.6. The distinct ranges for each scatterplot were retained for visualization purposes. Likewise with replicating the meta-analyses, the group members did a mass comparison of their reproduction of Figure 2 to determine whether it can be recapitulated.

3.2. Results

3.2.1. Univariate and multiple moderators

The results that were generated aligned with Table 2 and Table 3 from the paper, which summarize the univariate moderator (gender, age, informant) and multiple moderator analyses, respectively (Appendix A).

The authors found that gender and age were not likely significant moderators of MZ or DZ correlation, and this replication confirmed these results from the 95% confidence intervals that were generated from running the code. Because the intervals have a large degree of overlap between different genders and ages, one can conclude the gender and age do not significantly affect the heritability of self control. Additionally, the p-values for the MZ and DZ correlations between males and females were 0.49 and 0.9, respectively, which are significantly higher than

our α-value of 0.05. Hence, we failed to reject the null and concluded that there are no statistically significant differences in the heritability of self control for males and females. Even if we arbitrarily defined our own α-value and cannot necessarily confirm that we used the same α-value as Willem et al., our conclusions still align with their conclusions that there is not much correlation between gender and the heritability of self control.

The same process was carried out for the age variable, and this replication also concluded that there is no statistically significant difference between age and the heritability of self control due to the overlap in confidence intervals and the significantly larger p-values. However, there were high MZ and DZ correlations in the middle childhood era in comparison to their other age groups.

The informant was revealed as a large moderator for both correlations. For MZ correlations, this replication also found that the 95% confidence interval for MZ correlations that came from parent reports was [.83, .99], while it was only [.41, .55] and [.47, .67] respectively for correlations from self-reports and observations. MZ correlations were significantly higher when they were reported through parents rather than self-reports and/ or observations. This was not the case for DZ correlations as they were consistent across all informants. When running the R script which incorporated Falconer's formula, it also found that the heritability of self control was significantly higher when assessed by parent-report (75%) as compared to self-report (53%) or observations (41%).

When analyzing the effect of age and informant on MZ and DZ correlations, it was observed that age and informant were not independent, just as the researchers did as well. In earlier stages of life, particularly early and middle childhood, most reports were obtained from parents while most reports in later stages of life (adolescence and adulthood) were self-reports.

Because of this, they applied multiple-moderator models to account for the dependency. Thus, this replication followed this approach and examined age and informant in the same model to capture the dependencies. After conducting multivariate analysis like the researchers, it further supports that age did not have a significant effect on the MZ or DZ correlation. However, the informant was a significant moderator for MZ correlations, but not DZ correlations. Falconer's formula was used again in the script to find the heritability of self control based on different informants.

3.2.2. Heritability Estimates

From metanalyzing 31 studies, this replication found an overall MZ correlation of 0.58 and an overall DZ correlation of 0.28 like the researchers. After Falconer's formula was used again by running the R script, the overall heritability of self control was 60% (Appendix A). The code was also able to generate two confidence interval plots that visualize the overall MZ and DZ estimated effects of heritability (Appendix B).

3.2.3. Figure 2 Replication Results

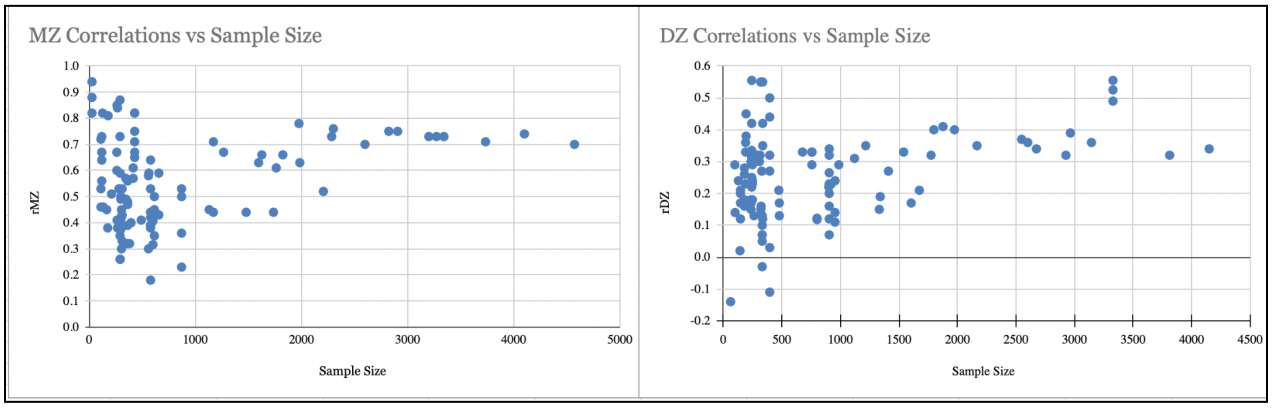

Fig. 1. On the left scatterplot, it shows the MZ correlations (rMZ) per sample size of the studies used. The right scatterplot depicts the DZ correlations (rDZ) per sample size of the studies used. No outliers were omitted.

We were also able to successfully recapitulate the scatterplots in Figure 2 of the paper using the researchers' R script. The results demonstrate that studies that had larger sample sizes had decreased variance for both MZ and DZ correlations.

3.3. Discussion

3.3.1. Univariate and Multiple Moderators

For gender, the correlations in MZ and DZ did not differ that much both in the study in the replication. A possible reason behind this is that although society has emphasized the differing qualities between males and females, self control can just be a pervasive ability that anyone can possess regardless of their gender. These results imply that self control may not display sex-linked inheritance. However to further ascertain this, future studies could attempt to discover which genes are involved in mediating self control. The reason age might have also resulted in no difference in the heritability of self control maybe that

For informants, it was observed that the parent report had a higher correlation with MZ while the self report had the lowest correlation with DZ both in the study and replication. A possible explanation for this could be that parents with MZ twins may have a tendency to overestimate the similarities in self control of their MZ twins than parents with DZ twins because MZ twins are way more similar in physical appearance and possibly behavior. This can introduce bias in evaluating the similarity of self controls between their twins, thereby artificially inflating the MZ correlations. However, it is also in equal possibility that this can be unbiased and there may be more legitimate similarity of self control in MZ twins than DZ twins. When running the multiple moderator analysis for age and informants, this further supported the aforementioned univariate results.

3.3.2. Heritability Estimates

This study found that the heritability of self control is 60%. This means that over half of our ability to control impulses and behaviors that are not beneficial to some future goal seems to be determined by our genes. The implication of this is that there are individuals who possess more self control simply due to their genetic makeup. Knowing this is significant because it provides a reason for differences in self control across individuals. Moreover, those in higher power positions in settings where self control is highly desired, such as schools and workplaces, should account for these inherent differences while understanding that self control can be improved through external, environmental factors.

A limitation of the study is that the data was gathered only from the United States (Willems et al., 2019). Thus, it requires further investigation as to whether self control behavior is truly inherited from genes or if it just differs culturally. If subjects from other countries had similar results as the ones in the US, there would be more certainty surrounding the conclusion that genes affect the self control of an individual. Another limitation was the insignificant number of studies that used the same self control assessment scales, as it makes it more difficult to compare studies and assess influence of specific measurements on the heritability estimates of self control (Willems et al., 2019). However, as far as our replication is concerned, our team did not have trouble replicating the data, as we all got the same outputs as the original researchers did.

3.3.3. Figure 2 Replication Discussion

The decreased variance in studies with larger sample sizes could mean that studies involving larger sample sizes have more accurate results because their results are closer to the results of other studies. According to the law of large numbers in probability theory, as a sample

size increases, the sample mean becomes closer to the true average of the population (Investopedia, 2022). This means that studies with larger sample sizes are better to examine in order to understand the true heritability of self control because they will produce a mean that is closer to the true heritability. This is supported by the decreased variance, or, in other words, the spread of the data.

4. Extension

One curious aspect of the Willems et al. meta-analysis is that their criteria explicitly filtered out studies that investigated MZ and DZ twins with existing mental disorders. As a result, the extent to which mental disorders influence the heredity of self control is not understood. Hence for the extension, we chose to conduct a meta-analysis aiming to investigate the heredity of self control in MZ and DZ twins either diagnosed with psychiatric disorders or present maladaptive features of psychiatric disorders. Thus, this meta-analysis attempts to understand if mental disorders, specifically ADHD and anxiety, can be another factor in affecting the heritability of self control. We predicted that there would be discrepancies between MZ and DZ correlations in the overall heritability estimates and univariate moderators such as gender, age, and informants.

4.1 Methods and Materials

We searched our papers through the following databases: PubMed, PsycInfo, ProQuest, and the Web of Science. In our initial screening, the following search terms we used included:

A. twin OR heritability OR genetics AND
B. Self-control OR self-regulation OR effortful control OR self-discipline AND
C. Psychiatric disorder

Upon doing this, we adjusted the setting as needed ensuring that all articles being examined were peer reviewed and filtering out specific key search words, like twins, dizygotic, monozygotic, twins, genetics, heritability, self-control, self-regulation, etc. Additionally, we ran a screening similar to what Willems et al. did. The preliminary screening performed by the authors was done by looking at the abstract alone. The criteria used is as follows:

A. Must include twin correlations or standardized heritability estimates
B. Had to assess self-control or a concept closely related to it such as self-regulation, effortful control, self-discipline, or emotional regulation
C. Only papers originally published in English that were published in peer-reviewed journals
D. MZ and DZ twins that have the psychiatric disorders we are looking into or present maladaptive features of those psychiatric disorders.

Screening Round #1				
	OCD	Bipolar Disorder	ADHD	Schizophrenia
# of Papers we started off with	60	40	86	22
# of Papers we excluded	0	35	74	20
# of Papers Shortlisted	Confirmed: 0 Uncertain: 0	Confirmed: 0 Uncertain: 5	Confirmed: 9 Uncertain: 3	Confirmed: 0 Uncertain: 1

Table 1. The table showcases the number of papers that came up upon following the eligibility requirements and doing the necessary filtrations we performed in the first Screening Round.

After the initial round of screening, there were not enough papers for OCD, Schizophrenia, and Bipolar Disorder. However, ADHD yielded the most papers so it seemed

promising to move forward with ADHD. While searching for ADHD, there were a handful of papers detailing autism so for the second round, autism was added to the disorders for screening.

Screening Round #2		
	Autism	ADHD
# of Papers we started off with	89	270
# of Papers we excluded	87	259
# of Papers Shortlisted	Confirmed: 2 Uncertain: 0	Confirmed: 9 Uncertain: 2

Table 2. The table showcases the number of papers that came up upon following the eligibility requirements and doing the necessary filtrations we performed in the 2nd Screening Round.

During this round, we examined and looked for articles that met the criteria and had twin subjects with autism and ADHD. Autism did not yield as many papers, but we chose to further investigate this as there were other databases we did not exhaust yet Hence for the third round, autism was decided to be repeated again, in addition to screening for studies that included MZ and DZ twins with anxiety and depression.

Screening Round #3			
	Autism (pt. 2)	Anxiety	Depression
# of Papers we started off with	63	37,865	46
# of Papers we excluded	58	37,829	41
# of Papers Shortlisted	Confirmed: 0 Uncertain: 5	Confirmed: 6 Uncertain: 30	Confirmed: 1-2 Uncertain: 3-4

Table 3. The table showcases the number of papers that came up upon following the eligibility requirements and doing the necessary filtrations we performed in the 3rd Screening Round.

After completing the third round of screening, it was determined that depression and autism did not yield enough papers to be used for the project. Hence, the two psychiatric disorders that ended up being further studied are anxiety and ADHD. With the remaining papers used for screening, the following eligibility criteria from Willem et al. was used to determine whether or not the papers we had would be selected for data processing. The criteria is as follows:

A. Has to include twin sample
B. Has to include a self-control measure
C. Has to include MZ/DZ twin correlations or heritability estimates of self-control

Additionally, our team also included additional requirements which are the following:

A. Being able to obtain access to the author's raw data.
B. Ensuring that article is peer reviewed.

With this eligibility criteria, we found a total of 15 papers, where 8 papers detailed MZ and DZ twins with ADHD and 7 papers detailed MZ and DZ twins with anxiety. In order to process these papers' data, we recorded the information into its respective Excel sheets which formatted accordingly for it to be compatible with the R script that Willems et al. provided. The database included columns such as Study_ID, Author, Title, Age_cat, Informant, rMZ, rDZ, rMZ_Z, rDZ_Z, Var_mz, Var_d. For some of the columns, the information was found by reading the papers. For the categorical columns, we used binary (0 or 1) to indicate if the information fulfilled those categories. To calculate the z-scores of the heritability for MZ and DZ correlations (rMZ_Z and rDZ_Z), we had to use the FISHER function. We calculated the variance of

monozygotic and dizygotic correlation (Var_mz and Var_dz) by using the two equations, Var_mz = 1 / (MZ_Sample_Pairs - 3) and Var_dz = 1 / (DZ_Sample_Pairs - 3).

After we constructed the two databases and completed the necessary columns corresponding to each eligible study, we ran the R script that was used by the original researchers and received the heritability estimates of self control for both MZ and DZ twins, two confidence interval plots for ADHD and anxiety, and the univariate moderators (Appendix C). We did not utilize any statistical methods that were not used in the original study. However, we operationally defined our own α-value, the threshold for statistical significance, as 0.05. This was necessary because the original paper did not state the α-value they used, making it impossible to determine whether the results bore any statistical significance. After we ran the R script for both the studies in the anxiety and ADHD groups, we took the respective values of rMZ and rDZ of both disorders and applied the Falconer's formula, 2(rMz - rDz), to get the overall heritability estimate for both MZ and DZ correlations of anxiety and ADHD.

4.2 Results

4.2.1. Descriptives

Included were a total of 15 papers, of which 8 were ADHD-related studies and 7 were anxiety-related. The majority of twin studies (k = 13) were conducted in the United States of America. The other studies (k = 2) were conducted in Sweden. There were 2,432 MZ individuals and 2,170 DZ individuals, for a total sample size of 4,602 based solely on the sample sizes of independent investigations for the ADHD studies. There were 1,316 MZ individuals and 1,782 DZ individuals, for a total sample size of 3,098 when only the sample sizes of independent studies for anxiety studies were accounted for. The earliest paper was published in 2009 (Anokhin et al., 2009), and the most recent was published in 2017 (Gagne et al., 2017).

4.2.2. Heritability Estimates for ADHD and Anxiety

We found the heritability estimate for MZ of 0.56 and the heritability estimate for DZ of 0.34 after analyzing eight studies on ADHD. Using Falconer's formula to determine the heritability based on the meta-analytic MZ and DZ correlations yields an overall heritability estimate of 0.44. In other terms, ADHD was responsible for 44% of individual differences in self-control. The MZ correlation was greater than the DZ correlation, suggesting that there was weak evidence of genetic effects. Rather, these findings suggest that the ADHD-related effects on self-control, which account for 56% of the variance, are specific to each individual.

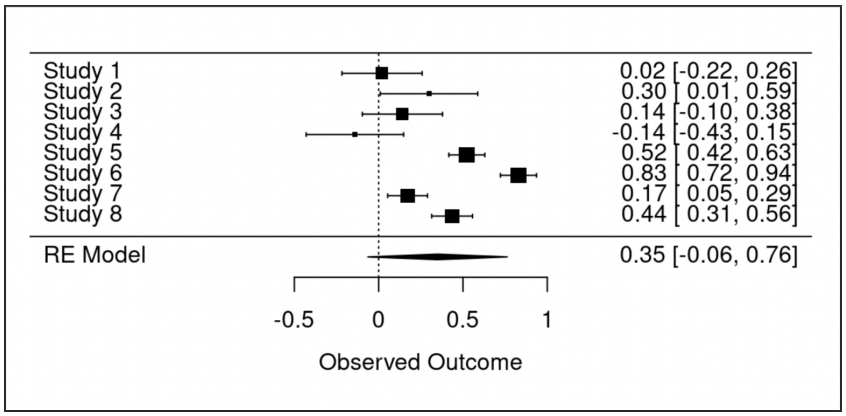

Fig. 2. The aggregate heritability estimates and their respective confidence intervals for each of the ADHD-related studies that were utilized.

For anxiety, the heritability estimate for MZ was 0.46, and the heritability estimate for the DZ correlation was 0.12. Using Falconer's formula to determine the heritability based on the meta-analytic MZ and DZ correlations yielded an overall heritability estimate of 0.68. In other words, anxiety accounted for 68% of individual differences in self-control, indicating that the heritability of self control with anxiety has a strong genetic component. Furthermore, these findings suggest that the effects of anxiety on self-control, which account for 32% of the variance, are unique to each individual.

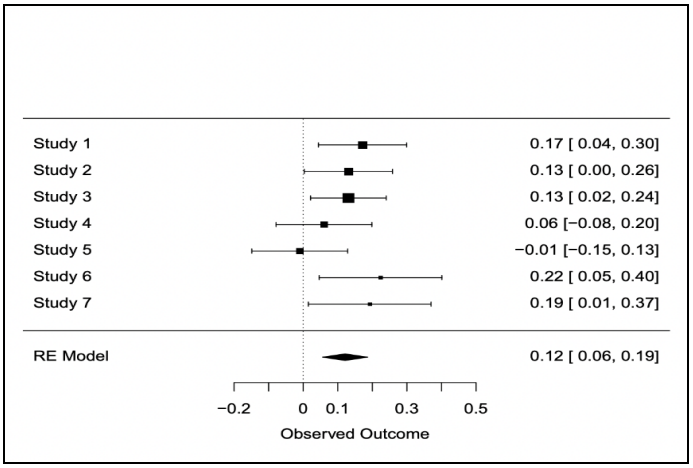

Fig. 3. The aggregate heritability estimates and their respective confidence intervals for each of the anxiety-related studies that were utilized.

4.2.3. Univariate Moderators for both ADHD and Anxiety

After conducting our meta-analysis on the data, we assessed whether our MZ and DZ correlations were significantly moderated by univariate moderators assessed in the study, which are gender, age, and informants. The MZ correlation for both males and females with ADHD was the same and therefore not moderated by gender (ES_{Zmz}= .663, S.E.= .233, t = 2.850, p < .029, 95% CI = [.094, 1.232]). On the other hand the DZ correlation for ADHD for males (ES_{Zdz}= .388, S.E.= .216, t = 1.796, p < .123, 95% CI = [-0.141, .916]) was slightly higher than for females (ES_{Zdz}= .239, S.E.= .190, t = 1.262, p < .254, 95% CI = [-.225, .703]). The correlation for MZ males with anxiety (ES_{Zmz}= .309, S.E.= .223, t = 1.385, p < .225, 95% CI = [-0.264, .882]) was significantly lower than that for MZ females (ES_{Zmz}= .688, S.E.= .086, t = 7.978, p < .001, 95% CI = [.514, .862]). The correlation for DZ males with anxiety (ES_{Zdz}= .144, S.E.= .046, t = 3.114, p < .026, 95% CI = [.025, .263]) and DZ females with anxiety (ES_{Zdz}= .094, S.E.= .044, t = 2.126, p < .087, 95% CI = [-0.020, .208]) showed the similar trend to the MZ twins with anxiety.

Gender	MZ		DZ	
	ADHD	Anxiety	ADHD	Anxiety
Female	0.663	0.688	0.239	0.094
Male	0.663	0.309	0.388	0.144

Table 4. The overall MZ and DZ correlations for males and females

The second univariate moderator was age. MZ correlations (ES_{Zmz}= .653, S.E.= .200, t = 3.267, p < .017, 95% CI = [.164, 1.143]) were significantly higher than DZ correlations (ES_{Zdz}= .445, S.E.= .185, t = 2.407, p < .053, 95% CI = [-0.007, .897]) in middle childhood for the ADHD group. However, the MZ correlations (ES_{Zmz}= .617, S.E.= .200, t = 3.080, p < .022, 95% CI = [.127, 1.107]) and DZ correlations (ES_{Zdz}= .249, S.E.= .185, t = 1.347, p < .227, 95% CI = [-0.203, .702]) for early childhood, adolescence, and adulthood was the same in the ADHD group. Age also significantly moderated the MZ correlations (ES_{Zmz}= .386, S.E.= .285, t = 1.355, p < .233, 95% CI = [-0.346, 1.119]) and DZ correlations (ES_{Zdz}= .025, S.E.= .050, t = 0.501, p < .638, 95% CI = [-0.103, 0.154]) for the anxiety group in middle childhood. Likewise with ADHD, the anxiety group had the same MZ correlations (ES_{Zmz}= .528, S.E.= .218, t = 2.425, p < .060, 95% CI = [-0.032, 1.087]) and DZ correlations (ES_{Zdz}= .158, S.E.= .031, t = 5.095, p < .004, 95% CI = [0.078, 0.238]) for early childhood, adolescence, and adulthood.

Age	MZ		DZ	
	ADHD	Anxiety	ADHD	Anxiety
Early Childhood	.617	.528	.249	.158
Middle Childhood	.653	.386	.445	.025
Adolescence	.617	.528	.249	.158
Adulthood	.617	.528	.249	.158

Table 5. The overall MZ and DZ correlations for different age cohorts

The third univariate moderator was informants, which refer to the source of information on subject symptoms. Informants also moderated MZ and DZ correlations for ADHD, as the correlations varied by informant category. For the parents, the MZ correlations (ES_{Zmz}= 1.293, S.E.= .248, t = 5.221, p < .003, 95% CI = [0.657, 1.930]) were significantly higher than the DZ correlations (ES_{Zdz}= .800, S.E.= .170, t = 4.696, p < .005, 95% CI = [0.362, 1.239]). For self-report, the MZ correlations (ES_{Zmz}= 0.416, S.E.= .144, t = 2.897, p < .034, 95% CI = [0.047, 0.785]) were significantly higher than the DZ correlations (ES_{Zdz}= .387, S.E.= .107, t = 3.624, p < .015, 95% CI = [0.112, 0.662]). For observant and lab task, the MZ correlations (ES_{Zmz}= 0.634, S.E.= 0.133, t = 4.765, p < .005, 95% CI = [0.292, 0.976]) were significantly higher than the DZ correlations (ES_{Zdz}= 0.080, S.E.= 0.126, t = 0.632, p < .555, 95% CI = [-0.245, 0.404]). However for the anxiety group, the MZ correlations (ES_{Zmz}= .268, S.E.= .171, t = 1.567, p < .178, 95% CI = [-0.172, 0.707]) and DZ correlations (ES_{Zdz}= 0.094, S.E.= .051, t = 1.867, p < .121, 95% CI = [-0.036, 0.224]) were the same for parents, self-report, and observant/lab tasks. It is similar with the ADHD group in that the MZ correlations were higher than DZ correlations.

Informants	MZ		DZ	
	ADHD	Anxiety	ADHD	Anxiety
Parents	1.293	.268	.800	.094
Self-report	.416	.268	.387	.094
Observant/Lab tasks	.634	.268	0.80	.094

Table 6. The overall MZ and DZ correlations for different informants. Parent refers to parents reporting self-control measures for their twin children, self-report are the subjects reporting for

themselves, and observant/lab task refers to any third-party observer or task the twin subjects had to complete to measure self-control.

4.3 Discussion

For the overall heritability estimates and the univariate moderators for MZ and DZ twins with ADHD and anxiety, there was an overwhelmingly greater correlation between MZ twin pairs compared to their DZ counterparts. The overall heritability estimate for anxiety suggests a strong genetic component of the heritability of self-control, but not so much for ADHD. However, our results are not telling of what causes these discrepancies. One possibility is that the heritability of these disorders can affect the heritability of self-control. Each disorder may have a different genetic heritability profile, which can affect the genetic influence of the overall heritability of self control. An alternative explanation can be that MZ twins generally have a more similar genetic profile than DZ twins, thereby increasing their correlation for their heritability of various traits such as self control. However, one limitation in our study that could have affected these correlations is that the sample size for both ADHD and anxiety was small. Hence, the variance of our data likely increased due to a lacking representation of all individuals within our desired population. With increased variability, the accuracy and precision of our data likely decreased, resulting in wider confidence intervals. This results in a greater sampling error, where there is a reduction in the generalizability of our findings.

Several other limitations were encountered when conducting our meta-analysis, mainly including the limited array of studies relevant to our research topic. We faced many roadblocks in the form of paywalls limiting our access to relevant research papers, papers lacking complete raw data to conduct our replication, and a further lack of response from researchers concerning inquiries regarding raw data requests. Our meta analysis was also conducted under a time

constraint, ultimately limiting our period of time allocated towards data collection and analysis. Regardless, with the available materials, the results of our meta-analysis and extension comprehensively extends the heritability estimates of self-control in MZ and DZ twins to populations facing ADHD and anxiety disorder. Our findings open the road for further– increasingly extensive and exhaustive– studies regarding the heritability estimates of twin pairs with relation to disorders within and beyond the scope of ADHD and anxiety.

Appendix

Appendix A

This ULAB - Data Analysis.pdf contains the console output the group obtained with the R-script provided by the original authors. It contains the heritability estimates, the univariate moderator results (Table 2), and the multiple moderator results (Table 3).

Appendix B

The following files are confidence interval plots that visualize the overall estimated effects of heritability: MZ Confidence Interval Plot and DZ Confidence Interval Plot

Appendix C

This ADHD_ R Console.pdf contains the console output we got for our extension for ADHD. It contains the heritability estimates, the univariate moderator results, and the multiple moderator results.

This [Anxiety] Console Output.pdf contains the console output we got for our extension for anxiety. It contains the heritability estimates, the univariate moderator results, and the multiple moderator results.

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Note

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