Movement and Mood: Relationship Between Physical Activity and Anxiety and Change over Time in Adolescents

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Abstract

Adolescence is a unique period of development where negative health outcomes, such as insufficient physical activity and anxiety are common. Both these affect future physical activity and anxiety. There is substantial work investigating the relationships between physical activity and other mental health disorders, such as depression. Anxiety, however, is more common than depression and there is less research on anxiety and physical activity, particularly in an adolescent population. In addition, the short-term variability of physical activity and anxiety is unknown. Therefore, the purpose of this research was to examine the relationships between anxiety and physical activity as well as explore their natural variation at proximal timepoints.

Aim one investigated the relative impact of self-reported physical activity (PA) on anxiety levels in a diverse group of adolescents, while controlling for age, sex, musculoskeletal injury, depression, and pain. The results indicated that PA was not associated with elevated nor clinical levels of anxiety symptoms. Self-identifying sex as a female and depression were associated with both elevated and clinical levels of anxiety. Pain was also associated with elevated levels of anxiety.

Aim two examined the influence of anxiety symptoms and diagnoses on levels of objectively measured PA in young adolescents while controlling for sex, body mass index (BMI), sports participation, pain, friend encouragement and neighborhood safety. The results indicated that those with anxiety symptoms and diagnoses accrued significantly lower PA than

those without. Having greater friend encouragement, self-identifying sex as male and obesity were also related to increased PA.

Aim three explored within-person and between-person variation of self-reported PA and anxiety symptoms in adolescents. The results indicated that the majority of adolescents did not meet PA guidelines and reported elevated anxiety symptoms at least once over a 10-week period. Substantial within-person and between-person changes were also noted.

Overall, our findings suggest that anxiety influences PA levels, but that PA does not necessarily influence anxiety. In addition, the majority of adolescents do not accrue sufficient levels of PA and concurrently suffer from elevated anxiety symptoms. Substantial variability in both PA and anxiety highlights the complexity of health behaviors during adolescence.

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Vitae

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Fields of study

Major Field: Health and Rehabilitation Science

Graduate Interdisciplinary Specialization: College and University Teaching

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Chapter 1: Introduction

Adolescence is a distinct developmental period that can be a crucial time to intervene to improve health.(1) Low physical activity (PA) levels are of great concern as these track to adulthood(2-4) and have a greater negative impact on adolescents compared to other age groups.(5-7) Only 20% of adolescents in the United States meet the current recommendation of 420 minutes of moderate to vigorous PA each week.(8, 9) Regular and sufficient levels of PA are critical to healthy development of adolescents, but the proportion of adolescents that meet PA guidelines is lower than children or adults.(5-7) PA behavior in adolescence is complex and theoretical behavioral models of PA correlates could not explain well the majority of PA variance.(10-14)

Most PA interventions have not demonstrated clinically meaningful changes that are maintained post-intervention.(14, 15) Designing more effective PA interventions is of utmost importance; pooled analyses of objectively measured PA only increased PA by 4 minutes per day post intervention.(16) A crucial step to designing PA interventions is a thorough understanding of the correlates and determinants of adolescent PA.(17) Individual level factors have the largest impact on PA, though current research has yet to elucidate a group of correlates that explain the majority of PA levels in adolescents. Other environmental variables also have been shown to contribute to adolescent PA, such as peer support. Recently, investigations on the relationships between mental health and PA have suggested that psychological affect can also strongly

influence PA, though many of these studies do not include other variables that have a significant impact on PA in adolescents.

Our work will examine variables commonly included in Social Cognitive Theory (SCT) studies such as age, sex, and social support while also expanding to include anxiety and depression symptoms and diagnoses which have not been previously studied together in adolescents. The variables were chosen carefully as known correlates PA will allow a more in-depth examination of which variables are the strongest predictors of PA. Age, sex and BMI have been studied extensively in adolescents as factors that influence PA levels. Other variables, such as sports participation is often thought of a means to increase PA. However, research does not control for individual and environmental factors that may influence PA levels.(18, 19) Because modifiable factors such as sports participation can be improved, relationships between these are important targets to elucidate, especially within the context of sex and BMI. There is significant interest in understanding why girls accrue less PA than boys. Some studies have only included girls,(20-23) but a majority of boys are also insufficiently active(8, 9). Some girls maintain high levels of PA through adolescence, highlighting the need for more work to understand the nuanced relationships among sports participation, affective state, peer support and built environment. Our work will help establish the relative contribution of correlates to better clarify true PA differences due to sex. A comprehensive understanding of both individual and environmental variables will help clinicians identify those most at risk of inadequate levels of PA and develop successful interventions.

Overall, mental health can have significant, negative long-term consequences, including reduced PA. During adolescence, rates of anxiety in adolescents almost double from childhood.(24) Sub-diagnostic levels of anxiety symptoms are also common and cause

substantial disability.(25, 26) PA generally appears to be beneficial for anxiety,(27, 28) though some recent studies suggest that PA may not impact mental health.(29, 30) Others have demonstrated that higher levels of PA are generally associated with better mental health outcomes.(31-33) In the adolescent population, elevated anxiety symptoms have been shown to be more common in specific groups, such as females and those with concurrent elevated depression symptoms. While some work assessing the relationship between PA and elevated anxiety levels has taken demographic factors into account,(34) there is no research on symptoms and diagnoses in addition to environmental factors such as social support. Therefore, it remains unclear if higher levels of PA are associated with fewer anxiety symptoms in adolescents. PA has generally been shown to be effective in reducing the burden of depression symptoms and is a valuable tool for clinicians to support implementing. Anxiety is much more common in adolescents and understanding the relationship between elevated anxiety symptoms and PA will assist clinicians in offering evidence-based recommendations for PA in adolescents.

The short-term variability of PA and anxiety symptoms in adolescence is largely unknown. Much of the current research evaluates these variables on an annual basis. Anecdotal evidence suggests that many factors such as sports participation and weather may dramatically impact PA levels.(35) The emotionality and uniqueness of development during adolescence may result in large differences in anxiety symptoms.(36, 37) Additionally, several studies have provided evidence of differing group trajectories for PA and anxiety symptoms.(38-40)

From a public health standpoint, it is common to recommend interventions early to promote better health outcomes. This strategy assumes that if an elevated risk is identified that it is representative of the risk outside of the assessment. It also assumes that individuals will generally follow the group changes. Assessing change over time can provide valuable

information. In examining only Time 1 and Time 5, one might falsely assume that each person had similar changes over time (Figure 1a. Hypothetical Individual Change over Time). Likewise, a group average can be similar, but variability can be markedly different (Figure 2. Hypothetical Group Mean with Substantial Individual Variation).

Figure 1. Hypothetical Individual Change over Time

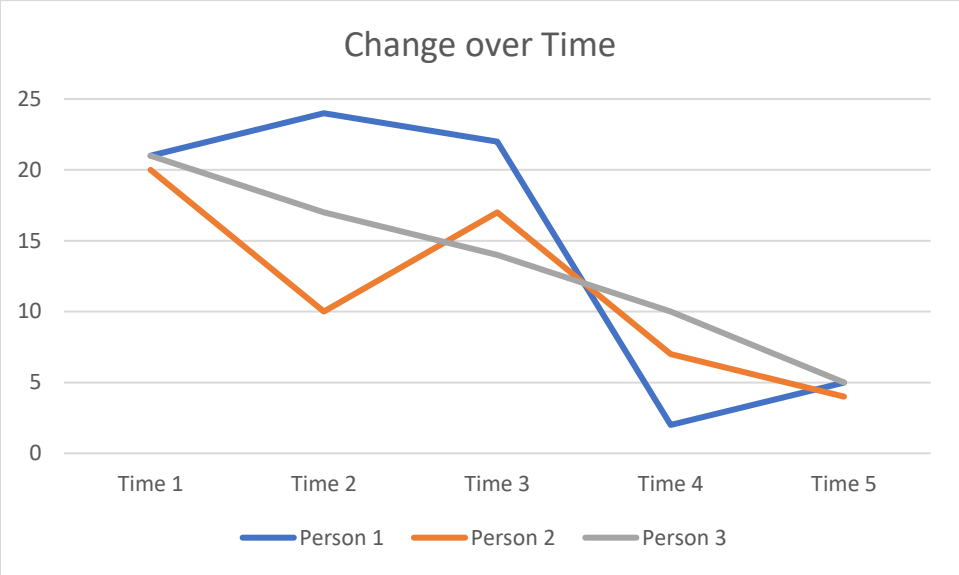
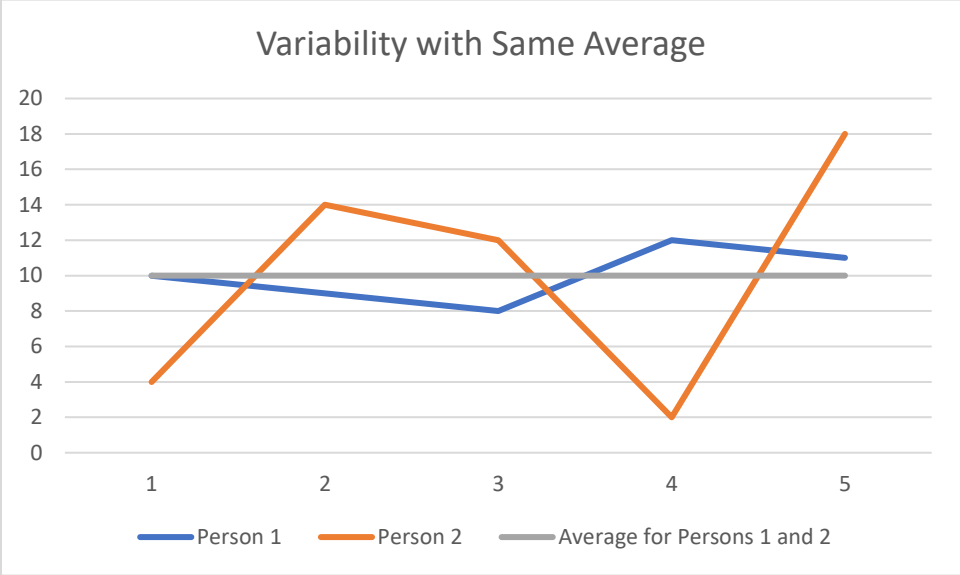


Figure 2. Hypothetical Group Mean with Substantial Individual Variation



While acute bouts of PA have health benefits, the impact of PA is significantly greater with regular, consistent levels. Likewise, elevated anxiety symptoms can cause distress, but individuals with sustained elevated levels are likely to suffer more. A clearer understanding of the variability of within-person and between person PA and anxiety in adolescents can lay the foundation to investigate factors that cause high variability. This information can help inform the design of interventions. If there is a high level of within-person change in PA or anxiety symptoms in adolescents, it may limit the interpretations of studies examining them on an annual basis. In addition, those that are identified at high risk may benefit from more frequent screenings.(41) Understanding the individual changes of PA and anxiety symptoms in adolescents is important to inform the frequency of screenings to identify those at risk for poor health outcomes.

Inadequate PA as well as anxiety symptoms are common and costly for adolescents and are associated with poorer adult health.(3, 42-44) As health behavior is complex, a better understanding of correlates of PA in adolescence is a critical step in developing more successful interventions. Elucidating the relationship between PA and elevated anxiety symptoms while factoring in other variables such as age and sex will aid clinicians in making sound recommendations for PA. Preventative medicine relies on identifying those at risk and assuming the individual will stay at elevated risk. If we find that there are large proximal individual changes of PA and anxiety symptoms, serial or more frequent screening may be warranted. The benefits of PA are greatest with sufficient and consistent volumes; elucidating short-term variability can help clinicians with targeted messaging to ensure adolescents acquire all the benefits of PA.

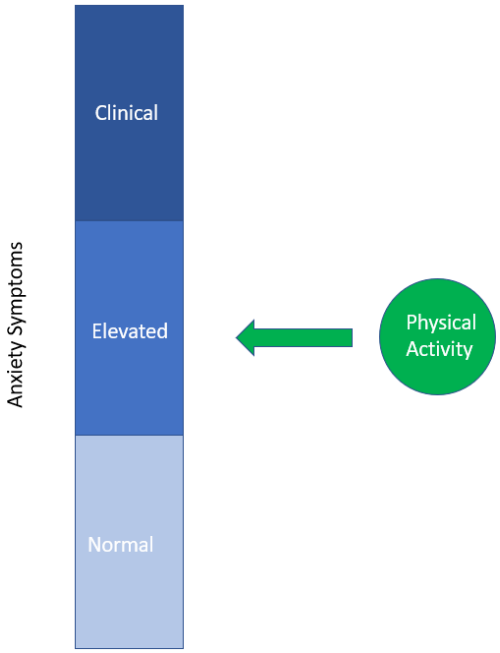
Purpose of the research:

The overall purpose of this research is to determine the relationships between PA and anxiety as well as to determine the natural short-term variation in PA and anxiety symptoms in adolescents.

Aim 1: Factors Related to Elevated and Clinical Anxiety in Adolescents

The purpose of the first project is to examine the impact of PA on

Figure 3. Concept for Project 1



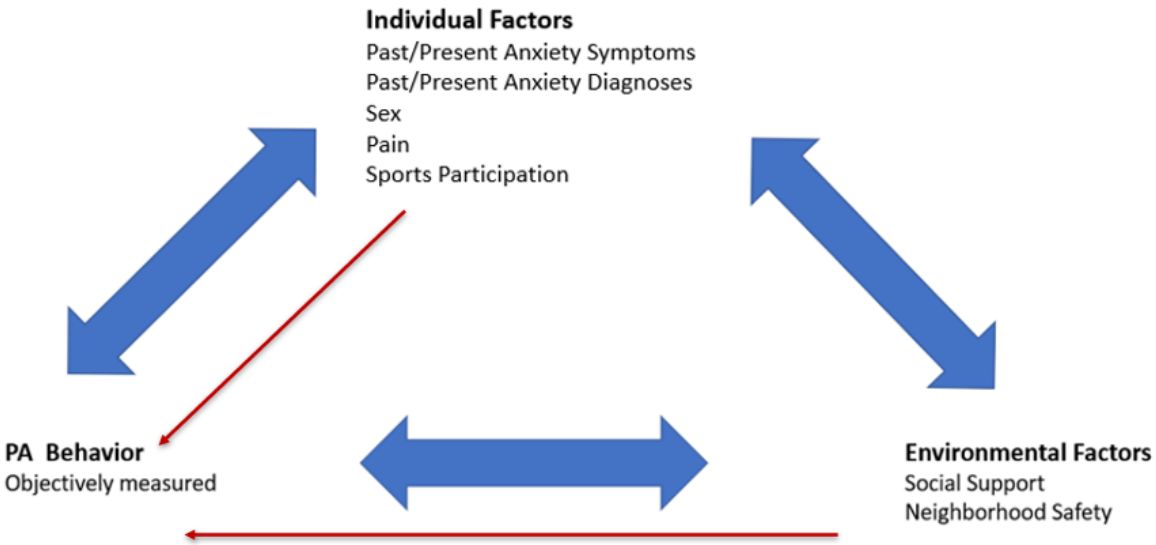
anxiety symptoms in adolescents. Elevated anxiety symptoms can cause substantial disability. While there is some evidence that PA can decease anxiety in older adult populations, there are other factors which may influence anxiety in adolescence including age, sex, depression, injury and pain. Project 1 is designed to examine the relationship between PA and elevated anxiety symptoms while controlling for these other factors (Figure 3. Concept for Project 1).

Project 2: Factors related to Objectively Measured Physical Activity in Young Adolescents.

The purpose of the second project is to apply social cognitive theory to understand variation in adolescent PA. Environmental and individual variables can each influence PA behavior. Specifically, information regarding current and past psychologic states will be included

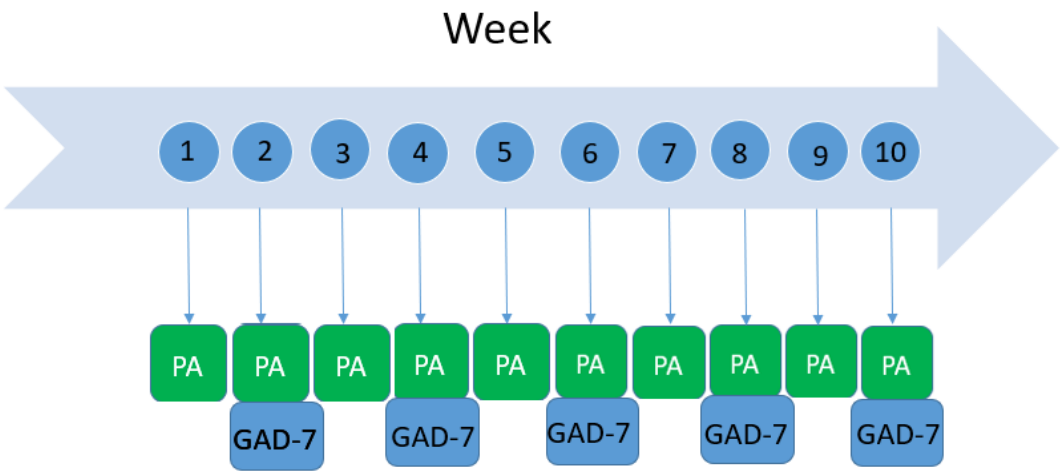
that have not been previously studied (Figure 4. Concept for Project 2 SCT Depicted in Blue, Project 2 in Red). Data from a large sample of adolescents with objective measurements of PA will include multiple environmental and individual level variables including sex, previous or current anxiety symptoms or diagnoses, sports participation, pain, peer social support, neighborhood safety, and BMI.

Figure 4. Concept for Project 2 SCT Depicted in Blue, Project 2 in Red



The purpose of the third project is to explore temporal changes in anxiety symptoms and PA in adolescents over a 10-week period of time (Figure 5. Timeline for Project 3). This project will examine overall as well as within-person and between-person changes in PA and anxiety symptoms.

Figure 5. Project 1: Short-term Variation in PA and Anxiety Over Time



Operational Definitions:

Adolescent: A child between the ages of 12-18

Social Cognitive Theory: A theory centering on triadic reciprocalism between the individual, environment and behavior.

Physical Activity: Weekly moderate to vigorous physical activity as self-reported by Exercise Vital Sign questions (Projects 1 and 3). Weekly minutes of moderate to vigorous physical activity as measured by a Fitbit in those with 7 consecutive days of wear time and >10 hours non-sleeping wear time (Project 2).

Anxiety: Total score on the Generalized Anxiety Disorder-7 (GAD-7) scale is used to categorize those who are not elevated (0-4), elevated (5-9) and clinically elevated (≥10). Total GAD-7 score is used for project 3. For project 2, current and past anxiety is determined as yes or no based on a clinical interview, including social anxiety, generalized anxiety, and separation anxiety.

Limitations:

Projects 1 and 3 use a self-reported PA questionnaire to determine total weekly PA.

Project 2 includes adolescents who are very close to age 12. These results may not be generalizable to adolescents who are younger or older.

Project 3 has a small homogeneous sample from a single school and may not be representative of adolescents as a whole. Missing data from this project may also influence the outcomes.

Delimitations:

Project one enrolled a diverse group of adolescents and controls for factors that influence both PA and anxiety.

The sample size for project two is robust and includes adolescents across the country. In addition, the ABCD study utilized objective measures of PA and only included those with sufficient wear time for one week.

Project three followed adolescents over the course of several weeks allowing investigations of fluctuations in PA and anxiety symptoms at more proximal timepoints than has previously been reported. This project assessed both between-person and within-person differences which will give valuable insights into the natural variability of both PA and anxiety.

Chapter 2: Literature Review

Adolescence as a unique time in development

Adolescence is a time of transition to adulthood with marked physiologic, psychologic, and social growth happening concurrently with an increase in autonomy.(1) Adolescents, as defined by the World Health Organization, are ten to nineteen years of age.(45) In recent years, adolescence has been determined as a distinct developmental period separate from childhood and adulthood. The adolescent period has lengthened as adolescents are starting puberty earlier and progressing to adult roles later in life.(1) Currently adolescents represent approximately a quarter of the world's population,(46) and, though generally considered healthy, adolescents bear 15% of the disease burden.(47)

During adolescence, interactions between brain development, physiologic growth, and changes in social roles are complex, but also offer a unique opportunity to influence future health trajectories.(1) As such, adolescence has been described as a critical time for health investment to leverage positive health through adulthood.(1) For example, in 2000, the Centers for Disease Control set twenty-one targets to improve adolescent health by 2008, but only three had made positive progress.(48) Other national and international organizations have recognized the importance of addressing the unique aspects of adolescent health and the potential impact on both individuals and society at large.(49-51)

There are considerable public health and economic benefits for promoting and protecting adolescent health.(50) This is evidenced by the fact that nearly 70% of premature deaths in

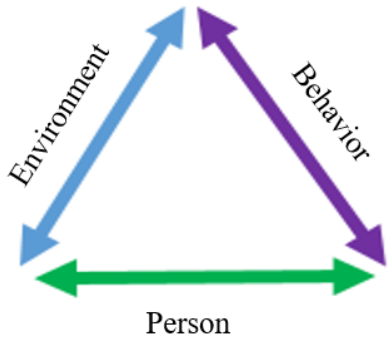
adulthood are largely a result of behaviors that began in adolescence.(46) While there are a number of factors that can impact mortality, insufficient physical activity (PA) is a leading cause.(52) Adolescents generally amass considerably lower than recommended PA. Additional concerns, such as increasing rates of developing mental health issues during adolescence, point to the complexity of health issues for this population. As a group, adolescents are less likely to meet PA guidelines and more likely to have mental health issues than either children or adults.(5-7) In addition, there is some evidence that declines in PA and increases in mental health difficulties are greatest during adolescence.(24, 53, 54) Due to the value of adolescent health and increasing concerns that many have poor PA behavior and mental health, studies further elucidating modifiable health targets as well as groups that are at risk for poor health outcomes within the adolescent time period are crucial to improve individual and population health.

Health Behavior Theories

Addressing a health behavior such as PA is complex and applying a theoretical framework to the problem can be beneficial. Using a theoretical framework to investigate correlates of PA is recommended to improve the development of effective interventions.(55) This is an important consideration as interventions to increase adolescent PA generally do not improve PA significantly(15, 16, 56) and maintenance of increased PA may dwindle.(14) With respect to improving interventions to increase adoption and maintenance of adolescent PA, identifying the determinants and correlates of PA are of utmost importance.(57, 58) As a group, individual factors are generally the strongest correlates of PA in adolescents.(59-62)

Social Cognitive Theory

Figure 6. Components of Social Cognitive Theory



The social cognitive theory (SCT) is one of the most widely applied to research in health.(17) At its development, SCT uniquely incorporated both cognitive and behavioral theories by including both internal factors, such as thinking and external factors such as rewards.(63) SCT posits that the individual is a rational actor while also accounting for factors that may not be under individual control such as biologic state or built environment.(64) As health behaviors can be affected by multiple levels,(65) the SCT is well-suited to apply to adolescent PA. The SCT is a framework where behavior, person and environment interact continuously (Figure 6. Components of SCT).(17) The person constitutes an individual with specific experiences and characteristics as well as individual beliefs. The psychological aspects of behavior are a key component of SCT and include perceptions of competence, and outcome expectancies.(66) The environment is broadly anything outside the self, and includes the observations of others as well as perceptions of social interactions and setting. Each factor within the SCT may or may not produce equal and simultaneous influences and the model allows for dynamic changes over time.(67) These qualities of SCT make it a suitable conceptual

framework for studying adolescent health behaviors, such as PA that are complex products of beliefs and environments that may change over time.

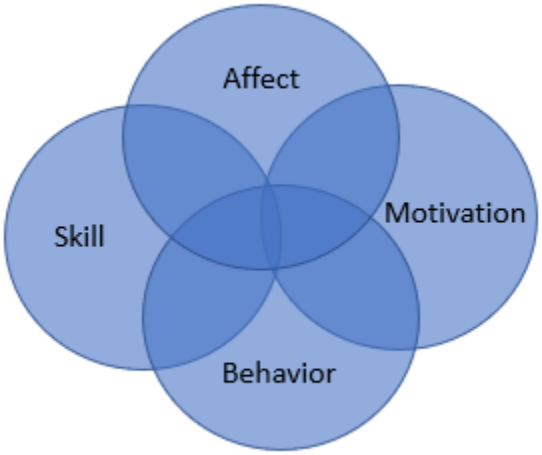
SCT has been studied extensively within PA research.(10-13, 17, 68-70) Grouped together, constructs measured within the SCT have accounted for between 0.29 - 0.52 of the variance of adolescent PA.(10-14) Environmental factors that influence adolescent PA include safety features, such as sidewalks and appropriate lighting,(71, 72) as well as built environment, such as availability of spaces for PA, such as parks, playgrounds, and fields.(73-75) In addition, the social environment can impact adolescent PA behavior through relationships with parents, teachers and peers.(76-78) There are a wide range of personal-level factors that are relevant to PA levels during adolescence, including sex, age, Body Mass Index (BMI), sports participation, musculoskeletal injuries, and pain levels. There is increasing interest in how psychological factors can influence health behaviors. Both habitual and transitory levels of affect have been associated with PA.(79-81). Increased within-person variability in affect could lead to diminished ability to self-regulate.(82) Those with fewer self-regulatory resources may have difficulty in engaging in health behaviors, such as PA.(83) Increased within-person variability in positive affect has been negatively associated with health behaviors.(84-86) but one showed no association between individual variability and PA.(87)

Physical Literacy

Physical literacy (PL) is another theoretical model (Figure 7. Physical Literacy Theory) that combines movement competence, positive affect, and movement confidence with social aspects of movement.(88) Similar to SCT, PL embodies reciprocal relationships between motor, affect, social and cognitive components.(88, 89) PL scores are significantly associated with a

number of health indicators including PA, blood pressure, body fat and quality of life.(90) While specific components of PL have been studied (91), a crucial element of PL is the holistic intent of the model (Figure 6. Physical Literacy Theory). An intervention that combined all four domains of PL have shown improvements in PA.(92, 93) Research has shown a positive correlation between PL scores and PA.(94, 95) PL allows for non-linear changes in components,(96) making this theory well-suited for exploring adolescent PA over time. PL is associated with higher levels of PA and the relationship is stable over time through early adolescence.(97)

Figure 7: Physical Literacy Theory



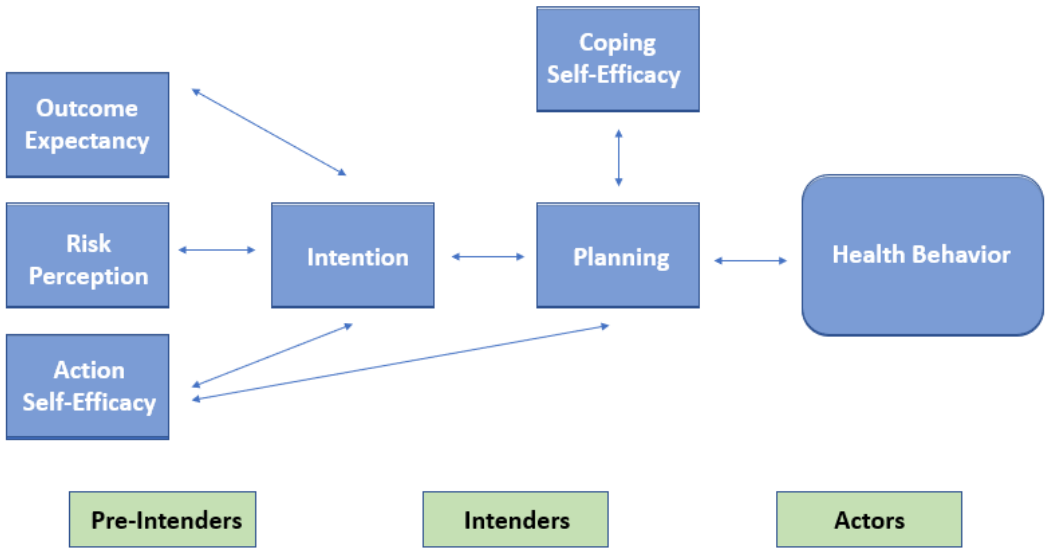
Health Action Process Approach

Another theoretical model that can be utilized to comprehend health behaviors is the Health Action Process Approach (HAPA) (Figure 8. HAPA Model). This model addresses the intention-behavior gap that is often found in other health behavior models.(98) HAPA posits that

different social cognitive factors may influence the progressions of intention and behavior.(98) HAPA also expands on previous social cognitive models by including post-intentional factors such as planning, action control, social support, and recovery self-efficacy.(98) Focusing on both intentional and volitional stages allows a more complete understanding of behavior by reflecting the mechanisms of behavioral change.(98) The HAPA model differentiates between pre-intenders, intenders, and actors across the two volitional states. (98) HAPA models have been used to understand multiple health behaviors.(99-101) In addition, a meta analyses confirmed significant pathways across behavioral health research.(102)

Research employing the HAPA model to adolescent PA is sparce. One study found the HAPA model to explain PA in adolescents.(103) A meta-analysis confirmed significant bidirectional pathways between the components of HAPA where the health behavior was PA.(104) Interventions utilizing the HAPA framework have demonstrated meaningful increases in PA.(105, 106)

Figure 8: HAPA Model



Importance of Measuring Change over time

Identifying subjects at risk for poor health outcomes early is an important aspect of preventative medicine. This strategy assumes that the risk behavior or characteristic will remain relatively stable and that decreasing the risk earlier will have greater impacts in health.(107) However, a comparison of a value with a previous value does not fully capture changes over time. Unfortunately, there is a large body of health sciences research that examines differences between two points in time. Change from a previous value often assumes that one of the values was 'normal' and these limited comparisons may offer contradictory information.(108)

A strength of SCT is the model's ability to examine not just the adoption of behavior but maintenance as well.(109) Level, or individual stability is the change over time for individuals.(110, 111) This approach is important as examining stability by studying group mean

differences over time may obscure important subgroup trends. Because of the natural variation of data over time, it is often difficult to categorize values as low or high without understanding the normal course of variation.(108) For example, rapid, substantial changes or related individual data that moves together may suggest strong external influences(108, 112) There are likely short term dynamic changes that are not linear between more distant time points.(113) While momentary states may vary, appreciating the summation of several measurements may give a better understanding about an individual's state.(112) In addition to the importance of proximal variability of adolescent PA and anxiety symptoms, within-person and between person variation can offer valuable information about these normally fluctuate in adolescents.

Variation between and within persons is natural. The measured value of many physiologic observations is the true value plus error.(114) This error can stem from measurement error, biologic error or biologic variation.(115) Measurement error is a threat to internal validity because of lack of precision and biologic error results from environmental factors.(116) Biologic variation, on the other hand, represents a true movement of a value(115) and can be measured as between-person and within-person.

Between person variation is frequently studied in physical and mental health. Interest in understanding within person variation has been growing; for example, manuscripts employing growth trajectory modeling, with clusters groups who change similarly over time, have been increasing over the last two decades.(117) Within-person variability is important in understanding health behaviors.(118) For example, within-person variability has been shown to account for almost all of the between person variability.(116, 119) Within-person variability of a construct over time can naturally vary a great deal (120) and can be greater if there are long periods of time between measurements.(114) Determining change over time via trajectory

analysis, for example, takes inter-individual data without accounting for intra-individual differences.(40) Within-person analyses examining change over time may provide valuable information regarding when to intervene for those at high risk.(40) As research often compares between-person responses, it is crucial to understand the within-person differences to avoid false conclusions. Understanding the natural within-person and between person variation can aide in appropriately planning for and assessing changes for intervention trials.

Physical Activity Definitions

PA is defined as any bodily movement, produced by skeletal muscle that increases energy expenditure above a basal metabolic rate.(121) Physical activity levels are categorized by metabolic equivalents of a task (METs). One MET is the amount of energy required to sit quietly, which is 1 kilocalorie per kilogram per hour.(122) Using METS to define the intensity of PA allows for a comparison of activities between people, regardless of stature or body composition. Moderate physical activity is activity that is >= 3 and <6 METs, meaning the activity uses 3-5.99 times the energy to sit quietly. Vigorous PA is >6 METs or 6 times the amount of energy to sit quietly.(123) Several examples of activities generally falling into moderate or vigorous PA are described in Table 1, Examples of Moderate and Vigorous Physical Activity. It is important to note, however, that actual MET levels is person-dependent and influenced by the fitness level.(124)

Table 1. Examples of Moderate and Vigorous Physical Activities

Moderate PA (3-5.99 METs)	Vigorous PA (>6 METs)
Brisk walking	Running
Household chores/gardening	Swimming
Outdoor recreation such as hiking or kayaking	Team sports such as soccer or basketball
Bicycle riding	Jumping rope
Yoga	Tennis
Dancing	Martial Arts

Recently, there has been increasing interest in light activity (>3 METS). These activities generally account for a large percentage of time and can be more accurately measured with newer technology than self-report.(125) However, most research suggests no benefit of light PA in adolescents in relation to weight or cardiometabolic markers.(126-129) Henceforth, PA will refer to moderate to vigorous PA for the purposes of this dissertation.

Importance of Appropriate Levels of PA for adolescence

PA during adolescence impacts physical, mental and social health. PA is instrumental in the healthy physical development of cardiorespiratory fitness and maintenance of a healthy weight,(130) as well as muscle and bone strength.(131) While physical benefits of PA are generally achieved with regular PA engagement,(130) even acute bouts of PA have positive effects on the brain. Improved cognition, memory and mood as well as reduced stress have been noted even after acute bouts of PA and these effects are strengthened with consistent PA.(130) Socially, PA often provides opportunities for interpersonal interaction and also can improve self-esteem, body image, and confidence.(132)

Perhaps the greatest impact of regular, sufficient PA in children is on their future health. Children who are consistently physically active are more likely to be active adults,(2, 133) which reduces all-cause mortality, in part by protecting against cardiovascular disease, type II diabetes, as well as certain cancers.(134)

Current PA recommendations in the United States are that all school-aged children should participate in sixty minutes of daily moderate to vigorous PA, where the majority of activities cause heavy breathing and/or sweating.(130, 135) PA levels among children are disturbingly low, and PA starts to decrease as early as age five and continues to decline throughout adolescence.(136) It is widely reported that only 20% of adolescents in the United States accrue the recommended 420 minutes of PA per week.(137-139) Estimates of adolescents participating in at least sixty minutes of PA on a daily basis are less than 10%, suggesting that even those who meet weekly PA recommendations are participating in more time on fewer day.(18, 127, 139) Less than 45% of early adolescents reported participating in daily PA(140) and over 15% of adolescents reported they did not engage in sixty minutes of PA goal *on any day* the previous week.(141) The financial fallout of insufficient PA in youth is substantial: even if only half of children met current PA guidelines, it is projected that there would be 243,830 fewer overweight and obese children, which would save the United States $20 billion of direct medical costs.(142)

PA change through Adolescence

Improving PA at earlier time points can elicit positive health outcomes, such as improved bone mineral density.(143) While multiple studies have assessed change of PA over time and generally find that PA volume decreases through adolescence,(59, 144-148) there are subgroups

which appear to maintain or even increase levels of PA through the adolescent transition.(23, 59, 136, 144) In general, the largest groups of adolescents are inactive maintainers; for example, nearly 70% of adolescents between 8th to 11th grades(59) and 59% of adolescents over a 5 year period reported consistently low levels of PA.(149)

Studies that assess the stability of PA across adolescence have somewhat conflicting results. Self-reported PA was not stable in early adolescents,(150) but others have shown PA tracking through adolescence to be significant albeit low to moderate.(151-154) For example, the self-reported PA levels of 11-16 year-olds over a seven year period had low inter-year correlations of 0.03 to 0.33.(155) In assessing self-reported PA over longer periods of time, Herman et al found that adolescents with the highest (16%) and lowest levels (18%) of self-reported PA remained in those categories as adults.(156) Objectively measured PA had significant moderate tracking for pre-adolescents through mid-adolescence after adjusting for covariates such season and day-to-day variation of PA.(157) Conflicting results regarding how adolescent PA changes may be different between sexes. Francis et al found tracking was stronger for adolescent girls than boys with objective measurements of PA(158) but others have found tracking higher for boys than girls who self-reported PA.(151, 152, 159)

PA is often assessed annually to evaluate the change in weekly volume of PA over time, but it is possible that PA may change significantly over shorter periods of time. Unfortunately, there is substantially less work assessing PA in adolescents at more proximal time points.(160, 161) Measuring PA at four time points over 1.75 years, Raudsepp et al found a curvilinear decrease in PA, but also moderately stable measures of self-reported PA for girls(162) Assessing objectively measured PA of adolescent soccer players revealed no differences between three separate weeks of PA over the course of twelve months.(163) In early adolescents, daily PA

within a week is highly variable and only 5% had stable objectively measured PA over seven days.(164) These results may partially be a result of school schedules as PA during school accounts for roughly one-third of total PA.(165) Moreover, decreases of adolescent PA on the weekend days may be a result of not being in school.(157) Younger children seem to compensate between days and have less PA on days following greater activity.(166, 167) In one of the few studies assessing individuals at multiple time points through a one year period, Martins, et al found high correlation of objectively measured PA in young adults when assessing one week for each month.(168) Some of the differences between studies assessing PA annually and more frequently may be due in part to study design; studies assessing PA over shorter periods of time will likely have higher correlation coefficients.(157) The variability of PA behavior during adolescence is of substantial importance because the benefits of PA are greatest with consistent participation at recommended levels.

Measurement of PA considerations

PA in adolescents can be measured subjectively via self- or parent-report or objectively though wearable devices. There are advantages and disadvantages to both. Self-reported PA is easier to administer but may introduce bias and error.(169) Objective measures are costly, are more time intensive to obtain measurements and also may introduce bias from non-wear times or the algorithms selected to define PA. For example, significant differences have been reported in PA depending on which count cutoff values have used in accelerometers.(170-173) The ability to better understand temporal changes and the success of interventions depends on valid PA measurements.(174)

Self-report PA measures

Exercise Vital Sign (EVS) is a set of two questions asking about the number of days and the number of minutes per day a person is physically active. A weekly total is calculated by multiplying these values. EVS is easy to administer and can be easily included in routine clinical care to promote PA.(175) In adults, EVS questions have excellent reliability.(176) There are conflicting results on the comparing EVS and accelerometry-derived values in adults, with some reporting strong correlations (176) and others reporting weak to moderate ones.(177-179) One study in adults reported minimal bias between EVS questions and objective measures of PA. (178) The questionnaire may have more clinical utility in identifying those who are not meeting PA guidelines(179-181) or when assessing bouts of activity >30 min.(180) The face validity and discriminant validity were strong for EVS in a large sample of adults.(182-184) In relation to mental health, EVS derived PA was significantly inversely correlation with anxiety and stress in adults.(185, 186)

Objective PA measures

Accelerometers

Accelerometers can capture objective measurement of PA by measuring body movement.(123) Body displacement is measured and converted to counts and thresholds for counts levels are employed to categorize activity intensity. This is based on the linear association between body movement and energy expenditure.(187) Accelerometers have improved the ability to quantify PA in both observational and interventional research(123) and are considered

optimal to measure continuous human movement.(188) There are a number of clinical decisions that may impact the PA values provided by an accelerometer.

Device placement: Accelerometers are most commonly worn at the hip. Limitations of this placement include activities with low amounts of hip movement, such as cycling, may not register because of the lack of hip movement as well as poorer wear time compliance.(189, 190) Wrist worn accelerometers have been more widely utilized recently as commercial grade fitness trackers have increased in popularity. Wrist worn accelerometers have higher wear compliance in adolescents;(190, 191) as a result, they provide higher PA validity due to the volume worn.(192) Wrist worn devices may over-estimate PA at the individual level, but group mean bias for PA levels appear to be insignificant.(193) In addition there is a strong linear relationship between wrist and hip worn accelerometers in free-living PA assessment of adolescents.(194) Wrist worn accelerometers have been shown detect 78% of total energy expenditure, which is similar to devices worn at the waist.(195)

Wear time: Measuring wear and non-wear time is crucial to accelerometer research to provide accurate information about daily PA. Generally, 10 hours per day is accepted as valid day, but adolescents may require longer wear time.(196) Assessing habitual PA in adolescents requires multiple valid days of wear time. Some have proposed that adolescents may require 4-8 days including at least one weekend day (197) and others have suggested that seven days may be optimal.(196) Wear times improve in adolescents with instructions for 24 hour wear.(198)

Epoch length: Epoch length is the amount of time for which counts are summed for data analysis. One minute intervals are the most common,(170) but because of the intermittent bursts of PA in adolescents, shorter epochs have been recommended to study PA in younger populations.(125, 197) In addition, the Physical Activity Guidelines for Americans, 2nd edition

states that any amount of PA counts towards the recommendation of 60 minutes of daily PA.(130) As such, some recent studies have begun utilizing shorter epochs for measuring PA with children and adolescents.(170)

Count cut-offs: The magnitude of acceleration is used to classify body movements into counts, which are then used to classify intensity levels of PA. The wide variation in cut-points across research can lead to large differences in PA levels.(170)

Commercial grade fitness trackers

Commercial grade fitness trackers have presented an opportunity to provide more objective measures of PA and are increasingly popular. Fitbit has been the most studied commercial grade tracker. There are many studies investigating the ability of Fitbit devices to measure steps, PA, energy availability (EE) and heart rate, mostly in adults.

PA: In adults, the ability of Fitbits to accurately measure PA is questionable. Fitbits had a high error compared to waist worn accelerometer.(199) Waist worn trackers have been found to be better than wrist worn trackers for measuring PA and there was moderate comparability across intensities of PA between device types.(200, 201) Type of movement accuracy for Fitbits ranged from 86-92%.(202) though in a controlled setting, wearable activity trackers provide accurate recognition of the type of some common physical activities, especially outdoor walking and running and walking on a treadmill.(203) The ability of Fitbits to distinguish change during activity, such as from light to moderate PA, was poor in adults.(203) Fitbit was responsive in determining differences between activities for heart rate and PA intensity,(204) though others reported that Fitbits were only able to accurate categorize PA based on heart rate just over half the time.(205) However, one study found that different Fitbit devices had strong correlations

between 0.77 and 0.91 compared to accelerometers in free-living adults.(206) Several studies have investigated the ability of Fitbits to measure PA in youth. In children, Fitbit had a sensitivity of 85% for detecting PA.(174) Fitbit showed high reliability for determining PA compared to an accelerometer, though the authors found that using an algorithm by Crouter was superior in PA classification than the Fitbit algorithm.(207) High correlations were found for PA between Fitbits and accelerometers in children.(208) In slightly older middle school students, Fitbit measured PA also had strong correlations with accelerometers.(209)

EE: Fitbit may be able to better estimate EE in youth than adults. EE was underestimated compared to a metabolic cart for men and women and mean absolute percent error was 20%.(210) The ability of Fitbit to measure EE was poor during higher intensity activities.(211) Overall, poor agreement was found for EE and objective measures(212-215)**,** and others have found no change in Fitbit reported EE when increasing exercise intensity.(216) However, in youth, Fitbit has accurately estimated EE during treadmill running in young adults,(217) but had a mean absolute percent error of roughly 40% for measuring EE in children and young adolescents.(218) In adolescents, there was a strong correlation with metabolic chamber and Fitbit measurements.(219)

Heart Rate: The ability of Fitbits to measure heart rate appears to be questionable.(220) In adults, Fitbits provided adequate heart rate monitoring during walking,(221) and heart rate measured by Fitbits were very accurate in mid age adults.(204) Heart rate accuracy declined as PA intensity increased in adults, (214, 222) though others have shown overall acceptable associations between Fitbit and a Polar monitor.(214) Some have concluded Fitbit provided reasonable HR data,(212) but others have demonstrated wide heart rate compared to echocardiograms.(223) and HR mean absolute precent error ranges between 2.38 and

16.99%.(216) In children, Fitbit showed moderate-strong agreement with a Polar heart rate monitor.(224)

Steps: On a day level, Fitbit had high correlations with accelerometers(201) with use in free-living adults.(206) Fitbit steps were more accurate in adult females when minutes with less than two steps and missing heart rate data were removed.(225) Some have reported that Fitbit under-recorded step(226) and others have found accurate step counts on the treadmill(227) This may be a result of speed; during slow or fast walking Fitbits produced inaccurate step counts.(213, 228), and step counts were more accurate than in slow walking.(229) . In children, steps were comparable to accelerometers except during PA, where Fitbit significantly over-estimated steps.(230) In adolescents, moderate associations were found between step counts of accelerometers and Fitbits.(219)

Factors that Influence Adolescent PA

Girls participate in less PA than boys

Sex is an important factor in PA levels, as research has consistently demonstrated that females engage in less PA than their male counterparts. There are a variety of proposed mechanisms for explaining decreased MVPA in girls including less participation in organized sports,(231) less perceived parental and peer support(232) and decreased motor competence.(233) Girls may have more pronounced PA declines than boys(234) and PA levels for females remain lower than males through adulthood.(139) For girls, objectively measured PA fell below the recommended sixty minutes of daily PA almost one and a half years sooner than boys.(235) By late adolescence, almost all girls are categorized as persistently inactive, regardless of previous PA levels, providing further evidence of differences in PA decline across sexes.(146) However, there are girls who maintain or even increase PA levels through

adolescence, indicating that sex alone is not responsible for overall PA differences. One study found that in adolescent girls, self-reported PA did not decrease over time, though mode of PA changed from more PE and sport based to leisure PA later on.(236) This is consistent with others who have shown that girls were more four times more likely to drop out of PA pursuits than boys.(237)

Studies assessing objectively measured daily PA have found girls are about 20% less active than boys(238, 239) and average 18 minutes fewer than boys per day.(235) Less than 2% of secondary school aged girls met daily PA recommendations, as measured by accelerometers.(240) While some have found no difference in decline of PA in girls,(136) pooled data from a recent meta-analysis showed that girls objectively measured PA declined at higher rates than boys annually through adolescence.(53)

Older adolescents participate in less PA

It is generally accepted that PA declines during adolescence.(139, 235) In a population based study, adolescents were less likely to report PA in secondary school compared middle school.(240) In older adolescents, only 19.1% of boys and 11.2% of girls were consistently and sufficiently active over three years.(241) In younger adolescents, objectively measured PA decreased by up to 30% over a two year time period(153) and similar declines were reported across early to mid-adolescence.(136) Starting at age nine, daily objectively measured PA was significantly reduced by roughly 40 minutes per week each year over a six year period.(235) Self-reported annual PA declines are generally smaller at 7%-11% through adolescence.(234, 242) Pooled data from over fifty longitudinal studies revealed an average of 3.4 minutes per day less PA from childhood through adolescence.(53) During early adolescence, a downturn of 8.5%

of PA has been shown,(53) while others have demonstrated more pronounced decreases in PA as adolescents transition to secondary school.(144) While some have suggested there are groups that have different trajectories of PA decline, a steady decline of objectively measured PA is most common and represents between 50-60% of adolescents while only about 20% are consistently active.(136, 243)

Effects of BMI on Adolescent PA are mixed

BMI is a measure of the relationship of weight for height and used to estimate adiposity.(244, 245) In children and adolescents, BMI is reported as percentile to normalize BMI for age and sex.(246) BMI percentiles >85 are considered normal weight, 85 to <95 are considered overweight and those with BMI percentiles >95 are considered obese.(245) BMI is strongly correlated with adiposity(247-249) and clinical measures of cardiovascular risk in adolescents.(250) Currently in the United States, over 20% of adolescents are obese and rates of obesity have doubled in the last several decades.(251) In addition to the number of obese adolescents, another 17% of adolescents are overweight.(252)

There is conflicting research on the role of adolescent BMI in self-reported PA of adolescents. Hwang et al found no differences in self-reported physical activity between normal weight, overweight and obese adolescents.(253) Others have demonstrated no difference in BMI in those that met or did not meet physical activity recommendations PA.(254, 255) BMI category was associated with self-reported PA level in younger adolescents but this was not true in older adolescents.(140) Conversely, other have found that overweight adolescents reported nearly an hour less PA per week than normal weight peers.(256) Adolescents who were inactive were

twice as likely to be overweight or obese than their normal weight counterparts.(257) A higher level BMI was associated with lower self-reported PA in girls.(162)

Studies objectively assessing PA generally find that overweight and obese adolescents participate in less PA or are less likely to meet PA guidelines. Several studies have shown no association between steps taken and BMI, when BMI is a continuous variable,(258, 259) but others found the opposite.(260) In utilizing BMI as a categorical variable, obese adolescents consistently take fewer steps than normal weight adolescents.(261-265) Young adolescents who were normal weight were significantly more active than those who were obese, but there were no differences in PA between overweight and normal weight adolescents.(164) There may be sex differences in BMI category and PA levels; normal weight adolescent girls were had higher levels of PA and more likely to meet PA guidelines, but these trends did not necessary follow in boys.(266) In addition, normal weight boys have demonstrated increased objectively measures PA when compared to overweight and obese counterparts, but this was not true of girls.(267) The conflicting results between objectively and self-reported measured PA could be due to increased bias of self-report PA measures for overweight and obese adolescents.(268) Furthermore, results have been mixed on the effect of BMI on adolescent PA over time,(149, 162, 269) making it more difficult to interpret the impact of BMI on adolescent PA.

Sports participation is an important contributor to adolescent PA

Participating in organized sports has traditionally been a significant avenue for adolescents to amass PA. While 60 million youth participate in sports, only 54% of total youth participated in sports in 2017,(141) and only around 40 percent of adolescents report regular sports participation .(42) In 2019, 18% of youth did not participate in any sports activity.(42)

Unfortunately, up to 70% of children will drop out of sport by the time they are 13 years old(270) and girls drop out at twice the rate of boys.(271)

Participating in sports increases self-reported PA in adolescents.(241, 272-274) Adolescent athletes self-reported almost eleven hours per week of PA than those who did not participate in sports,(275) and those who play sports were more likely to report meeting daily PA recommendations.(276, 277) In a large longitudinal study, Pfeiffer et al concluded that sports participation significantly contributed to 30 minute blocks of self-reported PA.(278) Adolescents involved with sports clubs were two to six times more likely to report PA that met guidelines than those not in sports clubs.(279) Over a four year period, 12-15 year-olds who reported participating in sports activities reported no change in yearly PA in those activities, and the authors suggested that those discontinuing sports were a significant cause of PA decreases over the same time.(280) Compared to those not participating in organized sports, boys and girls who participated in organized sports were 13.2 and 8.9 times more likely to be consistently active.(241) However, sports participation among girls through adolescence is not consistent.(281)

When assessing PA objectively, male and female adolescents who participated in club sports had higher PA levels at all ages, though only 20% of athletes met PA guidelines.(282) In adolescent boys, organized sports participation contributed to 35-42% of their objectively measured PA(283) and during an organized sports practice, adolescents accumulated roughly half of the recommended daily PA.(284) Soccer players engaged in a substantial portion of daily objectively measured PA on weekends through sport, with roughly a third participating in over 60 minutes and 70% accruing at least 20 minutes.(285) Adolescents engaging in organized sports

were between 39% and 64% more likely to achieve daily PA goal and accrued and an additional 5 minutes of PA per day.(277, 286)

The influence of pain on adolescent PA is unclear

Pain is defined as a distressing sensory or emotional experience with actual or potential tissue damage or events described in terms of such damage.(287) Two main types of pain are physiologic pain, originating via receptor stimulation, and pathologic pain, which originates within the central nervous system.(288) In nociceptive pain, free nerve endings call nociceptors respond to biological, electrical, thermal, mechanical, and chemical stimuli.(289) Impulses run through the dorsal horn of the spinal cord to the thalamus, where pain sensation occurs. Impulses traveling the cerebral cortex and limbic center allow pain to be perceived and interpreted.(289) Pathologic pain is a thought to be a result of nociceptive neurons in the central nervous systems having a decreased threshold for afferent responses.(290) There are several mechanisms through which pain can be modulated. Psychological state, memories, and expectations can increase or decrease the pain experience.(291) In addition, endogenous opioids are released by the dorsal horn of the spinal cord, brainstem and other tissues can inhibit pain impulse transmission.(289) Because PA stimulates the release of these endogenous opioids, there is some evidence to suggest that engaging in PA can reduce pain.(292-294) However, there is significantly less research on how pain levels may influence PA, though pain explained 11% of the variance of self-reported PA in a large sample of adults.(295)

Rathleff et al found no difference in self-reported PA levels in adolescents with anterior knee pain and those without.(296) Adolescents with chronic pain have less objectively measured PA than in matched controls.(297, 298) In adolescents with pain, those with the lower levels of

objectively measured and self-reported PA had the highest pain levels.(293, 299) Pain may have a bidirectional relationship with PA; adolescents having higher PA during the day lead to lower pain at the end of that day and higher pain levels lead to lower PA the following day.(294) Others have found that adolescents and young adults with pain did not report less PA than controls.(300) While there are limited studies on pain and PA in adolescents, the results mimic adult studies. Chronic back pain did not negatively influence objectively measured PA levels in adults.(301, 302) Adults with higher pain levels were 28% more likely to self-report reduced PA levels three months after an injury when controlling for injury and demographic characteristics.(303)

Peer Support

There is strong evidence that friend influence supports adolescents in participating in PA. Friend support was reported a facilitator of PA and lack of support from friends detracted from their PA.(304) Friends being physically active was significant predictive of adolescent self-reported PA.(305) Adolescent boys and girls friend encouragement, modeling and co-participation was associated with objectively measured PA.(306) Peer support was significantly related to objectively measured PA(232) and was a stronger direct link to PA in 10-17 year-olds than parent support, SE, enjoyment and barriers.(307) Peer use of parks was associated with adolescent park use and objectively measured PA.(308) Time alone was negatively associated with adolescent objectively measured PA and activity occurring in the presence of friends was a significant predictor of PA.(309) In addition, peer support for PA significantly strengthened the association between built environment and objectively measured PA.(310) Others have found conflicting results. Closest friend modeling, enjoyment as well as general peer support did not

influence objectively measured PA, though closest friend interest in PA was a significant predictor for PA on weekdays.(311) Some discrepancies may relate to age. In children, friend groups demonstrated similar objective PA measurements.(312, 313) Peer support was a significant predictor of PA in twelve year-olds (314) but not in older adolescents.(315) In addition, peer support was not a significant predictor of children and adolescent objectively measured PA during school.(316) In those aged 10-17, peer support was a significant predictor of objectively measured PA for boys, but not girls.(317)

Neighborhood Safety

The built and social environments likely play a role in adolescent PA. Neighborhood safety has been shown to a stronger correlate of adolescent PA than built environment.(318) Parent perceptions of neighborhood safety are more related to adolescent PA than adolescent perceptions of safety.(71) There is conflicting evidence related to how much parent perceptions of neighborhood safety influence adolescent PA. Some have found no association between objectively measured PA in adolescents with their perception of neighborhood safety.(319) In addition, neither objective and adolescent perceptions of area crime were not associated with objectively measured PA in adolescents.(308) Parental perceived neighborhood safety was associated with supporting PA, but not actual self-reported PA.(320) Parental perception of unsafe neighborhoods had children and adolescents who participated in less self-reported PA(321) In addition, neighborhood safety was significantly related to early adolescent independent mobility.(322) Child objectively measured PA was not influenced by parental perception of neighborhood safety.(323) Sex may influence how neighborhood safety relates to adolescent PA; in high crime areas, girls were less likely to have PA but this was not true for

boys.(324, 325) Parents of girls who felt that neighborhoods were unsafe had daughters who reported less PA.(326) The opposite has also been found as Carver et al noted that parental perception of neighborhood safety was associated with objectively measured PA of boys, but not girls, after school.(327)

Mental Health Importance in Adolescence

Mental health in adolescence has recently gained attention as prevalence and disease burden are increasing.(328) Rates of ever having been affected with anxiety or depression during childhood and adolescence climbed from 5.4% to 8% between 2003 and 2012 in the US.(329) Prevalence of anxiety and depression, two of the most common mental health conditions, are highest during adolescence, which affect roughly 6% and 11%, respectively.(330) Although adolescents generally have low point estimates for mental health concerns, by age twenty-one nearly two-thirds had met the criteria for a mental health diagnosis and an additional 21% displayed subclinical psychiatric problems.(3) In addition, the number of adolescents endorsing elevated anxiety and depression symptoms more than doubled from 1986-2006.(331) About half of mental disorders experienced through life will begin by age fourteen.(332) For adolescents, mental health conditions are among the most expensive to treat(333) and in the United States, adolescents with mental health conditions incur health care costs doubling those of their peers without a mental health condition.(334) Poor mental health in adolescence increases adulthood difficulties with mental health.(335, 336) Some research has suggested that the long term impacts of poor mental health during childhood and adolescence may be more significant than poor physical health.(337, 338) The importance of adolescent mental health has been acknowledged by international organizations such as the United Nations(51) and the World

Health Organization.(49, 50) Indeed, there is convincing evidence that suggests protecting the mental health of children and adolescents through early interventions can produce extensive benefits for adolescent health, as well as other divisions of society.(339, 340)

Anxiety symptoms, diagnosis and prevalence for adolescents

Anxiety is an unpleasant feeling ranging from mild uneasiness to extreme fears and presents with somatic and psychological features.(341) In adolescents, anxiety can range from mild and transient to a diagnosable disorder.(342) Anxiety symptoms can include restlessness, fatigues, difficulty concentrating, irritability, muscle tension and sleep disturbances(342) (Table 2. Common Anxiety Symptoms).

Table 2. Common Anxiety Symptoms

Restlessness
Worry or nervousness
Irritability
Difficulty falling or staying asleep
Fatigue
Sweating
Nausea
Inability to concentrate
Palpitations
Hypervigilance
Racing/unwanted thoughts

While there are several phenotypes of anxiety disorders, generally they all include symptoms of excessive anxiety and/or worry characterized by a single or multiple triggers (e.g. social situations, separation from caregiver). The individual finds the anxiety hard to control and

is associated with at least one symptom that presents for more days than not over the last 6 months.(343) In addition, anxiety must not be able to be explained by other mental or physiologic conditions, such as post-traumatic stress disorder or substance abuse.(342) There are multiple anxiety symptom scales that have been utilized to assess anxiety severity in adolescents and several common ones are listed in Table 3, Common Scales for Measuring Anxiety in Adolescents.

Table 3: Common Scales for Measuring Anxiety in Adolescents

Scale	Description	Ages	Time (Minutes)	Sensitivity, Specificity
Generalized Anxiety Disorder-7	7 items assessing general anxiety	13+	5	88%, 88% (330)
Multidimensional Anxiety Scale for Children	39 items with 4 scales: physical symptoms, social anxiety, harm avoidance, separation/panic	8-16, includes parent report	15	62.8%, 81.7% (344)
Revised Children's Manifest Anxiety Scale	37 items, 3 factors: physiological manifestations of anxiety, worry and oversensitivity, fear/concentration	6-19	10-15	47%, 66% (345)
Screen for Child Anxiety Related Emotional Disturbances	41 items loading on 5 factors, somatic/panic, general anxiety, separation anxiety, social phobia, and school phobia.	8-18, includes parent report	10	75-79%, 60-88% (346)

Anxiety is one of the most common mental health disorders and one-third of adolescents in the United States meet the criteria for an anxiety diagnosis.(347, 348) Anxiety disorders are one of the most prevalent categories of psychopathy in youth.(349) Changes in the brain during adolescence may increase the sensitivity for developing anxiety.(350) Although adolescents generally have low point estimates for mental health concerns, by age twenty-one nearly two-thirds had met the criteria for a mental health diagnosis and an additional 21% displayed subclinical psychiatric problems.(3) This is not particularly surprising, given that the onset of many anxiety disorders also occurs during adolescence, including social anxiety disorder, panic disorder, and generalized anxiety disorder.(342, 351, 352) Girls appear to suffer from greater anxiety than boys and have been shown to have both higher proportions of diagnoses and symptom burdens.(37, 39, 341, 353) Societal costs of families with clinically anxious children were almost twenty-one times higher when compared to families from the general population.(43) Adolescents with diagnosable anxiety may be frequently missed as is the case in adults.(354) For example, 13% of adults in a primary care clinic met the criteria for an anxiety diagnosis though they had no history of mental illness.(355)

In addition to diagnosable anxiety conditions, elevated subthreshold symptoms can impart significant deleterious health impacts on adolescents such as higher levels of distress and lower psychosocial functioning.(25) In adults, those with subthreshold anxiety symptoms had similar disability as those with diagnosed anxiety.(332, 342) A high proportion of adolescents demonstrate elevated anxiety symptoms, ranging from 15 to 56%.(331, 356, 357)

Anxiety stability through Adolescence

Some researchers have demonstrated moderate levels of the stability of anxiety symptoms through childhood and adolescence(358) and high stability of anxiety symptoms in adolescents through midlife.(359) Within adolescence, some individuals have shown anxiety symptoms to be highly stable during adolescence,(360) though others have described more moderate stability.(361) Though group stability of anxiety has been investigated, individual trajectories may significantly vary in adolescents. For example, in adolescents with high anxiety scores, half continued to report elevated scores one year later and the other half returned to normal levels.(353) Changes in anxiety symptoms may be in part a result of environmental factors that can change over time.(362) This is true in adults, where anxiety can change rapidly in highly stressful or treatment conditions, though minimal is known about the persistence of such changes over time.(363)

As anxiety disorder prevalence is relatively consistent across adolescence,(364) changes through adolescence may be due to difference in clinical symptom presentation as opposed to levels of anxiety changing.(3) There may be different anxiety symptom trajectories across groups may account for a general decline in anxiety symptoms;(3) one study found that 8% of adolescents had high anxiety that continued to rise, but the majority had stable low anxiety symptoms.(38) While many studies have assessed anxiety symptoms annually, it is likely that that anxiety symptoms may change substantially over shorter periods of time, especially considering adolescence is a time of high emotionality.(36) Understanding of changes in anxiety at shorter time intervals can help inform screening recommendations.

Factors Influencing Adolescent Anxiety

Age and Anxiety

Adolescents have higher rates of anxiety than any other age group.(365) Anxiety symptoms may change significantly through adolescence. Although anxiety symptoms consistently predict later anxiety pathology,(3, 44) overall anxiety symptoms generally decrease over middle adolescence(38, 39, 366) before beginning to rise again.(37, 286, 359, 367-370) Others have shown steady increases in anxiety over adolescence.(371) Lifetime prevalence of generalized anxiety disorder increased through adolescence, suggesting that anxiety diagnoses increase as adolescents age.(372) Sex differences may explain some of the divergent findings. Hale et al found that that anxiety symptoms increased for girls, but decreased for boys over a five year period.(39) In addition, although girls have demonstrated higher anxiety levels, there were no differences rates of anxiety development between girls and boys.(40)

Anxiety and Injury

Acute trauma is associated with higher levels of anxiety in adolescents.(373) Anxiety symptoms are common after injury and affect 22% of those with concussion.(374) Others have demonstrated similar rates of elevated anxiety symptoms following musculoskeletal injuries in adolescents.(375) In adults, anxiety predicted pain after an acute injury.(376)

Sex and Anxiety

Females suffer from anxiety more than males. (39, 40) There is a large difference between anxiety disorders occur during adolescence, with 38% of females and 26% of males suffering from any diagnosable disorder.(377) Some have suggested that anxiety in males is

more often caused by external factors and female anxiety is more often caused by internal factors.(378) Adolescent females report lower self-esteem, which has a negative correlation with anxiety.(379) Changes in estrogen and progesterone have also been implicated in female anxiety.(380)

Effects of Depression on Anxiety

In adolescents with anxiety, 10-15% will also suffer from depression.(371, 381, 382) Adolescents with anxiety may also experience subclinical levels of depression.(383) Adolescents with anxiety as a primary diagnosis with secondary depression symptoms may suffer greater impairment than even those with primary depression and secondary anxiety, though concurrent anxiety and depression cause more impairment than either on their own.(384-388)

Adolescent anxiety and pain

Pain is frequent in adolescents and while consistent pain is uncommon,(389) frequent pain is associated with female sex and anxiety.(390) Pain is a common co-morbidity with negative mood states.(391) In adults, anxiety is associated with multiple pain disorders including migraine, fibromyalgia, and neck pain.(392). Adults with joint pain were more likely to have increased anxiety over time regardless of baseline psychologic characteristics.(393) In young adults, anxiety was related to pain perception and females were more willing to report pain. (394) Unexplained somatic symptoms, including pain, are very common in adolescents with anxiety.(395) Adolescents with chronic pain were more likely to have anxiety(396) and baseline anxiety was a significant predictor of adolescent pain over the next five years.(397) Mother-

reported anxiety at age thirteen did not predict chronic pain at age seventeen, but may be a risk factor for increased disability in those with chronic pain.(398) Children with pain have increased anxiousness and fears to those without pain.(399) Others have found no associations between anxiety and pain levels in adolescent girls (400). In addition, Michalska et al found no differences between clinically anxious and healthy youth on perceived pain.(401) In young adults, pain perception differences were associated with differing levels of stress and anxiety.(402)

Relationship of PA with Mental Health in Adolescents

Anxiety and PA

Adolescents reporting low weekly frequency of PA were at greater odds of anxiety compared to those who reported 5-7 days/week of PA,(34) and those who reported exercising regularly have lower anxiety.(403) Anxiety symptoms demonstrated an inverse relationship with low, moderate and high self-reported PA in adolescents, though there no differences in symptoms between moderate and high active girls.(404) Objectively measured PA increases in adolescents were associated with lower anxiety symptoms one year later.(27) While evidence for the positive effects of PA on anxiety symptoms and diagnoses are limited in adolescents, studies from adults mimic adolescent studies. A number of studies have demonstrated that increasing PA can decrease anxiety symptoms,(33, 405) though not all research has found an inverse relationship between PA and anxiety.(406) In college students, exercising less than three days per week was not associated with an increased odds of experiencing anxiety.(407) In a group of children and adolescents, reporting not meeting PA guidelines was associated with a 45% increased odds of having an anxiety disorder.(408) Adolescents who screened positive for

anxiety on a diagnostic interview were 3.5 times more likely to report lower weekly days of PA compared to those with 4-6 days of PA. (409) Similarly, Liu et al found that adolescents reporting higher weekly PA (410)

Evidence to support meeting PA guidelines decreases anxiety is generally lacking.(411) However, in adults, self-reported PA levels in adults above recommended levels were associated with a negative anxiety diagnosis and lead to lower anxiety symptom incidence.(411-413) A large longitudinal study with older adults provided evidence that reported PA levels at recommended levels were associated with 25% decrease in prevalence and 62% decrease in incidence of anxiety.(414)

Depression and PA in Adolescents

Depression is characterized by a depressed mood and lack of interest or pleasure in activities and may coincide with fatigue, sleep disturbances, weight loss or gain, irritability, an agitated state observable by others, as well as impaired concentration and/or cognition. Common symptoms represent sometimes opposing complaints (e.g., weight loss or weight gain), demonstrating the potential heterogeneity within the disorder.(415) Adolescents can experience a range of mild and transient depressive symptoms to diagnosable depressive episodes.(416) As with anxiety, depression symptoms below the diagnostic threshold have substantial risk of later psychopathy(4, 26, 417-419) and high levels of functional impairment.(420) Nearly a third of adolescents reported significant depression symptoms in the last year and rates increased with age.(141) As with anxiety, females are more likely to experience depression than males.(421)

There is a large body of work supporting the idea that PA is beneficial to prevent and reduce depression. Previous work has demonstrated reduced PA in those with a history of

depression and those with current depression compared to controls.(422) A recent meta-analysis demonstrated that physical activity had a significant protective effect of developing depression and a strong treatment effect when used to manage depression symptoms,(423) echoing others who have concluded that PA helps alleviate depression burden in adolescents.(132, 424) In older adolescents self-reported low and high levels of PA both produced poorer well-being scores.(425) Adolescents with low weekly frequency of PA were at greater odds of depression compared to those who reported 5-7 days/week of PA(34) and those with self-reported greater than four days per week had less mental distress.(426) Depression symptoms were inversely related to low, moderate and highly active adolescents, though there no differences in symptoms between moderate and high active girls.(404) College students not meeting the self-reported PA recommendation had more frequent depressive symptoms than those meeting the PA recommendation.(427) Self-reported PA in adolescents showed significant negative correlations with depressive symptoms.(28) The adult literature endorses these findings. Self-reported PA had a U-shaped curve with mental health, indicating that low and high levels of PA lead to poorer mental health outcomes.(428) While some have shown that self-reported PA at levels higher than the current recommendations were associated with the lowest levels of depression symptoms,(429-431) others have concluded that PA reported at the recommendation level produces the greatest benefit for lower mental distress and depressive symptoms.(432, 433) Additionally, adults who report consistently meeting PA guidelines had lower odds of depressive symptoms.(434)

Objectively measured PA in adolescents and its association with depressive symptoms is mixed. Some have found no association of objectively measured PA with depression symptoms in adolescents.(32, 357), and others have shown higher levels of PA reduce depressive

symptoms.(435) Objectively measured PA in adolescents has been negatively associated with depression at age 18.(436) In adolescents with depression, PA significantly reduced depression symptoms.(437) While most studies objectively measuring PA change over time concludes that PA does not influence depression symptoms in adolescents,(29, 30, 438) one study found that a improving PA over three weeks was strongly negative correlated with depression symptoms in college aged girls.(439) Melnyk et al found that increasing steps lead to decreases in depression symptoms in adolescents that had higher symptoms at baseline.(440) Others have found no association between objectively measured PA in young adolescents and depression symptoms, but found that higher PA at baseline was associated with fewer emotional problems several years later.(31) In contrast, PA levels in early adolescence did not predict depression symptoms five years later.(441) A large simulation study concluded that even large increases in objectively measured PA would do little to decrease overall mental health in children.(442) In addition to anxiety and depression, there are a variety of individual and environmental factors that influence adolescent PA.

Statistical Considerations

Multinomial Logistic Regression

A multinomial logistic regression is similar to a logistic regression but the dependent variable has more than two levels.

Assumptions:

1. The dependent variable needs to be categorical and have more than two levels.
2. The independent variables are categorical or continuous.

3. Independence of observations and dependent variable is mutually exclusive and exhaustive.
4. No multicollinearity between independent variables.

    This is assumption is met if the VIF is less than 10, and less than 5 is ideal. VIF can be assessed by running a MLR and checking the VIF
5. A linear relationship between the independent variables and the log of the odds ration of the dependent variable.

    This is assessed by adding the interaction terms of the log of all continuous variables with the variable in the equation. If the interaction terms are non-significant, this assumption has been met.
6. There are no outliers, high leverage or highly influential data points.

Multiple Linear Regression

A multiple linear regression uses several independent variables to predict the dependent variable.

Assumptions

1. Observations should be independent
2. There is linear relationship between the outcome variable and each predictor variable in addition to having a linear relationship with the collective group of predictor variables.
3. The data are homoscedastic
4. There is no collinearity between two of the predictor variables.
5. There are no outliers

6. Residuals are normally distributed. These are assessed visually with a P-P plot and Q-Q plot.

AUC-ROC analysis

The receiver-operating curve is determined by plotting the sensitivity and specificity. Area under the curve refers to the ability of a model to distinguish between two groups. The AUC can be calculated for both individual variables as well as a group of variables.

Measuring change over time

Measuring change over multiple points in time can be completed in several ways. Graphical representations, such as line graphs, can be especially helpful.(108) Individual and group changes may look different and should be distinguished. Alluvial graphs can help visualize changes over time between subgroups.

Chapter 3: Relationship of Physical Activity on Elevated and Clinical Anxiety in Adolescents

Abstract

Background: Anxiety is the most prevalent mental health condition in adolescents and elevated symptoms cause substantial disability. The relationship between physical activity (PA) and anxiety in adolescents is unclear. The purpose of this study was to assess the impact of PA on anxiety in adolescents.

Methods: Adolescents coming to adolescent and sports medicine outpatient visits filled out a survey package assessing anxiety and depression symptoms as well as PA, musculoskeletal injury status and pain. Age and sex were recorded from the medical charts. Anxiety scores >4 were categorized as elevated and >10 were categorized as clinical. A multinomial regression assessed the relationship between PA and elevated and clinical anxiety while controlling for depression status, injury, pain, sex, age and clinic.

Results: 317 participants completed the study. Female sex, depression status and pain were significantly associated with elevated anxiety. Female sex and depression status were significantly associated with clinical anxiety.

Conclusions: Self-reported PA was not associated with elevated or clinical anxiety levels.

Introduction

Adolescents have higher rates of anxiety than any other age group(365) and one-third of adolescents in the United States meet the criteria for an anxiety diagnosis(347, 348) This may be in part due to changes in the brain during adolescence increasing the sensitivity for developing anxiety.(350) Even those with mild anxiety symptoms reported 25-30% lower physical and emotional functioning than those without,(443) demonstrating the impact of subclinical anxiety. Costs to families with clinically anxious children were almost twenty-one times higher when compared to families from the general population.(43) Anxiety diagnoses in adolescents may be frequently missed or poorly diagnosed as a different problem initially, as in the case with adults.(354)

Additionally, a significant proportion of adolescents demonstrate elevated anxiety symptoms, ranging from 15 to 56%.(331, 356, 357) In addition to diagnosable anxiety conditions, elevated subthreshold mental health symptoms can impart significant deleterious health impacts on adolescents such as higher levels of distress and lower psychosocial functioning.(25) Due to anxiety's deleterious impact on function and large number of adolescents affected, more research is needed to identify factors associated with anxiety in this population.

One such factor is physical activity (PA), which has recently been investigated as an avenue to reduce mental health burden. Adolescents reporting low weekly frequency of PA were at greater odds of anxiety compared to those who reported 5-7 days/week of PA,(34) and those who reported exercising regularly have lower anxiety.(403) Anxiety symptoms demonstrated an inverse relationship with low, moderate and high self-reported PA in adolescents.(404) While evidence for the positive effects of PA on anxiety symptoms and diagnoses are limited in

adolescents, research findings in adults mimic adolescent study results . A number of studies have demonstrated that increasing PA can decrease anxiety symptoms,(33, 405) though not all research has found an inverse relationship between PA and anxiety.(406)

While the results for PA on anxiety are lacking, other factors also influence anxiety symptoms in adolescents such as sex, depression, pain and musculoskeletal injuries. Females suffer more from anxiety than males. (39, 40) and are more likely to suffer from a diagnosable anxiety disorder.(377) Co-occurring depression occurs in 10-15% of adolescents with anxiety(371, 381, 382) and results in greater impairment than either on anxiety or depression on its own.(384-388) Musculoskeletal injuries are common during adolescence(444) and may increase anxiety symptoms.(373) Likewise, pain is a common co-morbidity with negative mood states.(391) Children and adolescents who experience pain were more likely to have increased fears and anxiousness,(399) though others have found no associations between anxiety and pain levels(400). Age may also be factor as the prevalence of anxiety increases as adolescents age.(372) and steady increases in anxiety over adolescence.(371) However, others describe trajectories of overall anxiety symptoms generally decrease over middle adolescence(38, 39, 366) before beginning to rise again in late adolescence.(37, 286, 359, 367-370) The purpose of this study is to investigate the impact of PA on anxiety in adolescents while controlling for factors such as age, sex and depression.

Methods

Adolescents between the ages of 12-18 were recruited from sports medicine and adolescent medicine clinics. Those without a parent or guardian present and those who did not speak English were excluded from participation. Verbal parental consent and participant assent were obtained to fill out a survey package on an i-Pad including Generalized Anxiety Disorder -7

(GAD-7), Patient Health Questionnaire-9 (PHQ-9), Exercise Vital Sign (EVS), as well as pain and injury status. The GAD-7 is a seven-item instrument that assessing the previous two weeks regarding anxiety symptoms. This scale has high sensitivity (70-90%), specificity (82%) and test-retest stability (ICC = 0.83).(330, 445) While originally developed to screen for generalized anxiety disorder, it is also commonly used to screen for anxiety in general;(446) this is acceptable as the core feature of GAD is worry, which transcends multiple anxiety phenotypes.(447) Anxiety symptoms were categorized as none (>4), elevated (5-9) or clinical (>9) based on GAD-7 score. In addition, the sensitivity and specificity of the GAD-7 for detecting moderate anxiety are optimized when scores are >10.(445)

The PHQ-9 is a nine item questionnaire used to assess depression symptoms and has high specificity (88%) and sensitivity (88%) to detect major depressive disorder.(448) In addition, this scale correlates with disability.(449) Depression symptoms were coded as present with a score of >10 on the PHQ-9 as this cutoff has been shown to have the optimal sensitivity and specificity in adolescents.(450) EVS questions assessed physical activity by asking, “Last week, how many days did you participate in moderate to vigorous physical activity? (Caused breathing heavy or sweating)” and “Last week, how many minutes per day did you participate in moderate to vigorous physical activity”. The answers were multiplied to calculate minutes per week of PA. EVS has strong discriminant validity in children and adolescents.(451) In addition, participants reported average pain level on a scale of 1-10 in completing activities of daily living. Age was calculated as the survey completion date minus birthdate and sex were recorded from the medical chart.

Statistical approach

A multinomial logistic regression analyzed the influence of PA on elevated and clinical anxiety levels in adolescents while controlling for sex, age, depression status, injury status, clinic and pain. Based on *a priori* power calculation in G-power (452), at least 250 subjects would be needed to be recruited.

Results

Three hundred twenty-one potential participants were approached about the study and 317 completed the surveys between January 2020 and July 2022 during their clinic visit. Participants had clinic visits from one of two Sports Medicine clinics or one of three adolescent medicine clinics. Demographics are presented in Table 4, Demographic Characteristics.

Comparison of no anxiety to elevated anxiety

For each one-point increase in pain, adolescents were 25% more likely to have elevated anxiety compared to those with no anxiety. Females were over 2.4 times more likely to endorse elevated anxiety than their male counterparts compared to those without anxiety. Those without elevated depression were 85% less likely to report elevated anxiety symptoms compared to those without anxiety (Table 5. Factors Predicting Elevated Anxiety).

Comparison of no anxiety to clinical anxiety

Females were 7.4 times more likely to report clinical anxiety than males compared to those without anxiety. Those without elevated depression symptoms were 98% less likely to report clinical anxiety compared to those without anxiety (Table 6. Factors Predicting Clinical Anxiety).

Discussion*:*

We found that girls were much more likely to endorse elevated and clinically elevated anxiety compared to boys. This is in line with other research demonstrating that girls appear to suffer from greater anxiety than boys and have been shown to have both higher proportions of diagnoses and symptom burdens.(37, 39, 40, 341, 353) There is a large difference between anxiety disorders occur during adolescence, with 38% of females and 26% of males suffering from any diagnosable anxiety disorder.(377) Some have suggested that anxiety in males is more often caused by external factors and female anxiety is more often caused by internal factors.(378) Adolescent females report lower self-esteem, which has a negative correlation with anxiety.(379) Changes in estrogen and progesterone have also been implicated in female anxiety.(380) Recently, the women's preventative services initiative has advised that all female patients 13 and older be screened for anxiety.(453) Our findings support this recommendation due to the detrimental effects of anxiety symptoms in addition to the high success of treatment. (454)

We found that elevated depression symptoms were associated with elevated and clinically elevated anxiety in adolescents. In adolescents with anxiety disorders, 10-15% will also suffer from depression disorders.(371, 381, 382) We found higher rates of co-morbidity with 48% of those with elevated and clinical anxiety levels endorsing elevated depression symptoms. This is in line with research that suggest the prevalence of elevated symptoms is much higher than adolescents with a diagnosed disorder.(352) The comorbidity of anxiety and depression during adolescence is well documented.(388, 455-460) Some have proposed a continuum where chronic anxiety symptoms can lead to depression.(455) In that scenario, it would be plausible

that current depression would not increase the rates of elevated and clinical anxiety, though we did not have a measurement for the length of time elevated symptoms were present.

We found that pain was predictive of elevated but not clinical levels of anxiety symptoms. Pain is frequent in adolescents and while consistent pain is uncommon,(389) frequent pain is associated with females and anxiety.(390) Unexplained somatic symptoms, including pain, are very common in adolescents with anxiety(395) and pain is a common co-morbidity with negative mood states.(391) Children and adolescents who experience pain were more likely to have increased fear and anxiousness.(399) Others have found no associations between anxiety and pain levels in adolescent girls (400). Pain as a predictor of elevated, but not clinical anxiety levels could signal that other factors are more influential on clinical levels of anxiety.

We did not find that the presence of a musculoskeletal injury was predictive of elevated or clinical levels of anxiety symptoms in adolescents. Musculoskeletal injuries can be disruptive for adolescents. Anxiety symptoms are common after injury and affect 22% of those with concussion.(374) Others have demonstrated similar rates of elevated anxiety symptoms following musculoskeletal injuries in adolescents.(375) Our findings conflict with others who have found that acute trauma is associated with higher levels of anxiety in adolescents, though this study also included inpatient and emergency room visits which may represent more severe injuries than typically report to an outpatient clinic(461) Our data suggest that pain level, as opposed to injury status, is related to elevated anxiety in adolescents.

We hypothesized that increased PA decreased the odds of elevated and clinical anxiety in adolescents. However, we did not find that weekly volume of PA was associated with either elevated or clinical levels of anxiety. It has been previously reported that adolescents with low weekly frequency of self-reported PA were at greater odds of anxiety compared to those who

reported 5-7 days/week of PA,(34) and those who reported exercising regularly have lower anxiety.(403) Anxiety symptoms demonstrated an inverse relationship with low, moderate and high self-reported PA in adolescents, though there no differences in symptoms between moderate and high active girls.(404) Others have also found decreased odds of anxiety in low compared to high weekly frequency of PA.(408-410) We did not categorize PA based on weekly frequency, which may explain why our results differed from other studies. Further research examining the dose-response of PA with anxiety is warranted.

There were several limitations for this study. First, we had a large percentage of participants who endorsed an injury, mostly as a result of the large number of participants recruited from the sports medicine clinics. In addition, most of these data were collected during the COVID-19 pandemic, which likely influenced both anxiety and PA levels.

Conclusions

Anxiety symptoms in adolescents likely cause substantial disability as has been shown in adults.(332, 342) Female gender and co-occurring depression symptoms were associated with and increased likelihood of experiencing both elevated and clinical anxiety. Higher levels of self-reported pain also increased the likelihood of reporting elevated anxiety symptoms. Screening for anxiety symptoms, particularly in females, should be implemented in clinical and school settings.

Table 4: Demographic Characteristics

Means of Continuous Variables

	N	Mean	Std. Deviation
PA (minutes/week)	317	324.29	281.58
Age (years)	317	15.79	1.64
Pain (0-10)	317	3.26	2.79

Frequencies of Categorical Variables

		N	Percenta
Anxiety Symptoms	No anxiety	201	63.4%
	Elevated anxiety	76	24.0%
	Clinical anxiety	40	12.6%
Depression	Normal	258	81.4%
	Elevated	59	18.6%
Gender	Female	218	68.8%
	Male	99	31.2%
Injury Status	No	93	29.3%
	Yes	224	70.7%
Clinic	Adolescent	104	32.8%
	Sports Medicine	213	67.2%

Table 5. Factors Predicting Elevated Anxiety

	Odds Ratio	p value	95% CI
Age (years)	1.17	0.12	0.96-1.41
PA (Minutes/week)	1.00	0.94	0.99-1.00
Pain with ADLs	1.25	**<0.001**	1.11-1.42
Female Gender	2.55	**<0.001**	1.21-5.37
Elevated Depression	0.15	**<0.001**	0.06-0.37
Injury	1.71	0.65	0.17-16.91
Clinic	1.54	0.72	0.15-15.91

Table 6. Factors Predicting Clinical Anxiety

	Odds Ratio	p value	95% CI
Age (years)	1.22	0.16	0.92-1.62
PA (Minutes/week)	0.99	0.14	0.99-1.00
Pain with ADLs	1.10	0.30	0.92-1.31
Female Gender	7.42	**0.01**	1.73-31.75
Elevated Depression	0.02	<**0.001**	0.01-0.05
Injury	0.56	0.62	0.05-5.84
Clinic	0.96	0.96	0.08-10.57

Chapter 4: Relationship of Anxiety with Objectively Measured Physical Activity in Young Adolescents

Abstract:

Background: Only about 20% of adolescents meet the current physical activity (PA) guidelines. The impact of psychological factors, such as anxiety, have not been well studied. The purpose of this study was to assess the relationship between anxiety symptoms and diagnoses with objectively measured PA.

Methods: Data from year two of the Adolescent Brain Cognition Development Study was utilized for this study. Weekly PA was measured by Fitbits as weekly volume of moderate to vigorous activity. Neighborhood safety was reported by parents. Current and past anxiety symptoms and diagnoses were assessed via the Kiddie Schedule for Affective Disorders-5 interview. Amount of friend encouragement and how much pain interfered with function were self-reported. BMI category, sports participation, age and sex were recorded. A multiple linear regression analyzed the impact of individual and environmental factors on weekly PA.

Results: A total of 1313 participants were included in the analysis. BMI, female sex, friend encouragement, and anxiety were significantly associated with PA.

Conclusions: Adolescents with anxiety accrued significantly less PA than those without. Clinicians should consider counseling those with anxiety on the benefits of PA on mental health.

Introduction

All school-aged children should accrue 60 minutes of daily moderate to vigorous physical activity (MVPA), which equates to 420 minutes on a weekly basis.(462) The benefits of physical activity in children cross all domains of health. Physically, exercise improves the strength of muscles and bones, increases coordination and assists with weight control.(462) Socially, physical activity allows for social interaction and a feeling of belonging.(463) Mentally, physical activity improves sleep,(464) reduces depression and anxiety(404) and is also associated with greater cognitive(465) and academic performance.(466) Perhaps the greatest impact of proper physical activity in children is on their future health. Children who are physically active are more likely to be active adults(2), which reduces all-cause mortality, in part by protecting against cardiovascular disease, type II diabetes, as well as certain cancers.(467)

Alarmingly, physical activity starts to decrease as early as age 5 and continues to decline through adolescence, (136) where only 20% of accrue the weekly PA recommendation.(138, 139) Physical activity levels that are inconsistent with the current guidelines cause a cascade of events that can lead to a decrease in functional motor skill development, motor skill competence, and motor skill confidence. This leads to an increase in sedentary behaviors and development of disease risk factors.(468)

Health behaviors, such as PA, are complex and influenced by a number of factors. Using a theoretical framework to investigate correlates of PA is recommended to improve the development of effective interventions.(55) Social Cognitive Theory (SCT) has been studied extensively within PA research(10-13, 17, 68-70) and posits a triadic reciprocalism between the individual, environment and behavior. Environmental factors that influence adolescent PA include safety features, such as sidewalks and appropriate lighting,(71, 72) as well as built

environment, such as availability of spaces for PA, such as parks, playgrounds, and fields.(73-75) In addition, the social environment can impact adolescent PA behavior through relationships with parents, teachers and peers.(76-78) There are also a wide range of factors that are relevant to PA levels during adolescence, including sex, Body Mass Index (BMI), sports participation, pain level, friend encouragement and neighborhood safety. Psychologic factors, such as stress and anxiety, are commonly integrated into PA interventions(469), though their contribution to PA in adolescents is unclear.

Previous work has demonstrated that constructs within SCT have accounted for between 0.29 - 09.52 of the variance of adolescent PA.(10-14) Although psychologic factors such as anxiety increase substantially during adolescence, their effects on PA have not been well studied in a SCT framework. The purpose of this study was to assess factors related to objectively measured PA in adolescents with a focus on the contributions of anxiety symptoms and diagnoses to PA levels.

Methods

The Adolescent Brain and Cognition Development (ABCD) study follows children ages nine to ten through adolescence and tracks a plethora of biologic and behavioral data. Data from the second year of the ABCD study were utilized for this study. Participants were approximately 12 years old during this wave.

Physical activity was recorded using Fitbit devices for participants that had at least 10 hours of wear time during waking hours for seven consecutive days. PA included both active and very active minutes as recorded by the Fitbit to calculate moderate to vigorous physical activity for the week.

Neighborhood safety and friend encouragement were the environmental factors included in this analysis. A neighborhood safety scale comprised of three questions was administered to the parents and the total score was included with a higher score indicating a safer environment. Friend encouragement was coded based on amount of encouragement to participate in sports and activities on a scale of 0-10, with a higher score equaling a higher level of support.

Individual factors were anxiety, sports participation, sex, BMI and pain level. The Kiddie Schedule for Affective Disorders-5 is a semi-structured interview designed to be compatible with the Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition, (DSM-5). The KSAD-5 was administered to participants to determine present or previous anxiety symptoms or diagnosis. Past and current anxiety symptoms included excessive worries more days than not, social situations invariably provoke anxiety, social situations are endured with distress, social fear is excessive given the sociocultural context, social impairment in functioning due to social anxiety, clinically significant distress due to social anxiety, excessive worries across breadth of domains, symptom duration of at least 6 months, worry associated with defined symptoms, difficulty controlling worries, impairment in functioning due to worries, clinically significant distress due to worries and worries lasting at least 6 months. Anxiety diagnoses (current and past) included social anxiety disorder, generalized anxiety disorder, other social anxiety disorder not meeting criteria for full diagnosis and other generalized anxiety disorder not meeting criteria for full diagnosis. Those with any current or past symptoms or diagnoses for anxiety were coded as positive for anxiety. Sports participation assessed lifetime involvement in organized activities in ballet, dance, softball, baseball, climbing, field hockey, football, gymnastics, ice hockey, horseback riding, polo, ice or inline skating, martial arts, lacrosse, rugby, skateboarding, skiing, snowboarding, soccer, surfing, swimming, water polo, tennis,

track, running, cross-country, wrestling, mixed-martial arts and volleyball. BMI percentile was calculated from the age in months at assessment with height and weight utilizing the formula from the World Health Organization. BMI was categorized as normal (<85%), overweight (85-94.99%) or obese (>95%). Sex was reported by the parents as sex at birth and coded as male, female, other or not recorded. Pain was coded as the amount to which pain limited activity on a scale of 0 to 10 with a higher score indicating increased difficulty. Those who did not report any pain in the last month were coded as a 0.

Statistical analysis

PA is described by mean and standard deviation. Multiple linear regression analyzed the impact of sex, sports participation, anxiety, pain, neighborhood safety, friend encouragement and BMI on PA. The residuals in a linear model were not normally distributed; therefore, we performed a square root transformation of the dependent variable to ensure the assumption of normality for linear regression was met. After determining which variables were significant ($p< 0.05$) in the linear regression model, an Area Under the Curve analysis was completed with PA being dichotomized as meeting (≥420 minutes) or not meeting (<420 minutes) weekly recommendations.

Results

A total of 1313 participants had complete data. Demographics are shown in Table 7, Participant Demographics. Estimated mean group differences are displayed in Table 8, Estimated Marginal Means Minutes/Week PA. Overall, more individual factors were related to PA than environmental factors. Sex, BMI, encouragement and anxiety were significantly related to PA. Girls accrued significantly less PA than boys ($p<0.001$). Those with anxiety participated in significantly less PA than those without ($p=0.009$). Normal weight adolescents participated in

significantly less PA than their overweight or obese counterparts ($p<0.001$ and $p<0.001$, respectively). Those with more friend encouragement participated in significantly more PA ($p=0.003$). Neighborhood safety, pain, and sports participation were not associated with PA ($p=0.163$, $p=0.066$, and $p=0.961$), respectively. We included sex, BMI, encouragement and anxiety into the AUC analysis. Overall, 81.3% did not meet the PA guidelines. The model was good at determining meeting or not meeting PA with an AUC of 0.78 (Figure 9. ROC curve of BMI, Sex, Encouragement and Anxiety for Predicting Meeting PA).(470)

Discussion

We found that sex, BMI, anxiety and encouragement were significantly associated with adolescent PA. On average, girls participated in 177 minutes less PA per week than boys. This is a larger difference than has been previously reported.(235, 238, 239) Others have found girls are about 20% less active than boys(238, 239) and accrue approximately 126 minutes fewer than boys per week.(235) Less than 2% of secondary school aged girls met daily PA recommendations, as measured by accelerometers.(240) There are a variety of proposed mechanisms for explaining lower MVPA in girls including less participation in organized sports(231), less perceived parental and peer support(232) and decreased motor competence(233).

Those with anxiety symptoms or diagnoses participated in approximately 37 less minutes of PA per week. Our findings are in line with other research, which demonstrate an inverse relationship between PA and anxiety.(34, 403, 404, 407-410, 471, 472). However, one study found no association between PA and anxiety.(473) We confirmed the findings of the majority of the research with objective measurements of PA. Some have shown that girls and boys may

have different relationships between PA and anxiety. (404, 474) Generally, proposed mechanisms for PA to influence anxiety fall into biologic and psychologic groupings, though the exact pathways are unknown.(475)

We found that a normal weight BMI was associated with a 51 and 87 minute/week decrease compared to those that were overweight or obese, respectively. This is contrary to other work that suggests being overweight or obese generally is associated with less PA, though some have reported differences in sex. (164, 261-267) Our findings may be a result of the extremely high levels of organized sports participation by our participants. Although not all time in sports practices or games is PA(284), those who are overweight or obese have a higher metabolic cost of movement and may actually be working harder during activity than their normal weight peers.(476, 477) The relationship between BMI and PA should be further studied as this is a clinical measure that is often captured during medical visits

Encouragement from peers was significantly associated with higher PA levels, which is in line with previous research.(68, 310, 312-314, 317) Friend support was reported a facilitator of PA and lack of support from friends detracted from their PA.(68) Adolescent boys and girls with supportive friend encouragement, modeling and co-participation was associated with objectively measured PA.(306) Peer support was significantly related to objectively measured PA(232) and was a stronger direct link to PA in 10-17 year-olds than parent support, SE, enjoyment and barriers.(307) In young adolescents, friend groups demonstrated similar objective PA measurements(312, 313) and peer support was a significant predictor of PA in twelve year-olds.(314) In addition, peer support for PA significantly strengthened the association between built environment and objectively measured PA.(310) Overall, it appears that friend support significantly influences adolescent PA.

We found no significant association between parent-reported neighborhood safety and adolescent PA. Others have shown that the interaction between parent and child rated neighborhood safety was significantly associated with objectively measured PA.(323) Carver et al noted that parental perception of neighborhood safety was associated with objectively measured PA during non-school hours of boys, but not girls.(327) Parents and adolescents use somewhat different features to determine neighborhood safety;(478) it is possible that as adolescents become more autonomous, parental perceptions about safety are less likely to influence their behavior.

We found no significant association between pain and PA. There is a paucity of work investigating this relationship, though previous research demonstrates adolescents with chronic pain have less objectively measured PA than in matched controls.(297, 298) In adolescents with pain, those with the lower levels of objectively measured and self-reported PA had the highest pain levels.(293, 299). Our studied utilized how much pain limited function, which may have a different relationship with PA than a pain scale.

We found that organized sports participation was not associated with PA. Multiple studies have established that sports participation equates to a substantial amount of PA.(283).(284, 285) Overall, less than five percent of the sample did not participate in organized sports. In addition, we were not able to ascertain if participants were actively participating in sports at the time of PA data collection, which may explain our findings. Others have shown that a majority of middle and high school interscholastic athletes do not meet current PA guidelines, which may be in part due to the number of athletes who are out of season.(18)

This study had several strengths. The large sample size and objective measures of PA improves the external validity of the results. However, the participants in the study were all

roughly the same age and the results may not be generalizable to older adolescents. In addition, the vast majority were participating in organized sports, which may have biased our results toward those who are generally more physically active.

Conclusions

We found that sex, BMI, friend encouragement and anxiety were significantly related to objectively measured PA in early adolescents. The relationship between PA and anxiety has historically been investigated with self-reported PA, which can be biased. Because of the objective PA measurement in this study, clinicians should be encouraged to assess and address anxiety when promoting PA. Friend encouragement should be promoted to improve early adolescent PA participation. Even after controlling for a variety of factors, girls participated in less than half the PA of boys. Future research should try to identify those at risk for insufficient PA as this could lead to poor health outcomes later in life.

Table 7. Participant Demographics

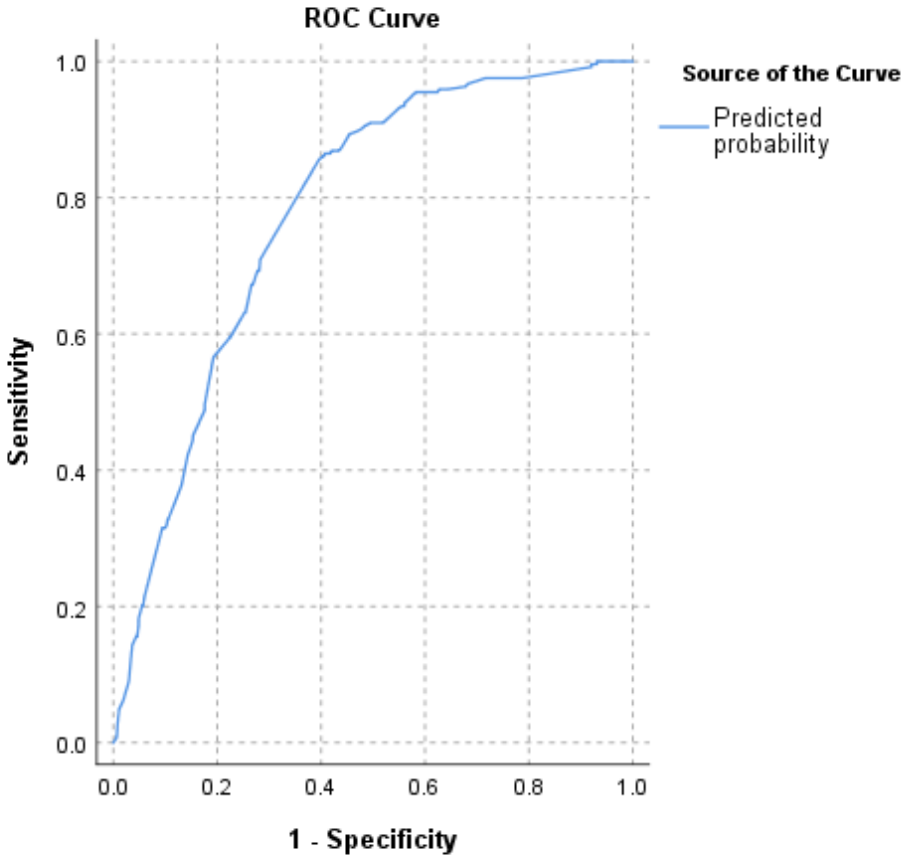
Female		47.90%
BMI		
Normal	63.70%	
Overweight	12.60%	
Obese	23.60%	
Participate in Sports		95.70%
Anxiety		13.60%
Age		11.97±0.65
Pain		1.86±2.28
Encouragement		3.78±3.59
Neighborhood Safety		11.80±2.47

Table 8. Estimated Marginal Means Minutes/Week PA*

Organized Sports		
	Yes	211.99
	No	211.70
Girls		132.25
Boys		308.70
BMI		
	Normal	166.92
	Overweight	223.50
	Obese	247.75
Anxiety		
	Yes	230.13
	No	193.49

* Covariates appearing in the model are evaluated at the following values: Neighborhood Safety = 11.80, friend encouragement = 3.78, pain = 1.86.

Figure 9. ROC curve of BMI, Sex, Encouragement and Anxiety for Predicting Meeting PA Recommendation



Chapter 5. Proximal Changes in Adolescent Physical Activity and Anxiety: An Exploratory Analysis Abstract

Background: Adolescence is a time of rapid growth. Both low physical activity (PA) levels and elevated anxiety symptoms are common during this time. Little is known about the short term-variability of PA and anxiety. The purpose of this study was to explore proximal changes in self-reported PA and anxiety symptoms in adolescents.

Methods: Students in a ninth-grade health class filled out weekly Exercise Vital Sign (EVS) and bi-weekly Generalized Anxiety Disorder-7 questionnaires over a ten week period.

Results: The majority of participants (80%) reported insufficient PA and elevated anxiety symptoms at least once during the study. There was substantial within-person and between-person variability in PA and anxiety symptoms.

Conclusions: Serial screening may provide a more accurate picture of adolescent PA and anxiety symptoms.

Introduction

From a public health standpoint, it is common to try to intervene early to promote better health outcomes. This strategy assumes that if an elevated risk is identified that it is representative of the risk outside of the assessment. It also assumes that individuals will generally follow the group changes. PA and anxiety are both factors which can significantly influence the health of adolescents. Regular and sufficient levels of PA are critical to healthy development of adolescents, but adolescents meet PA guidelines less than children or adults. (5-7) Anxiety symptoms even in the absence of a diagnosis can cause substantial morbidity (angst 2006). While many studies have assessed PA and anxiety annually, it is likely that they both may change substantially over shorter periods of time. Significant PA changes can be a result of weather(35) and because adolescence is a time of high emotionality,(36) anxiety levels may also change frequently. These more short-term changes may not be strictly linear between more distant time points, such as in the case of annual assessments.(113)

Variation between and within persons is natural. The measured value of many physiologic observations is the true value plus error.(114) The error can stem from measurement error, biologic error or biologic variation.(115) Measurement error is a threat to internal validity because of lack of precision and biologic error results from environmental factors.(116) Biologic variation, on the other hand, represents a true movement of a value(115) and can be measured as between-person and within-person. Between person variation is frequently studied. Interest in understanding within person variation has been growing; for example, manuscripts employing growth trajectory modeling, which clusters groups who change similarly over time,

have been increasing over the last two decades.(117) Within-person variability is important in understanding health behaviors.(118) For example, within-person variability has been shown to account for almost all of the between person variability.(116, 119) Within-person variability of a construct over time can naturally vary a great deal (120) and can be greater is there are if there are long periods of time between measurements(114) As research often compares between-person responses, it is crucial to understand the within-person differences to avoid false conclusions.

A clearer understanding of how PA and anxiety changes over time in adolescents has several important clinical implications. Within-person and between-person variation can offer valuable information about how much these normally fluctuate in adolescents. If there is a high amount of change in PA and anxiety symptoms at proximal timepoints in adolescents, it may limit the interpretations of studies examining them on an annual basis. This information can be used to inform best practice guidelines for frequency of screenings for PA and anxiety in adolescents.

Methods

Participants enrolled in a 9th grade health class were recruited during the spring of 2021 and fall of 2022. Parental consent and participant assent were obtained verbally after IRB approval. Participants filled out Exercise Vital Sign (EVS) questions weekly and Generalized Anxiety Disorder-7 (GAD-7) bi-weekly over the course of 10 weeks. The GAD-7 is a seven-item instrument that assessing the previous two weeks regarding anxiety symptoms. In adolescents, this scale has high sensitivity (70-90%), specificity (82%) and test-retest stability (ICC = 0.83). Analyses were explored using total data as well as those with at least three data points for PA

and at least three data points for anxiety. Meeting PA guidelines was defined as >419 minutes/week on EVS and elevated anxiety symptoms were defined as >4 on GAD-7. Within person variation was calculated as the standard deviation for the person based on their EVS and GAD-7 scores through the study. Between person variation was calculated as the standard deviations at each point in time.

Results

Twenty-nine participants were recruited, 10 in the fall of 2020 and 19 in the spring of 2021. Thirteen participants were female. Overall, 25 participants had at least three time points for EVS and 14 had at least three time points for GAD-7.

Physical Activity

Except for timepoint six, average minutes of weekly PA remained below the guidelines (Figure 10. Average PA over Three Timepoints). Eighty percent did not meet the PA guidelines at least once over the study period (Figure 11. Percentage of Those Meeting and Not Meeting PA Guidelines by Timepoint) Overall, 36-48% of adolescents met PA guidelines over the nine timepoints (Figure 12. Percentage of Adolescents who did not Meet PA Recommendation at Least Once). Eight participants had variability above 150 over the study period (Figure 13. Within-Person Standard Deviation for PA over Time by Participant). On seven of the nine timepoints, between-person variation exceeded 250 (Figure 14. Between-Person Standard Deviation for PA over Time). Over the course of three timepoints, 36% tended to have stable, low PA levels (Figure 15. Individual PA over Three Timepoints – Consistently Low). An additional 20% had relatively sufficient, stable PA over three time points (Figure 16, Individual PA over Three Timepoints – Consistently High). Over the course of three timepoints, 44%

reported PA levels with substantial changes (Figure 17. Individual PA over Three Timepoints – Substantial Change). When examining all data, similar trends were observed. Over nine timepoints, 40% reported stable, insufficient PA levels (Figure 36. Individual PA over Nine Timepoints – Consistently Low). Over the course of nine timepoints, 32% reported generally stable, sufficient PA (Figure 37. Individual PA over Nine Timepoints – Consistently High). Over the nine timepoints, 28% reported substantial PA changes (Figure 38. Individual PA over Nine Timepoints – Substantial Change). Three participants had over 150% decrease and six participants had over a 50% increase in PA from timepoint one to timepoint three (Figure 18. Percent Change in PA between First and Third Timepoint). When assessing change between the first and last timepoints, the majority of participants reported an increase, but three subjects reported at least a one hundred percent decrease (Figure 39. Percent Change in PA between First and Last Timepoint). There were significant person fluctuations between meeting and not meeting PA guidelines through the study (Figure 19. Individual Trajectories of Meeting and Not Meeting PA Through Three Timepoints and Figure 40. Individual Trajectories of Meeting and Not Meeting PA Through Nine Timepoints). More males tended to consistently meet the PA guidelines than females when looking at both three and nine timepoints (Figure 20. Male Trajectories of Meeting PA Guidelines over Three Timepoints, Figure 21. Female Trajectories of Meeting PA Guidelines over Three Timepoints, Figure 41. Male Trajectories of Meeting PA Guidelines over Nine Timepoints, Figure 42. Female Trajectories of Meeting PA Guidelines over Nine Timepoints)

Anxiety

Average anxiety is shown in Figure 21, Average Anxiety over Three Timepoints. The number of participants dropped from 14 to 10 and the average anxiety score increased by

timepoint five (Figure 21b. Average Anxiety over Three Timepoints). Nearly 80% of adolescents reported elevated anxiety symptoms at least once over five timepoints. (Figure 22. Percent of Adolescents with Elevated Anxiety by Timepoint). The standard deviation demonstrates considerable variability within the anxiety scores (Figure 24. Percent with Elevated Anxiety at Least Once). Except for participant 13, the within-person standard deviation remained under 2.5 across study timepoints (Figure 25. Within-Person Standard Deviation of Anxiety). Between-person variation was similar to the average values, suggesting high levels of variation (Figure 26. Between-Person Standard Deviation of Anxiety by Timepoint). A majority of participants (57%) had low anxiety across three points in time (Figure 27. Individual Anxiety over Three Timepoints – Consistently Low). Three participants (21%) had clinically significant anxiety increases over three points in time (Figure 28. Individual Anxiety over Three Timepoints – Consistently High). Three participants (21%) had elevated anxiety across three timepoints (Figure 29. Individual Anxiety over Three Timepoints – Substantial Change). When examining data from all timepoints, slightly different trends are observed. Three participants (21%) had low anxiety across the study (Figure 45. Individual Anxiety across Five Timepoints – Consistently Low). Three participants (21%) had elevated anxiety across the study (Figure 46. Individual Anxiety across Five Timepoints – Consistently High). Over half of participants (57%) reported clinically significant increases in anxiety over five timepoints. (Figure 47. Individual Anxiety across Five Timepoints – Substantial Change). All but one participant had increased anxiety at the third timepoint (Figure 30. Change in Anxiety Between First and Third Timepoint). No participants reported a decrease in anxiety over the study (Figure 48. Percent Change in Anxiety Between First and Last Timepoint). The majority of people remained below the threshold for elevated anxiety across three timepoints (Figure 31. Individual Trajectory of Anxiety across

Three Timepoints). Over five timepoints, the majority of participants began without elevated anxiety and the majority also ended with elevated anxiety (Figure 49. Individual Trajectory of Anxiety across Five Timepoints). Females tended to have more changes than males over three and five timepoints (Figures 32 Male Trajectories of Anxiety across Three Timepoints, Figure 50. Male Trajectories of Anxiety across Five Timepoints, 33. Female Trajectories of Anxiety across Three Timepoints, Figure. 51. Female Trajectories of Anxiety across Five Timepoints).

Discussion

We found moderate to substantial variation in PA and anxiety over a nine-week period in adolescents. For both PA and anxiety, within-person variation was less than between person variation. This suggests that individual levels of PA and anxiety symptoms are more stable than group means over time. However, the within- and between-person variability of both PA and anxiety are substantial suggesting that both groups and individuals experience clinically significant changes over a short period of time. Some have suggested that large changes within proximal timepoints may be indicative of environmental change. The participants in this study were enrolled in the same freshman health class. These data were also collected during the Covid-19 pandemic which certainly is an environmental factor that plausibly influenced both PA and anxiety symptoms.

Physical activity

PA is often assessed annually to evaluate the change in weekly volume of PA over time, but we found that PA may change significantly over shorter periods of time. Unfortunately, there is substantially less work assessing PA in adolescents at more proximal time points.(160, 161) Measuring PA at four time points over 1.75 years, Raudsepp et al found a curvilinear decrease in

PA, but also moderately stable measures of self-reported PA for girls.(162) Assessing objectively measured PA of adolescent soccer players revealed no differences between three separate weeks of PA over the course of twelve months.(163) In early adolescents, daily PA within a week is highly variable and only 5% had stable objectively measured PA over 7 days.(164) These results may partially be a result of school schedules as PA during school accounts for roughly one-third of total PA.(165) Moreover, decreases of adolescent PA on the weekend days may be a result of not being in school.(157) Younger children seem to compensate between days and have less PA on days following greater activity.(166, 167) In one of the few studies assessing individuals at multiple time points through a one year period, Martins et al found high correlation of objectively measured PA in young adults when assessing one week for each month.(168) Some of the differences between studies assessing PA annually and more frequently may be due in part to study design; studies assessing PA over shorter periods of time will likely have higher correlation coefficients.(157) The short-term variability of PA behavior during adolescence is important because the benefits of PA are greatest with consistent participation at recommended levels. The majority of the participants in our study did not meet the PA guidelines at least once. Future research should investigate the short-term variability in PA in a larger group of participants. In addition, differences between those who always meet, sometimes met and never met PA guidelines should be studied as interventions for each group may need to be tailored.

Anxiety

Research investigating anxiety in adolescents over time often employs measurements on an annual basis. Some have demonstrated moderate levels of the stability of anxiety symptoms through childhood and adolescence(358) and high stability of anxiety symptoms in adolescents

through midlife.(359) Within adolescence, some have shown found anxiety symptoms to be highly stable during adolescence,(360) though others have described more moderate stability.(361) Though group stability of anxiety has been investigated, individual trajectories may significantly vary in adolescents. For example, in adolescents with high anxiety scores, half continued to report elevated scores one year later and the other half returned to normal levels.(353) Changes in anxiety symptoms may be in part a result of environmental factors that can change over time.(362) This is true in adults, where anxiety can change rapidly in highly stressful or treatment conditions, though minimal is known about the persistence of such changes over time.(363) Understanding of changes in anxiety at shorter time intervals can help inform screening recommendations as well as evaluate the effectiveness of interventions. Ecologic momentary assessments can be valuable because appreciating the summation of several measurements may give a better picture about an individual's state.(112) We completed multiple assessments over a short period of time, albeit not daily, and found that the majority of participants reported elevated anxiety at least once during the study period. Because elevated symptoms can cause clinical important disability, regular screening at intervals less than one year are recommended. Future work should consider factors related to those who consistently have elevated symptoms, consistently do not have elevated symptoms and those who fluctuate.

Conclusions

Overall, we found the majority of adolescents were not meeting PA guidelines and reported elevated anxiety symptoms. We found clinically relevant changes in the between person and within person variability of PA and anxiety symptoms in adolescents. These results suggest that more frequent screenings would be valuable to have a clearer understanding of the

consistency of PA and anxiety symptoms in adolescents. Understanding natural variation should be utilized in planning and interpreting results from intervention studies.

Figure 10. Average PA over Three Timepoints

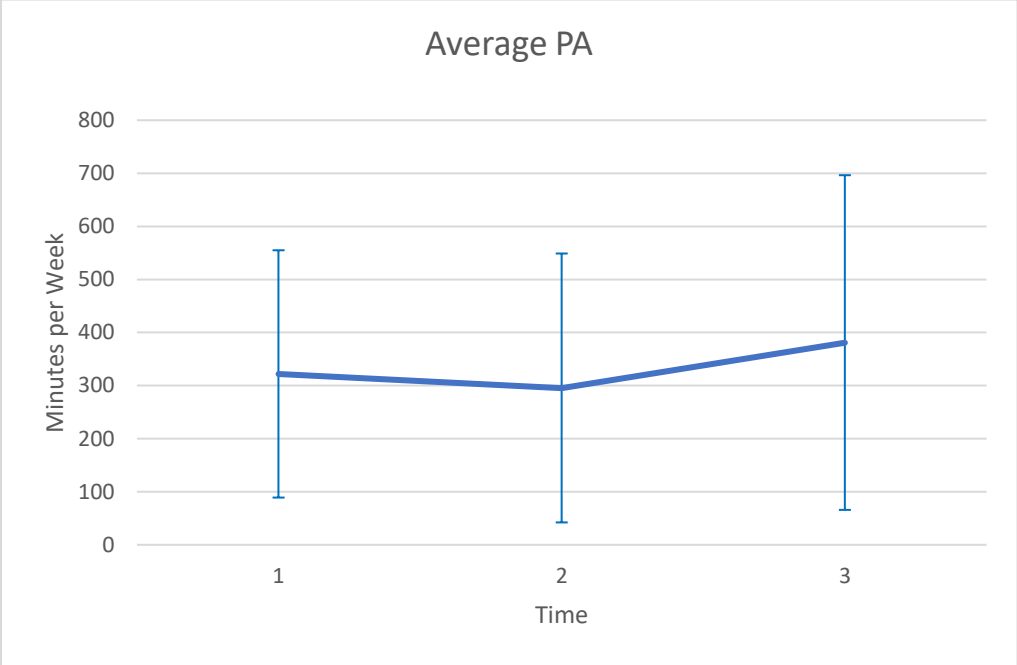


Figure 11. Percentage of Those Meeting and Not Meeting PA Guidelines by Timepoint

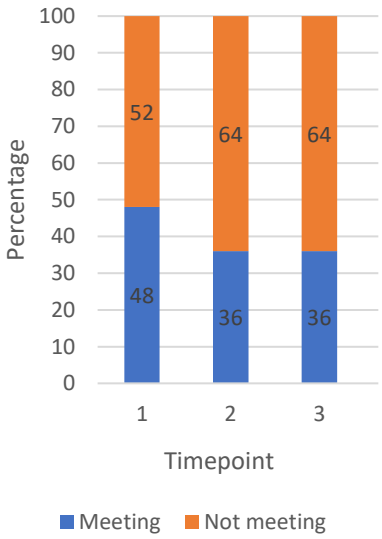


Figure 12. Percentage of Adolescents Who Did Not Meet PA Guidelines at least Once

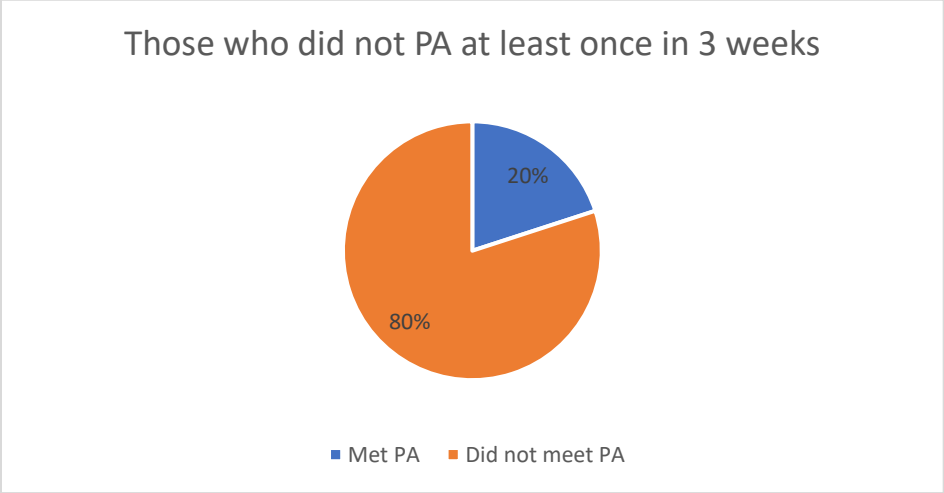


Figure 13. Within Person SD for PA by Participant

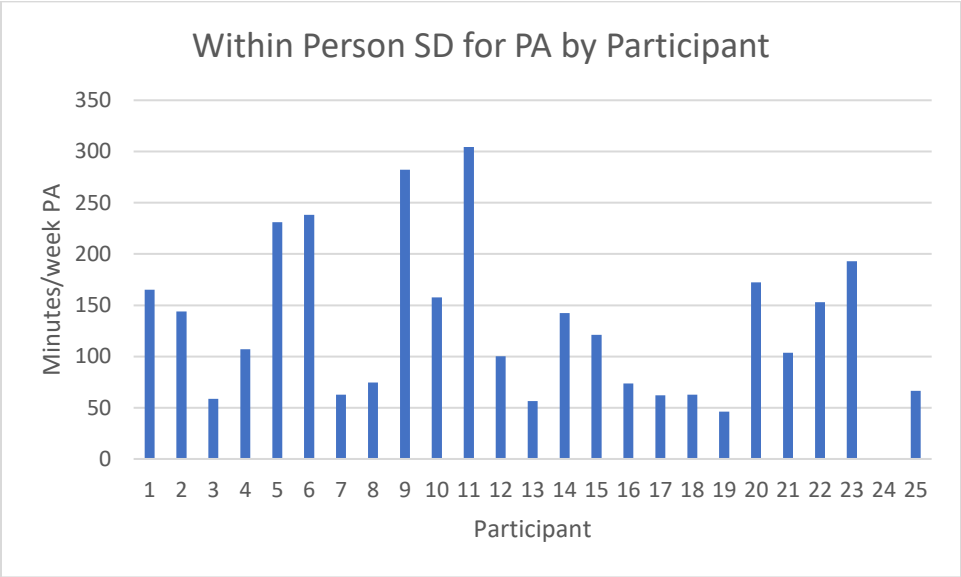


Figure 14. Between-Person Standard Deviation for PA over Time

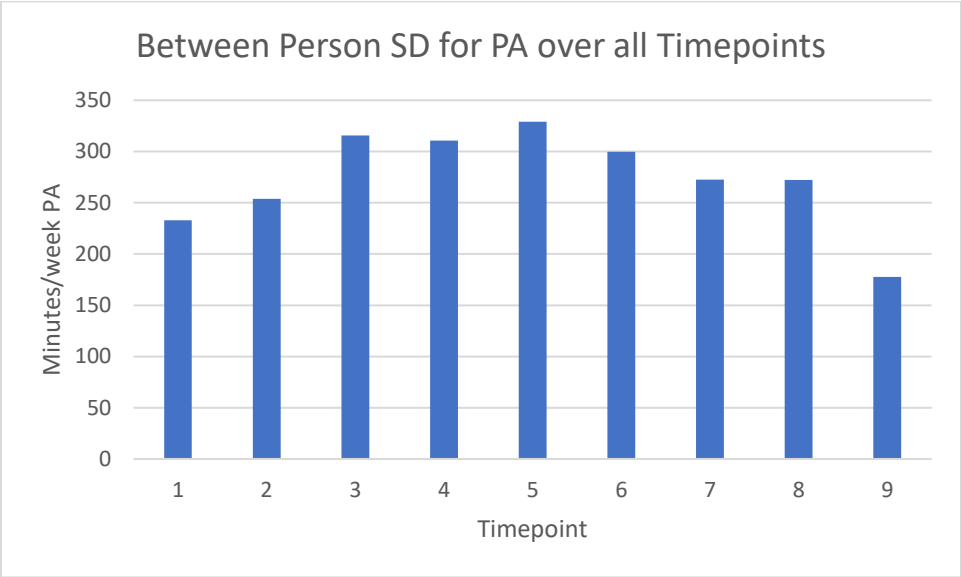


Figure 15. Individual PA over Three Timepoints – Consistently Low

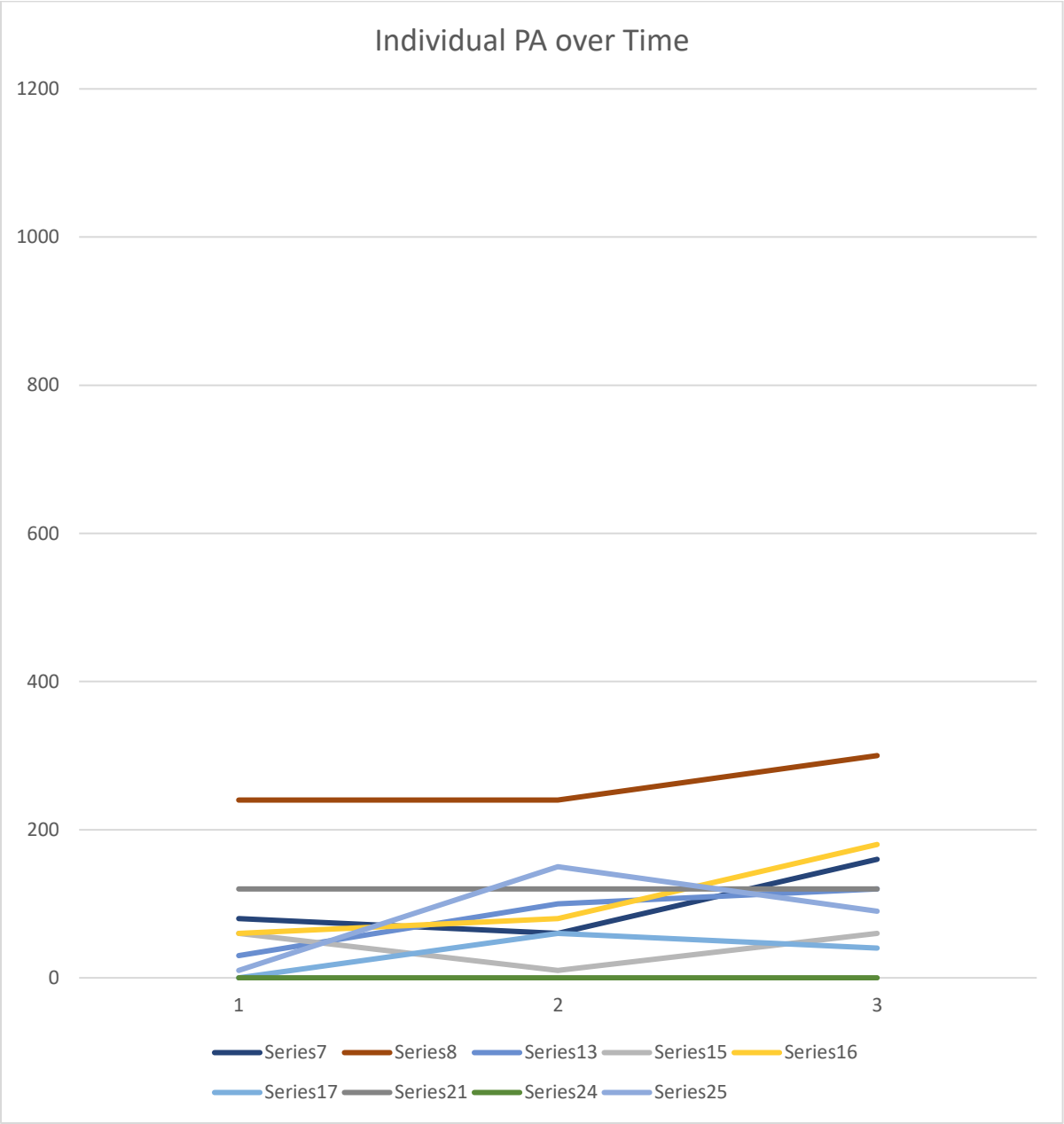


Figure 16. Individual PA over Three Timepoints – Consistently High

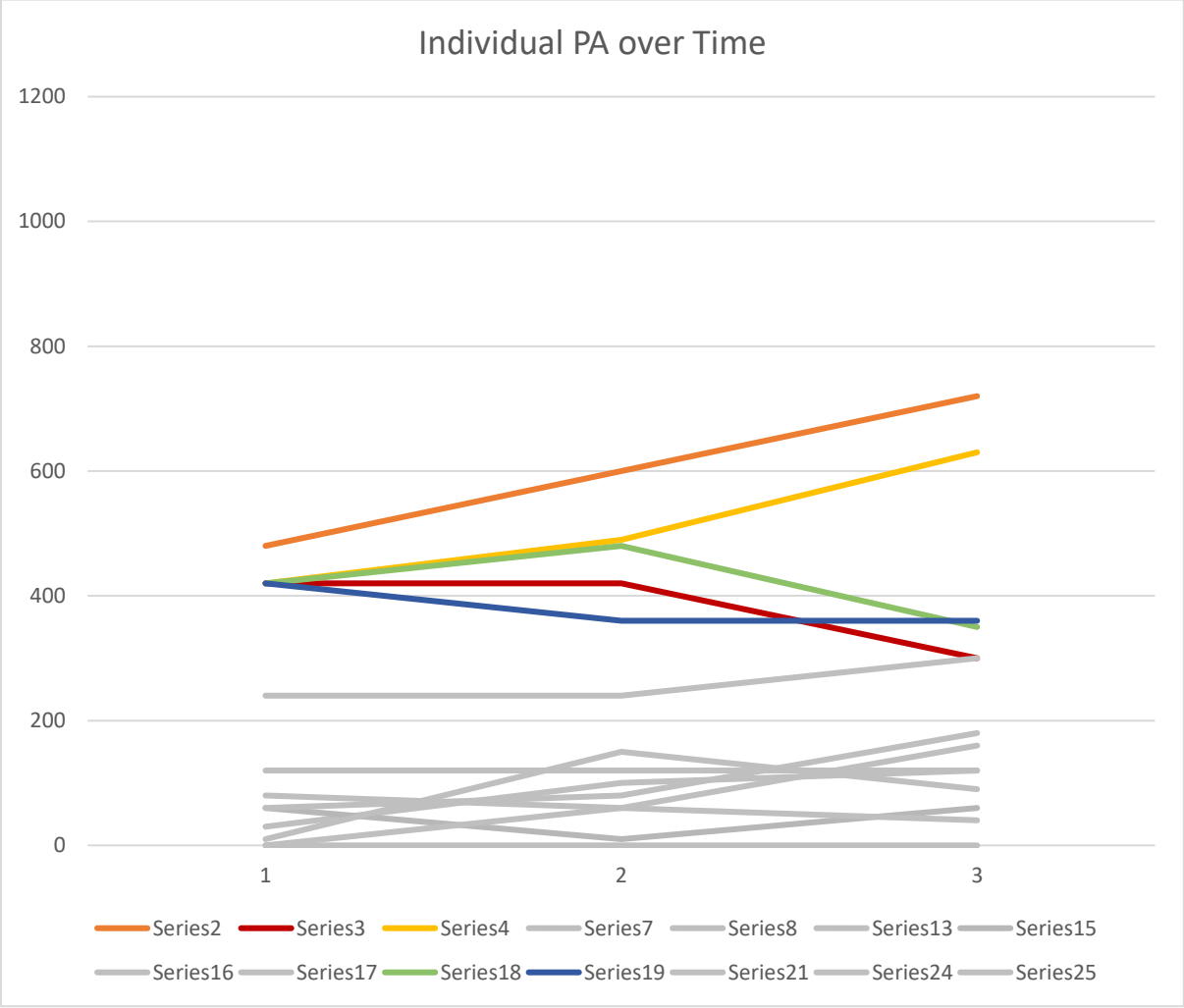


Figure 17. Individual PA over Three Timepoints – Substantial Change

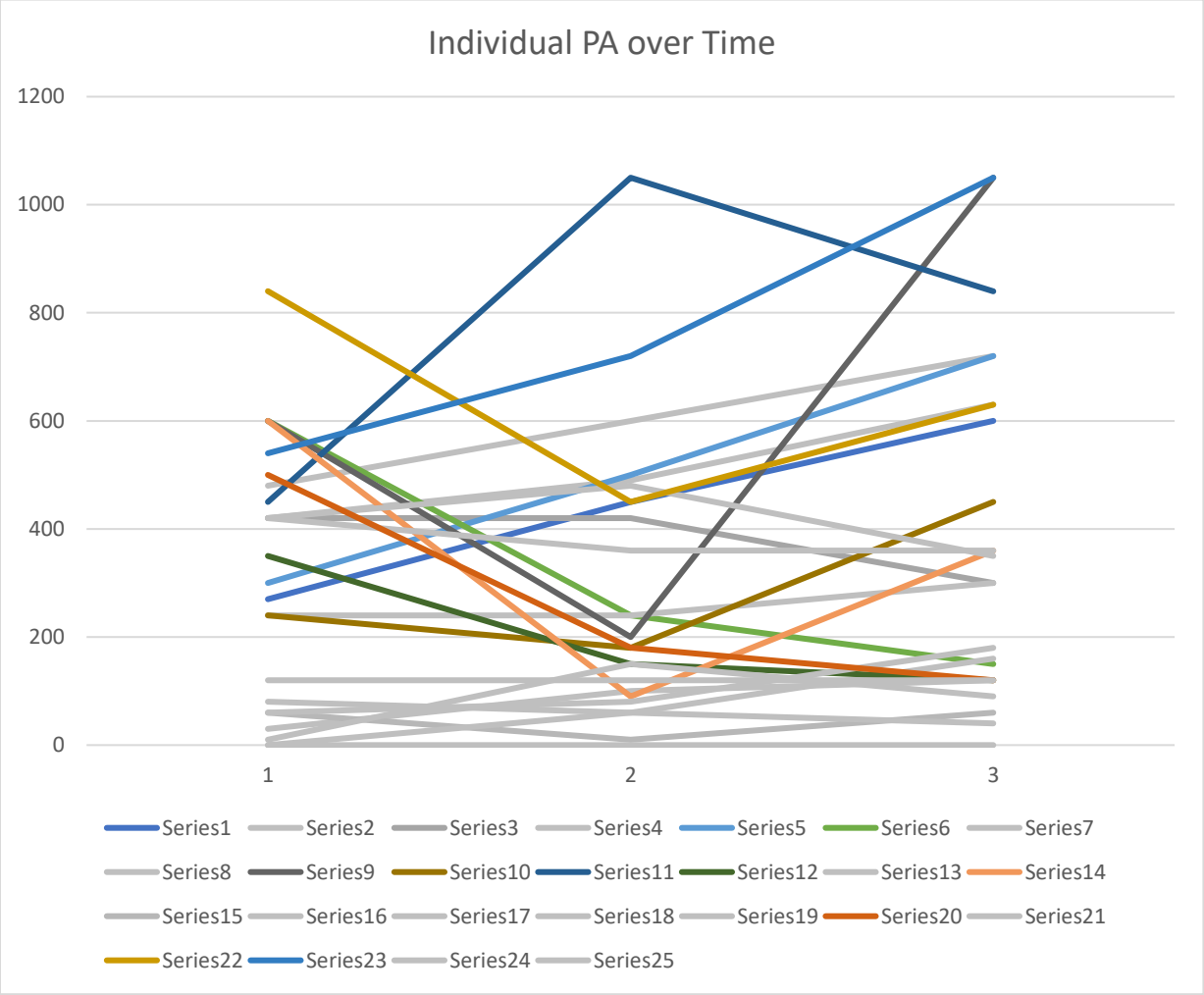


Figure 18. Percent Change in PA Between First and Third Timepoint

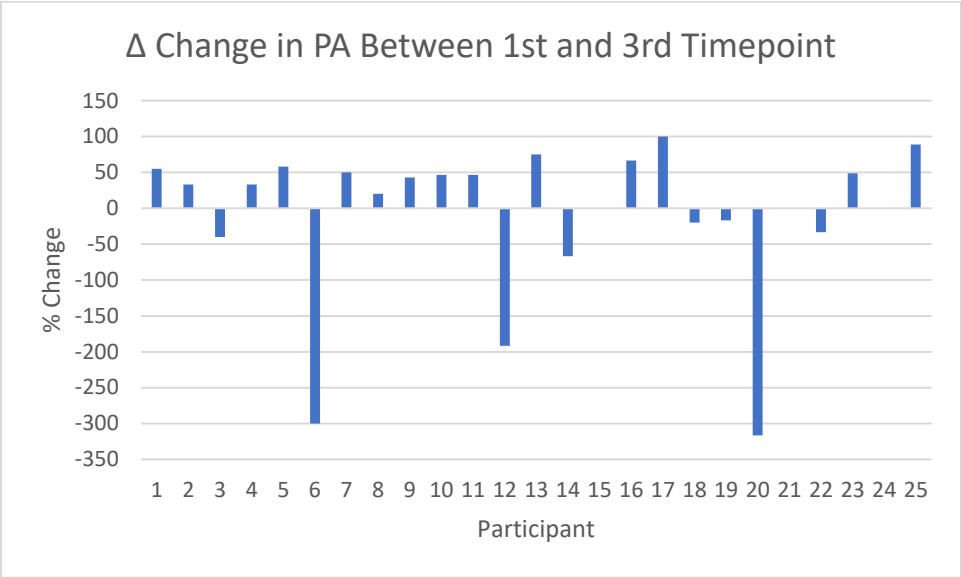


Figure 19. Individual Trajectories of Meeting PA Guidelines over Three Timepoints

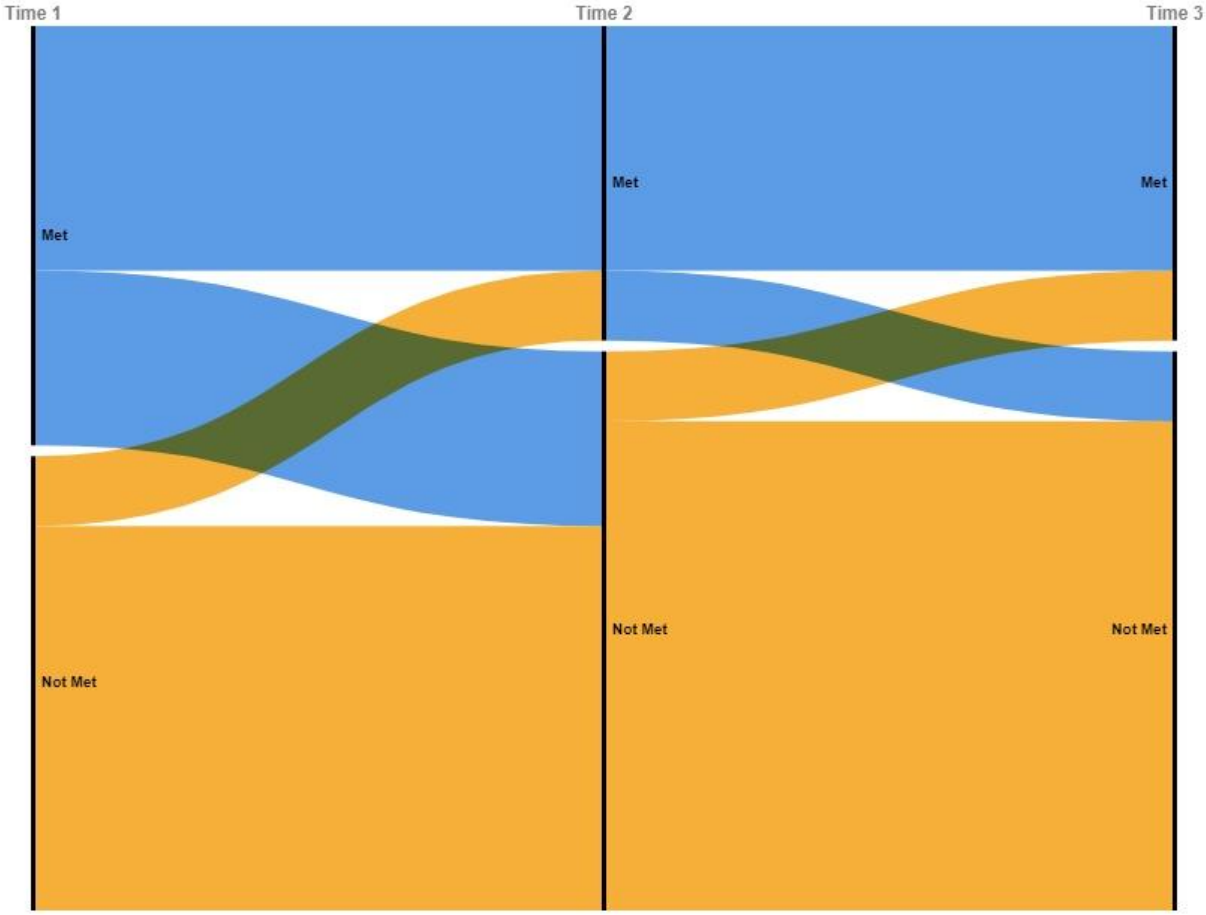


Figure 20. Male Trajectories of Meeting PA Guidelines over Three Timepoints

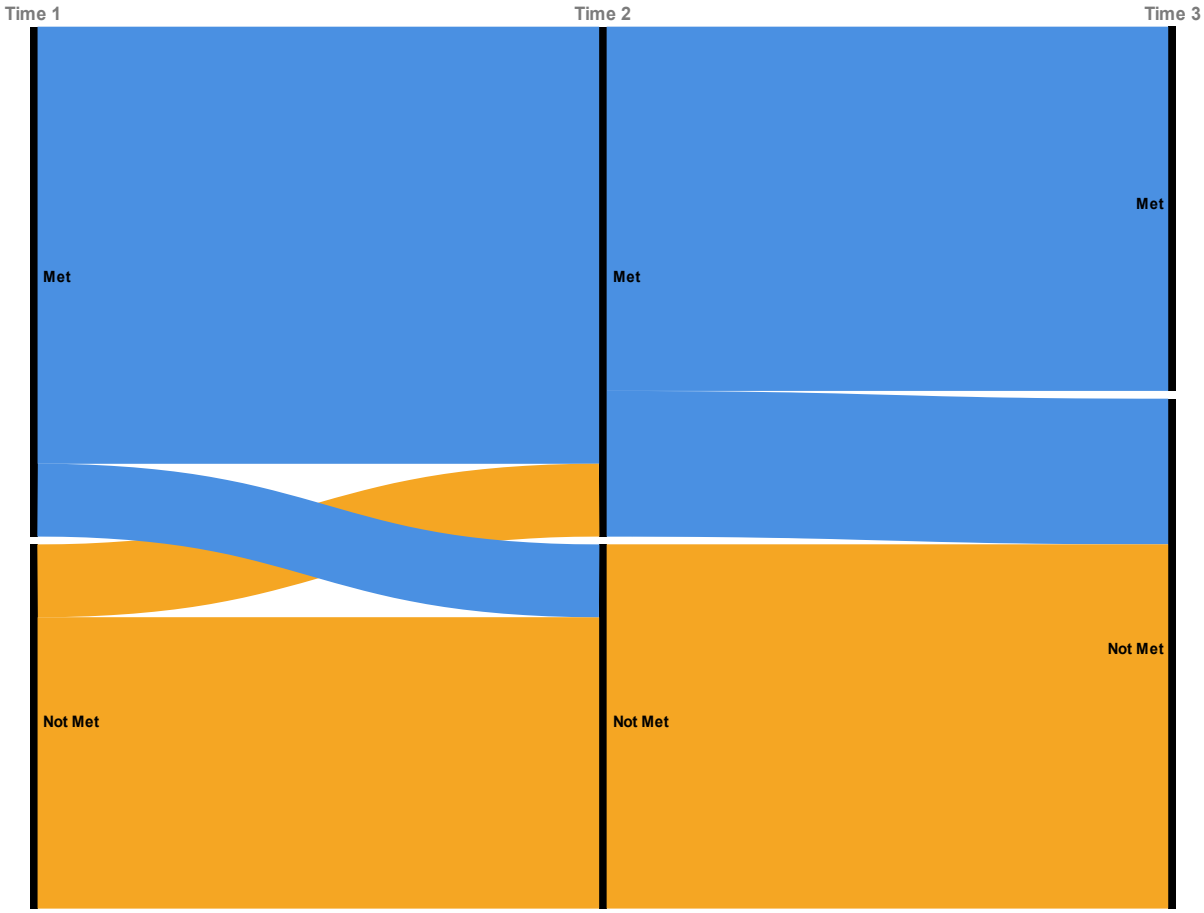


Figure 21. Female Trajectories of Meeting PA Guidelines over Three Timepoints

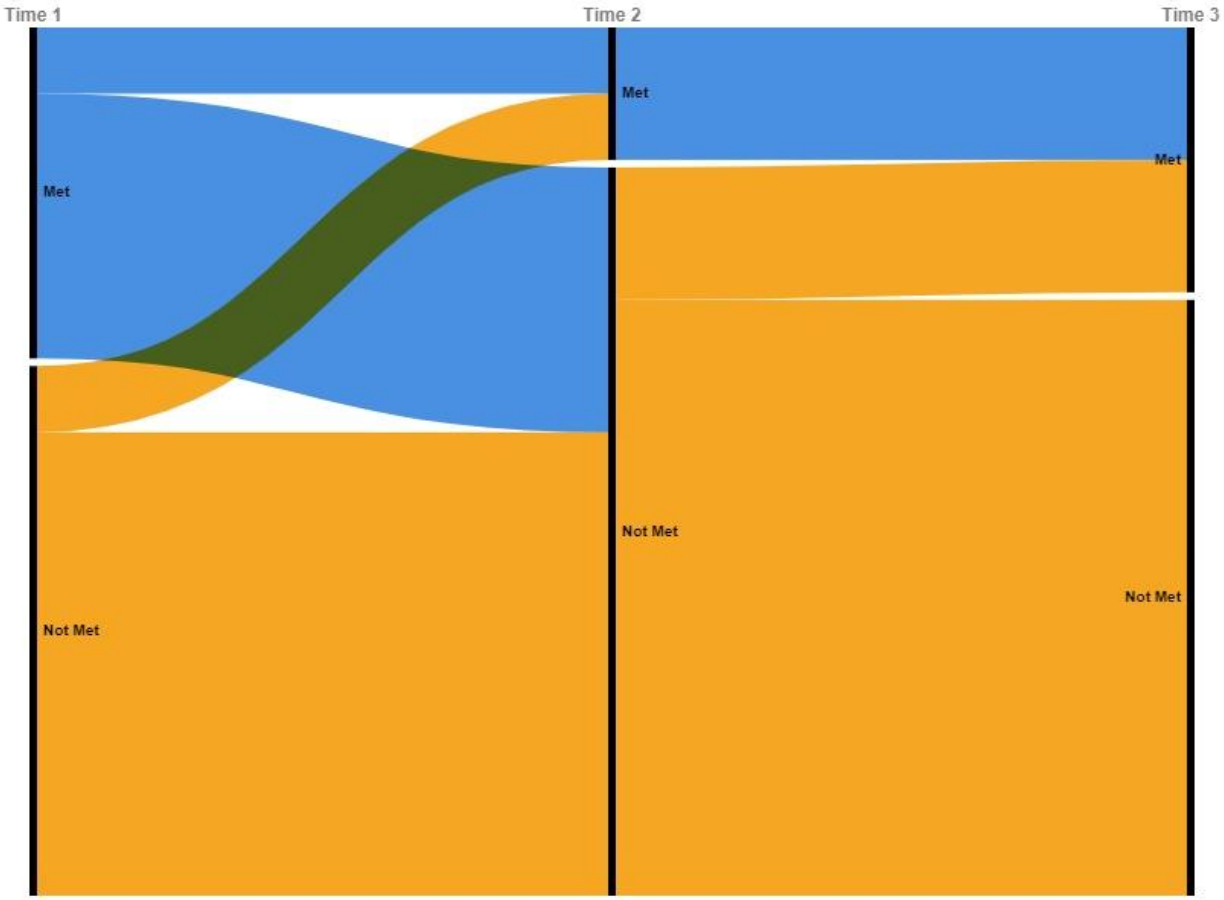


Figure 22. Average Anxiety over Three Timepoints

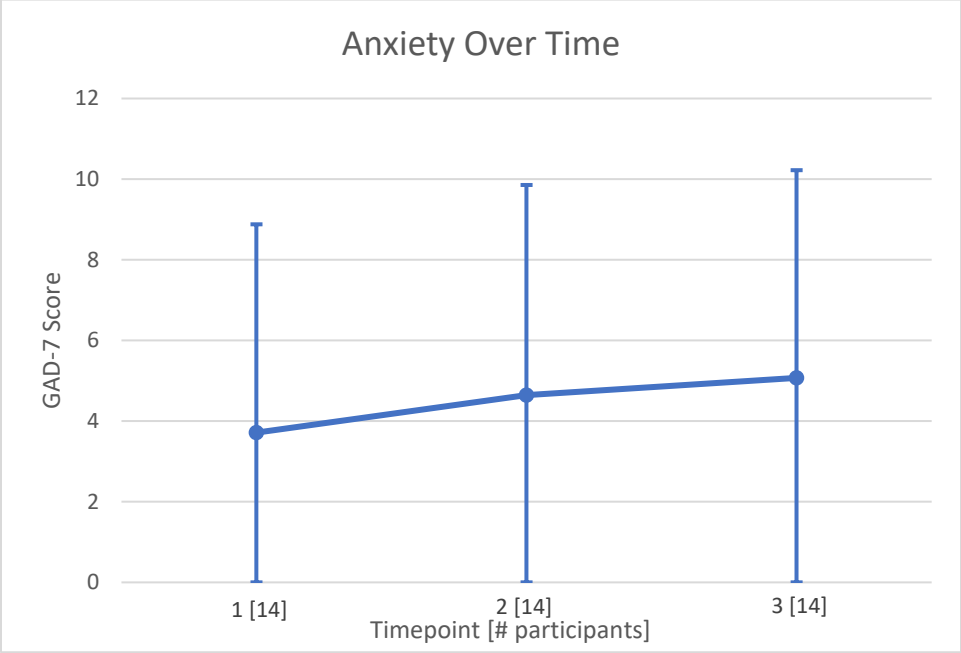


Figure 23. Percent With Elevated Anxiety Over Three Timepoints

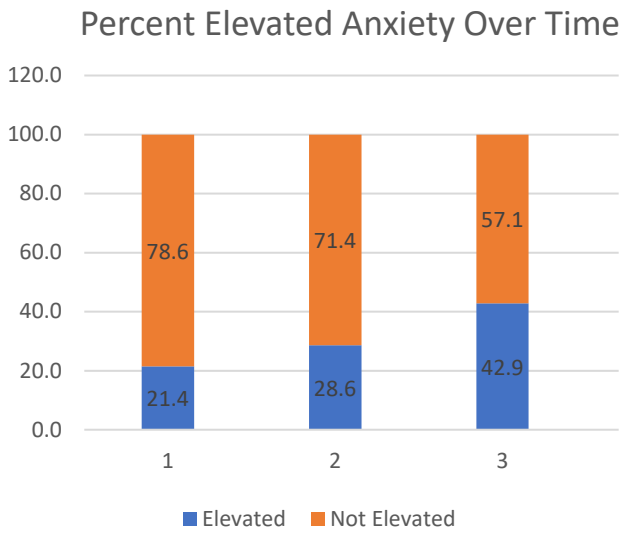


Figure 24. Percent with Elevated Anxiety at Least Once

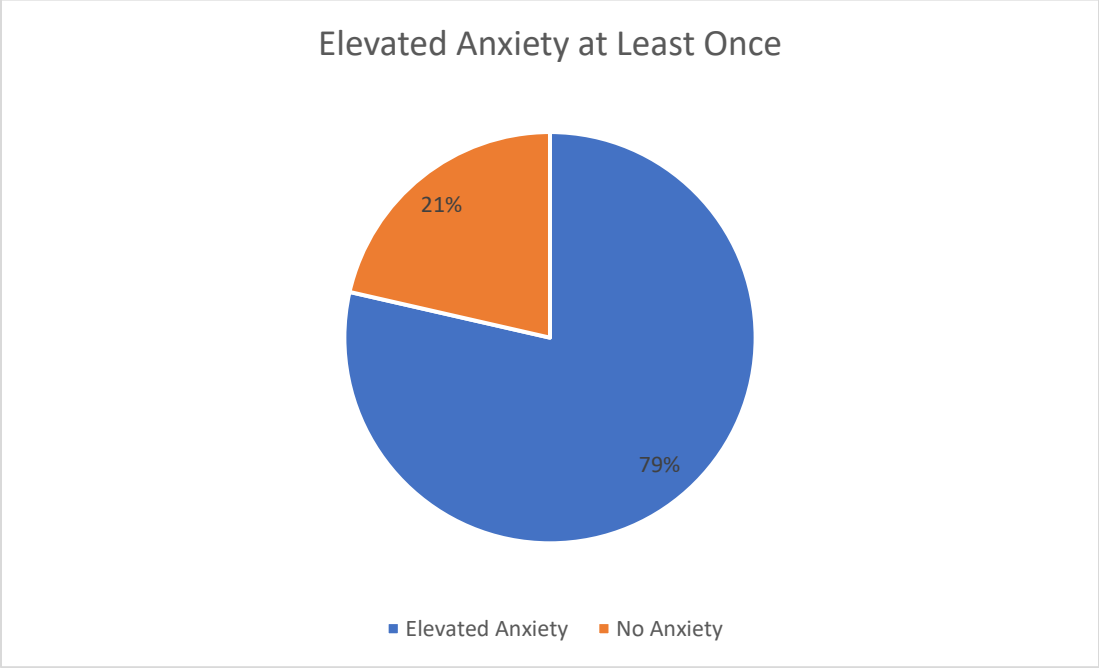


Figure 25. Within-Person Standard Deviation of Anxiety

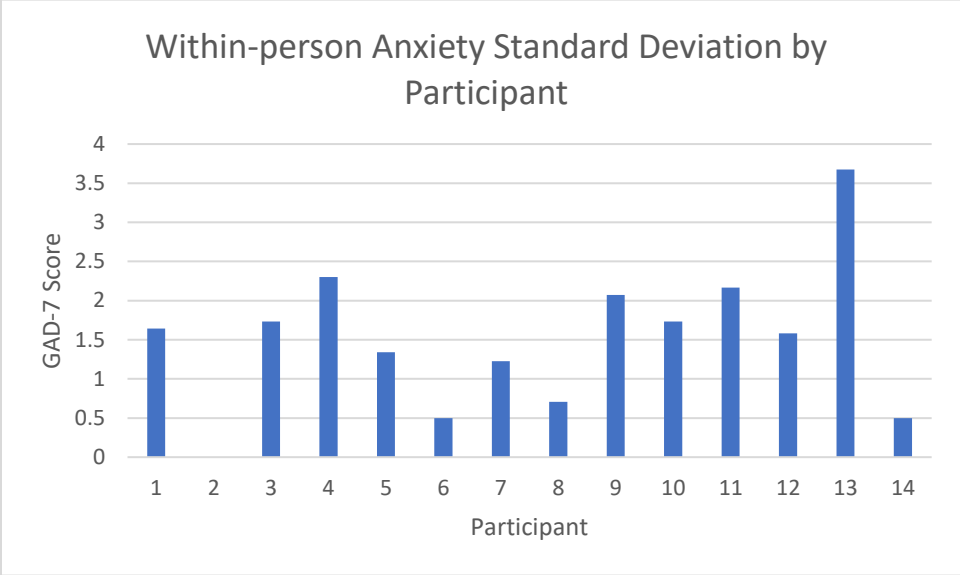


Figure 26. Between Person Standard Deviation of Anxiety by Timepoint

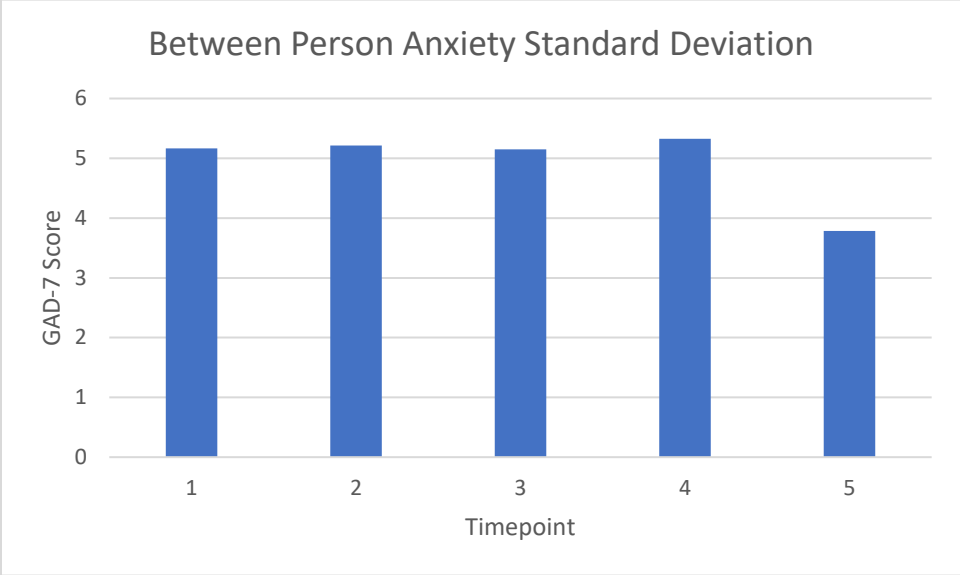


Figure 27. Individual Trajectory of Anxiety over Three Timepoints – Consistently Low

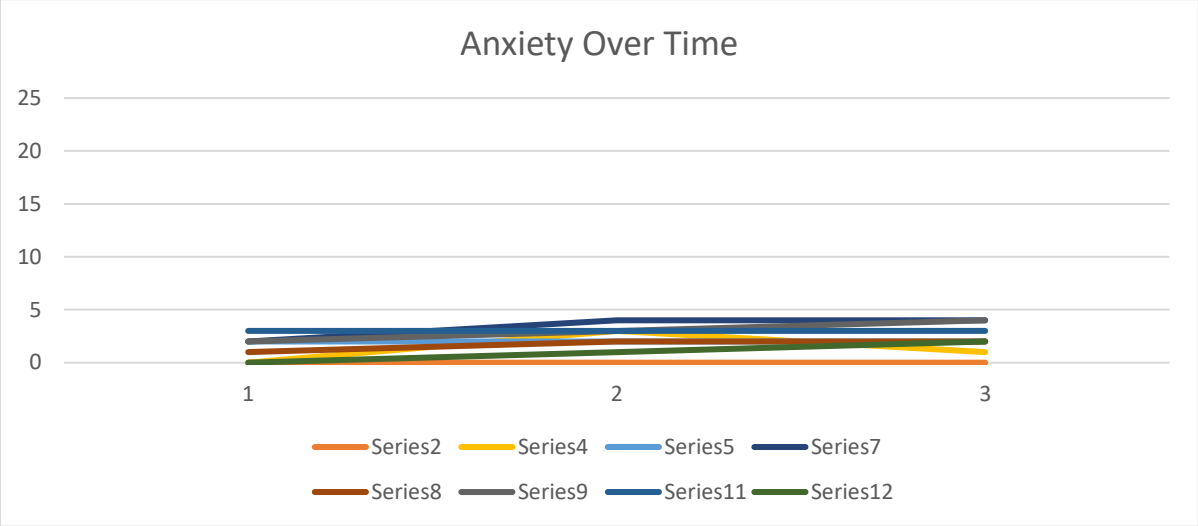


Figure 28. Individual Trajectory of Anxiety over Three Timepoints – Consistently High

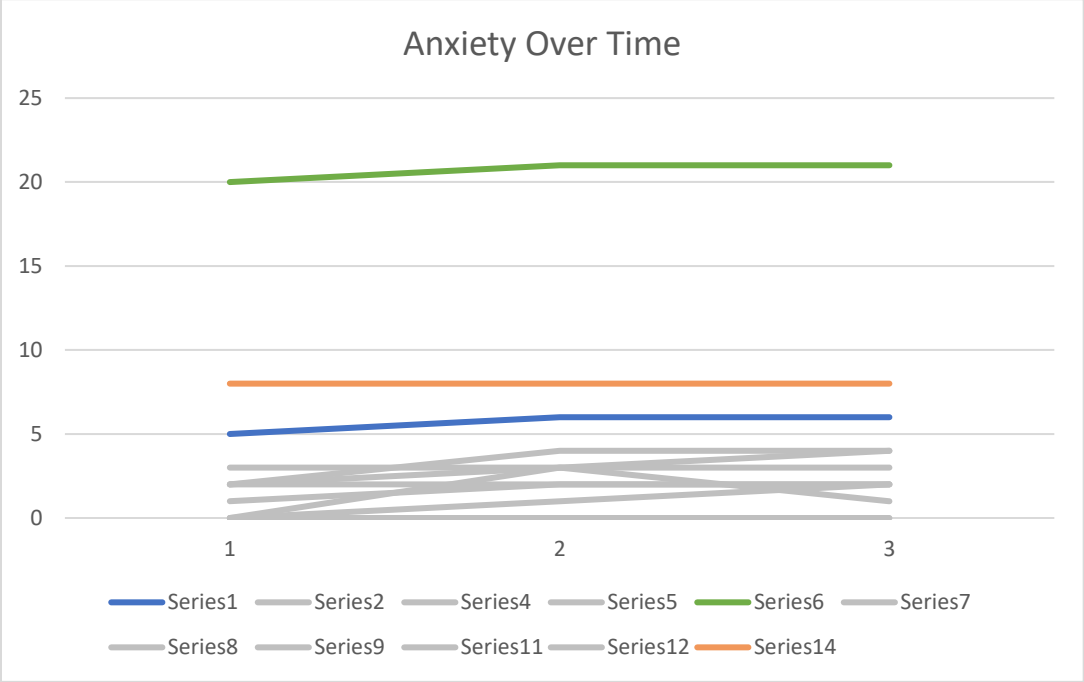


Figure 29. Individual Trajectory of Anxiety over Three Timepoints – Substantial Change

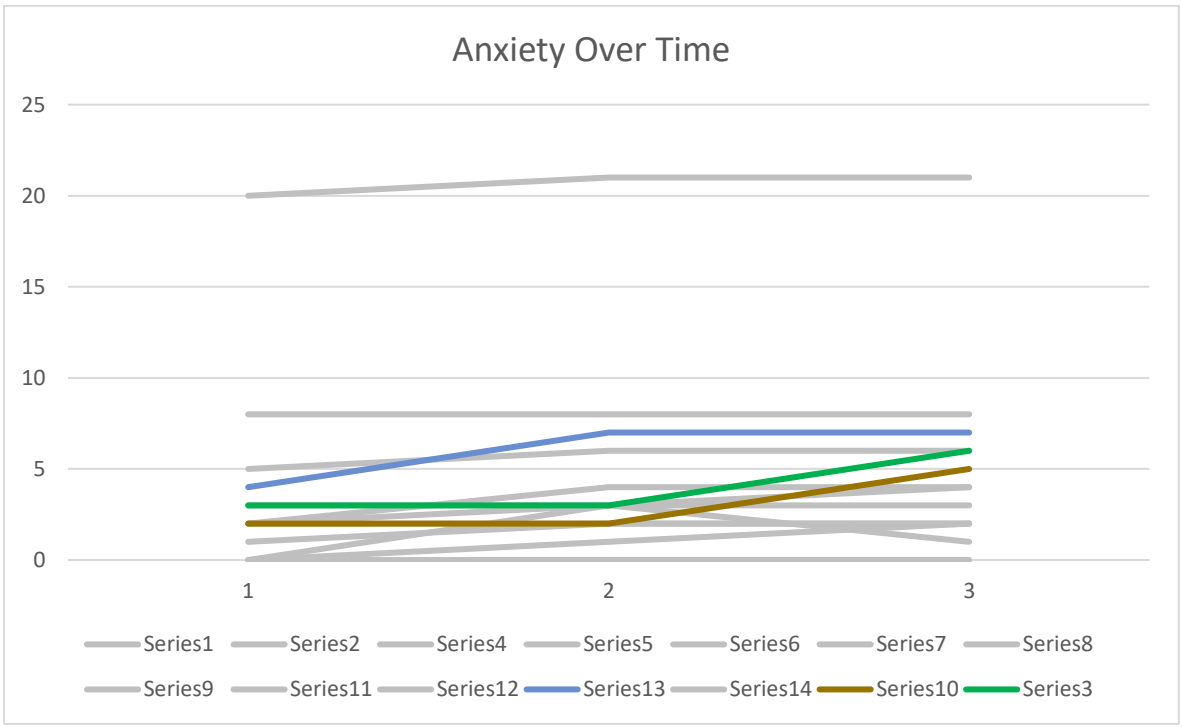


Figure 30. Change in Anxiety Between First and Third Timepoint

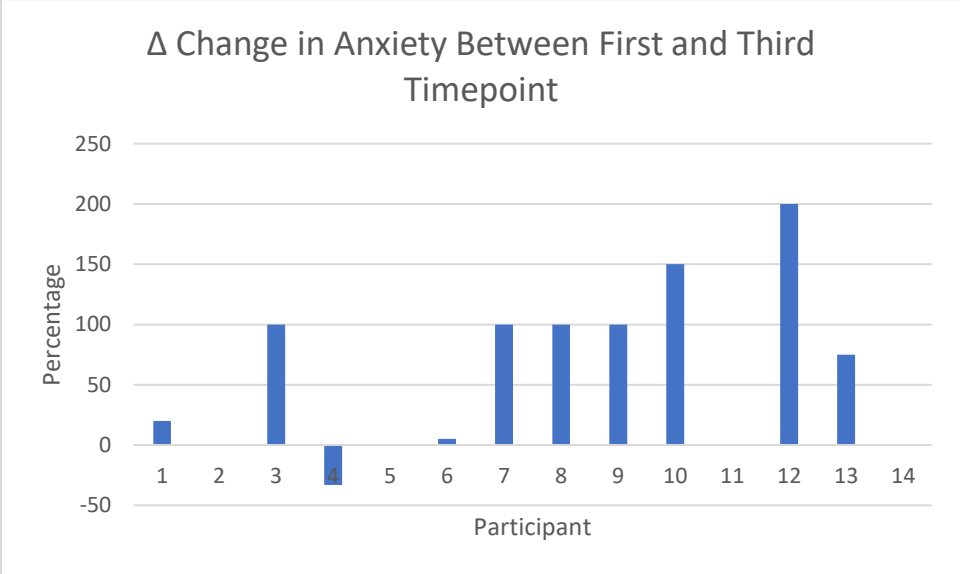


Figure 31. Individual Trajectories of Anxiety over Three Timepoints

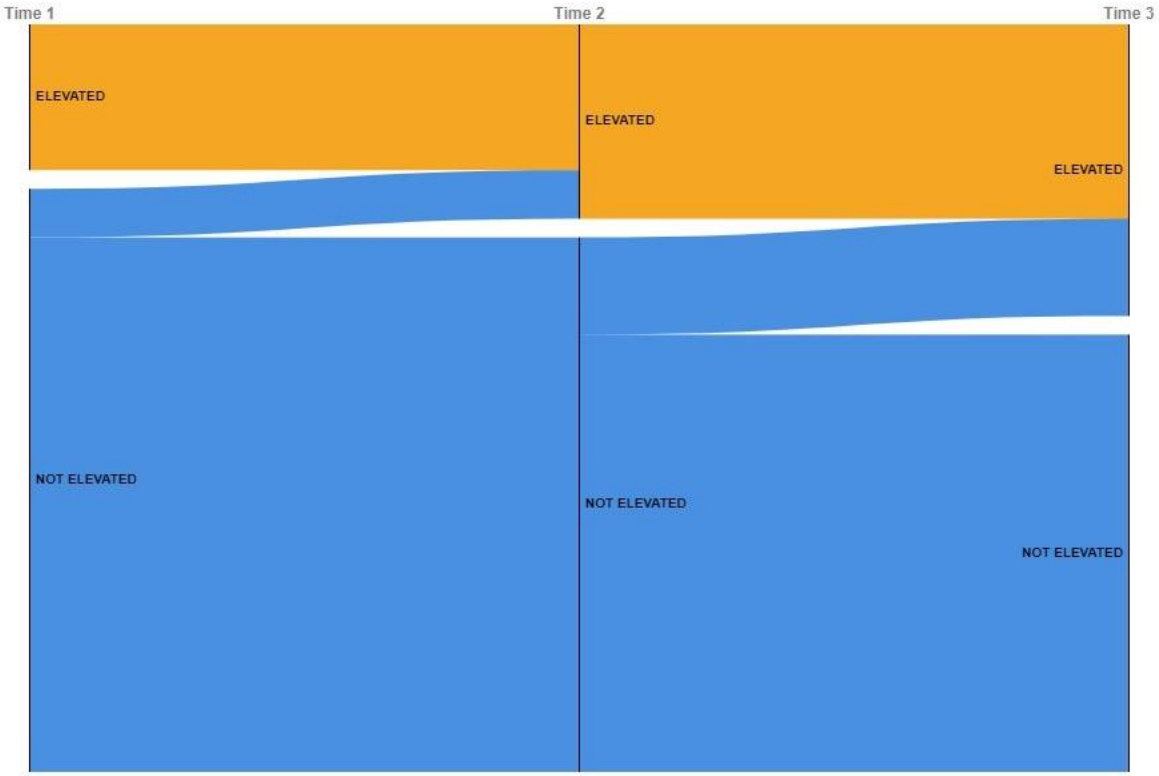


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Figure 32. Male Trajectories of Anxiety over Three Timepoints

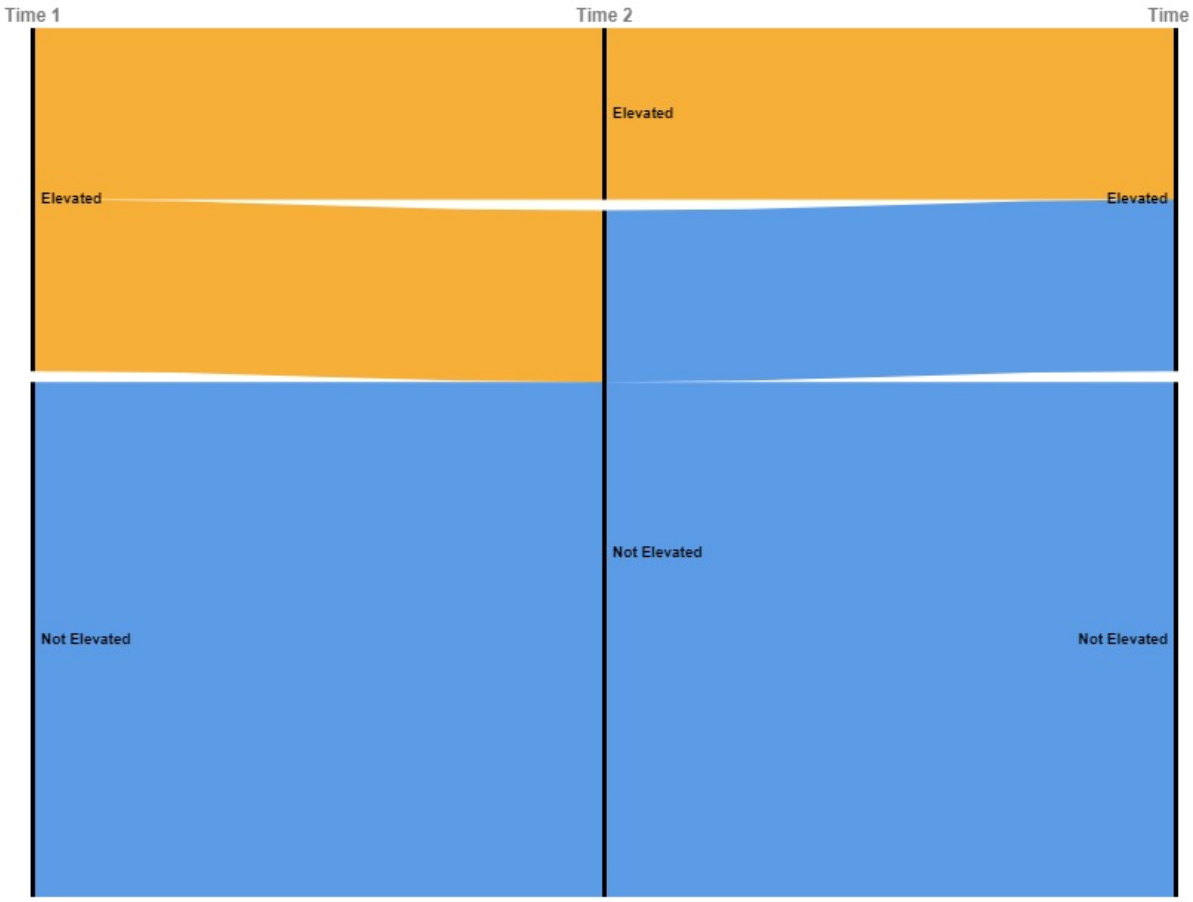
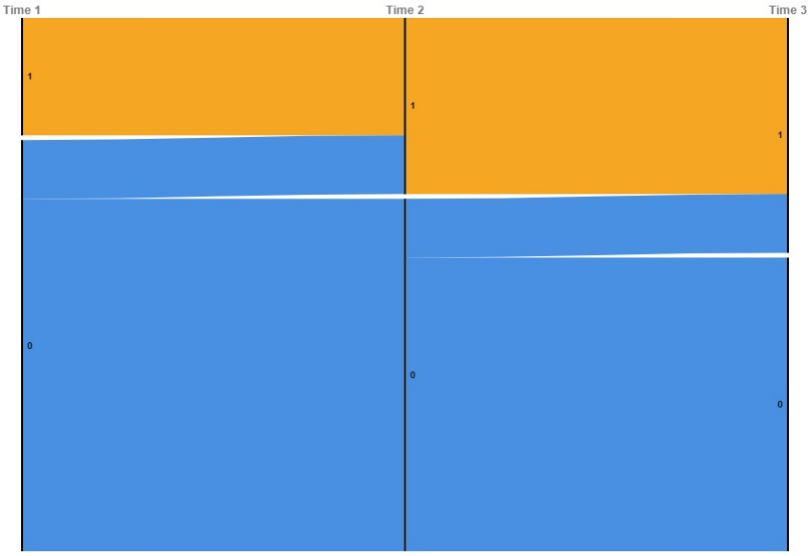


Figure 33. Female Trajectories of Anxiety over Three Timepoints



Chapter 6: Conclusions

The overall purpose of this research was to examine the relationship between PA and anxiety and adolescents and to explore their natural short-term variation. These objectives are important as low levels of PA and elevated anxiety symptoms are common in adolescence and often impact future health. The main findings of this research indicate that self-reported PA was not associated with anxiety symptoms, but that anxiety was significantly reduced objectively measured PA. In addition, substantial within-person and between-person variability was observed over a short period of time. These findings highlight the need for a personalized approach to improve both PA and anxiety in adolescents.

Chapter three evaluated the impact of PA on elevated and clinical anxiety in adolescents. Self-reported PA was not a significant factor for reporting elevated of clinical levels of anxiety. Instead, self-identifying as female sex and co-occurring elevated depression symptoms were found to have the largest influence on anxiety. Over a third of adolescents reported clinically relevant anxiety symptoms, indicating universal screening may be beneficial.

Chapter four assessed how anxiety symptoms and diagnoses affected objectively measured PA. After controlling for sex, BMI, neighborhood safety, friend encouragement, pain and sports participation, the presence of anxiety resulted in a statistically and clinically significant reduction in PA. This supports a growing body of research suggesting that psychologic factors can have a powerful effect on PA.

Chapter five explored within-person and between-person changes in PA and anxiety over a ten-week period. Overall, 80% did not meet PA recommendation at least once and substantial within-person and between person changes in PA. These results emphasize the

need for support of consistent PA over time so that adolescents can accrue the most health benefits. Overall, 80% also reported elevated anxiety symptoms at least once. Between-person and within-person changes were sizable. These results suggest that serial screening over several weeks may be more indicative of adolescents' overall PA and anxiety symptoms as opposed to yearly time point check-ups.

Future Research Directions

Future research should build on this work to help holistically improve adolescent health by focusing on PA and anxiety. The impact of objectively measured PA on anxiety symptoms should be quantified. Measuring a wide range of factors related to PA across different behavior theoretical models will help elucidate which components have the strongest relationship with PA. This will allow for easier identification for those at risk for insufficient PA and dictate which modifiable factors should be emphasized during PA interventions for adolescents. Additionally, the relationships between PA and anxiety should be evaluated over time to elucidate if there are factors that are consistently influential. Cross-lagged modeling would be beneficial to determine how anxiety and PA affect each other chronologically. Collectively, this information will help clinicians better screen and counsel patients and families on PA and anxiety for adolescents.

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Appendix A

Figure 34. Average PA over Nine Timepoints

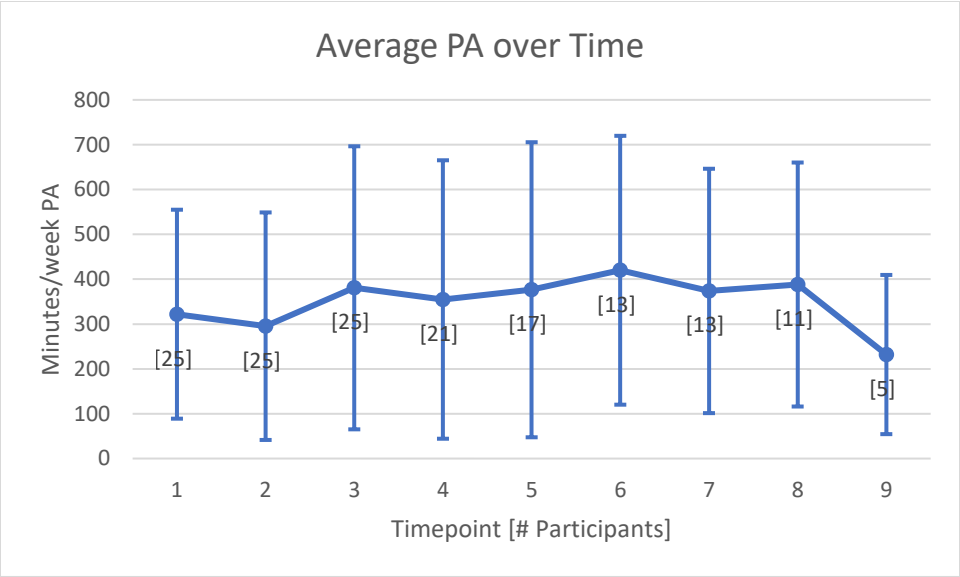

Figure 35. Percentage of Those Meeting and Not Meeting PA Guidelines by All Timepoints

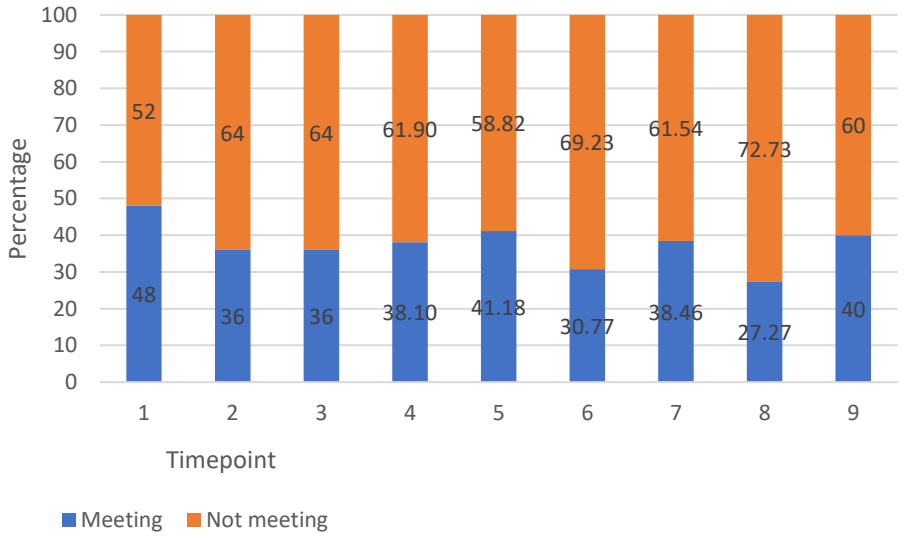

Figure 36. Individual PA over Nine Timepoints – Consistently Low

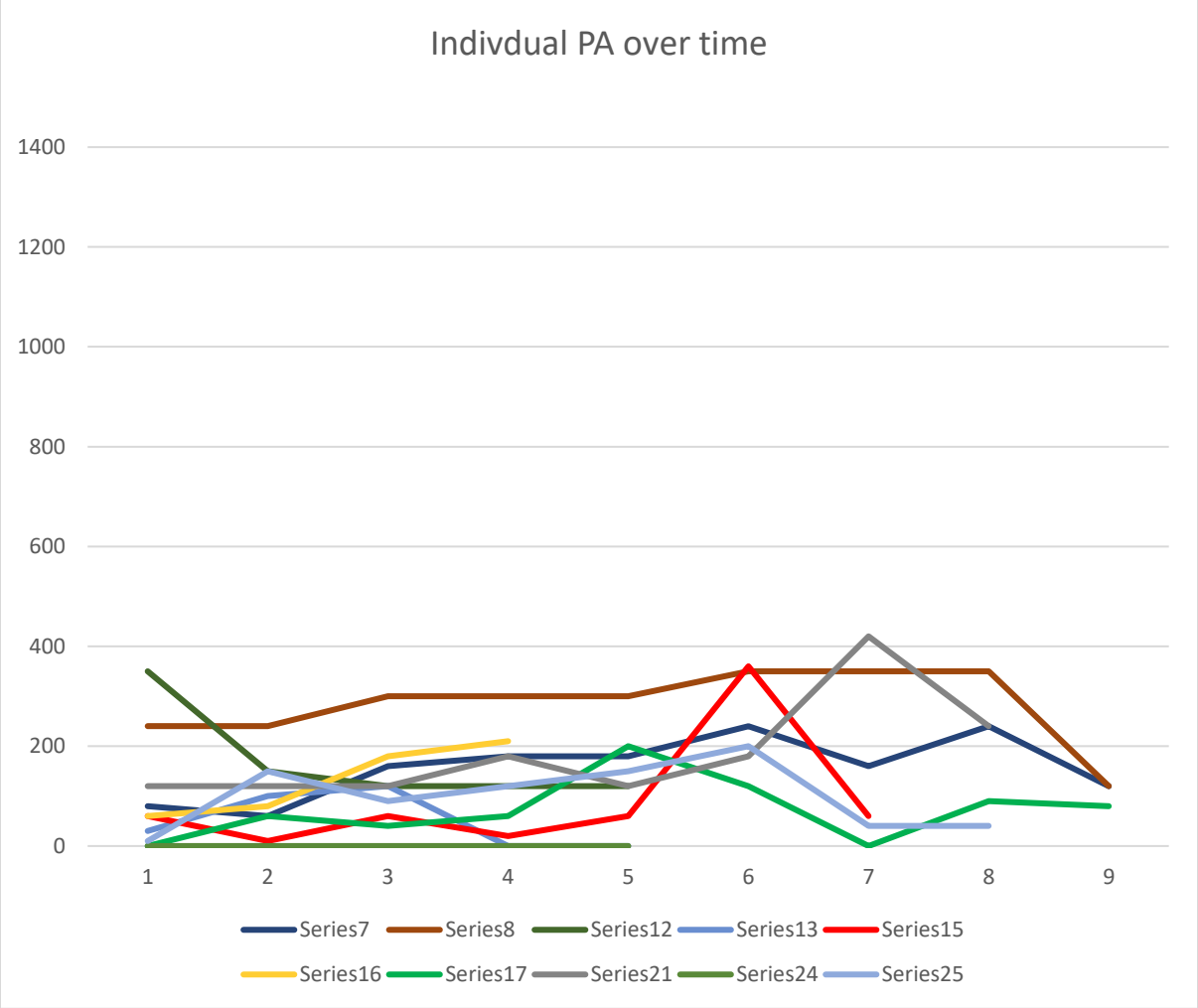

Figure 37. Individual PA over Nine Timepoints – Consistently High

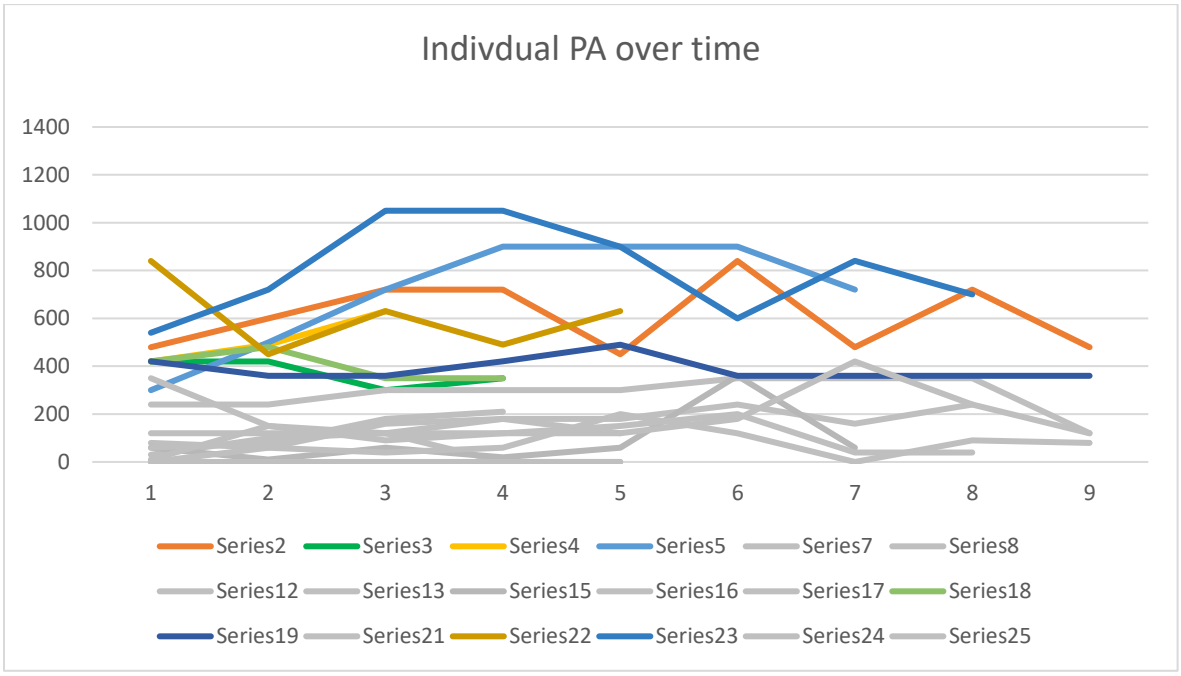

Figure 38. Individual PA over Nine Timepoints – Substantial Change

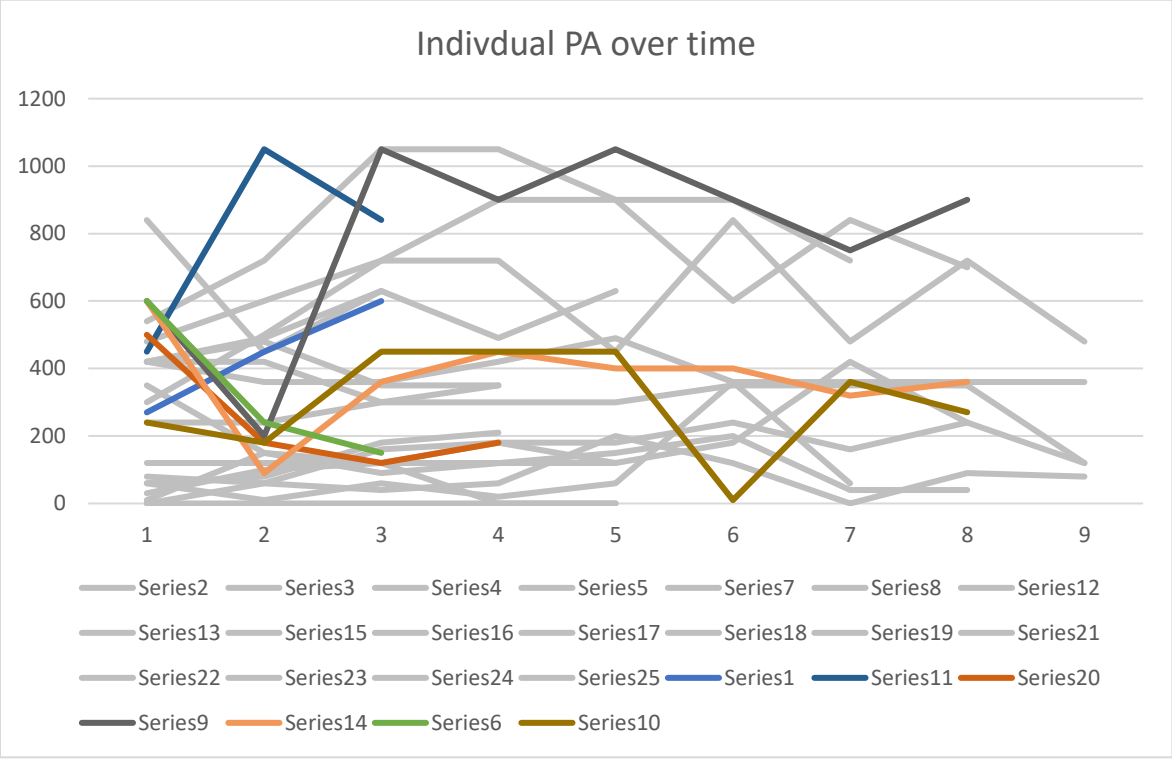

Figure 39. Percent Change in PA between First and Last Timepoint

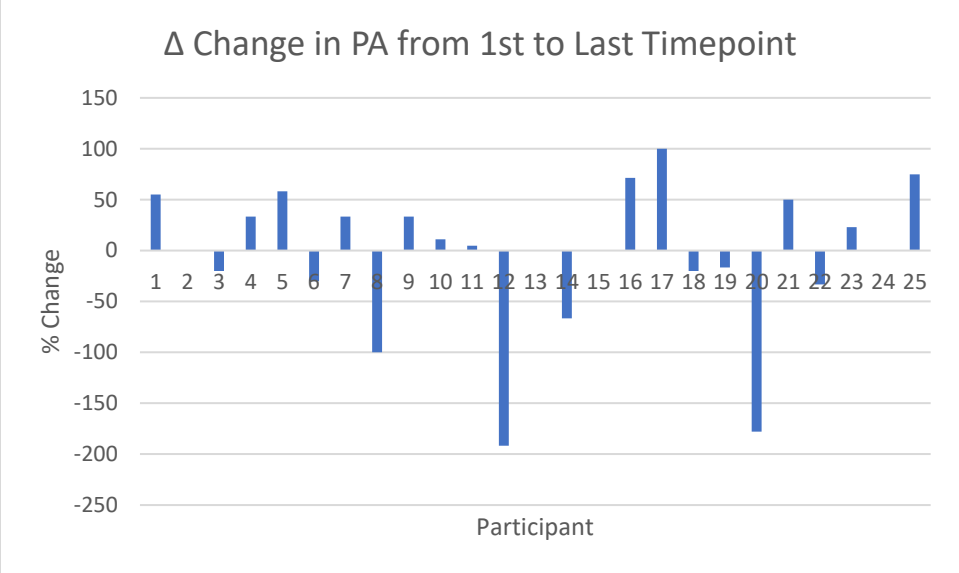

Figure 40. Individual Trajectories of Meeting PA Guidelines over Nine Timepoints

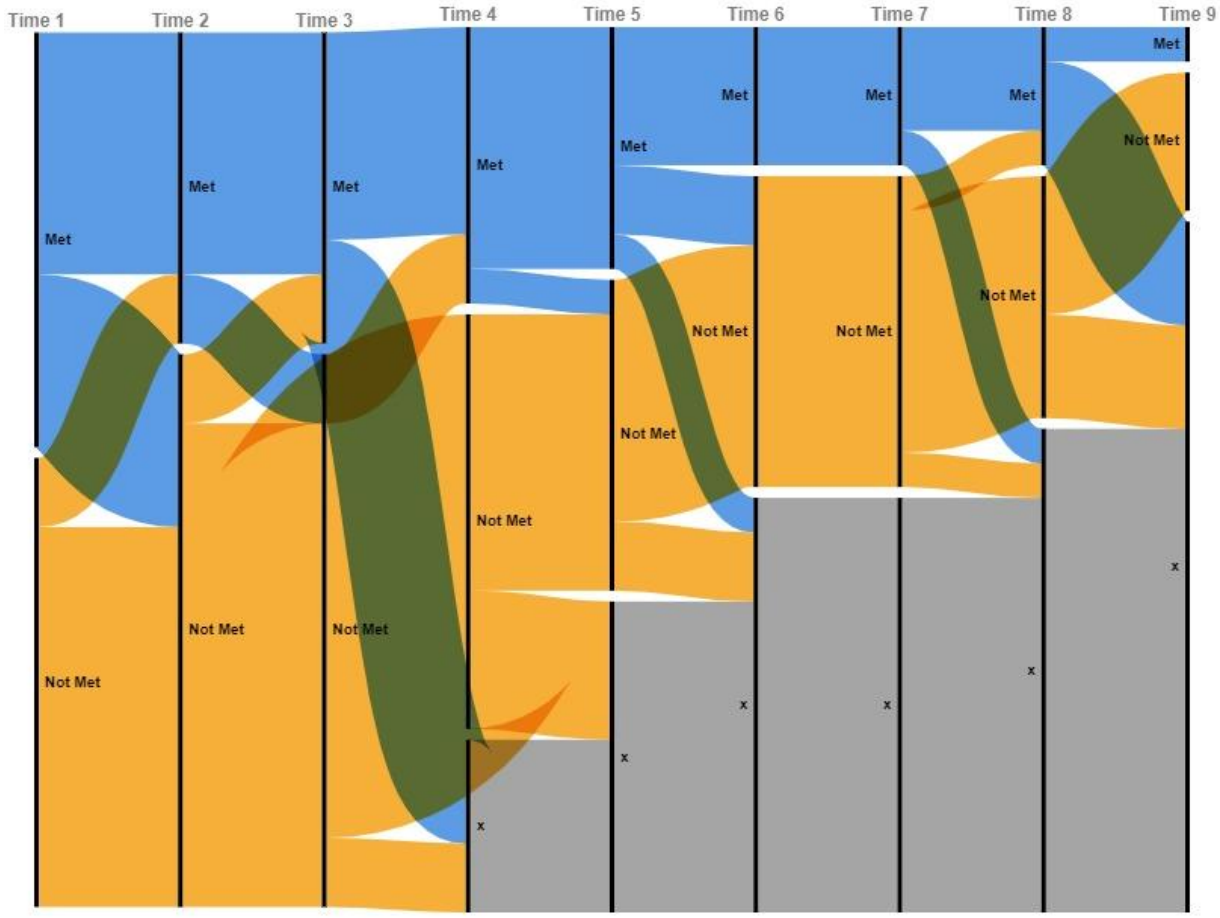

Figure 41. Male Trajectories of Meeting PA Guidelines over Nine Timepoints

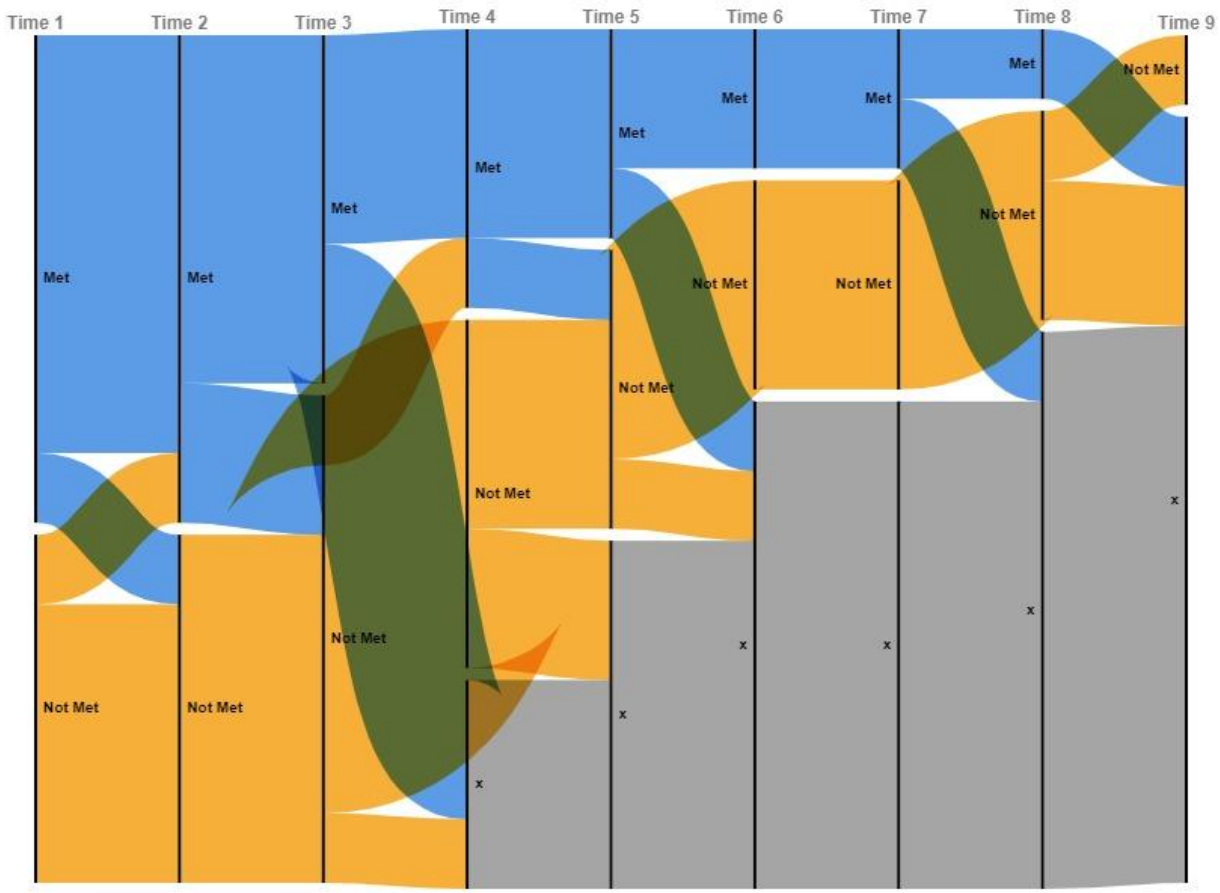

Figure 42. Female Trajectories of Meeting PA Guidelines over Nine Timepoints

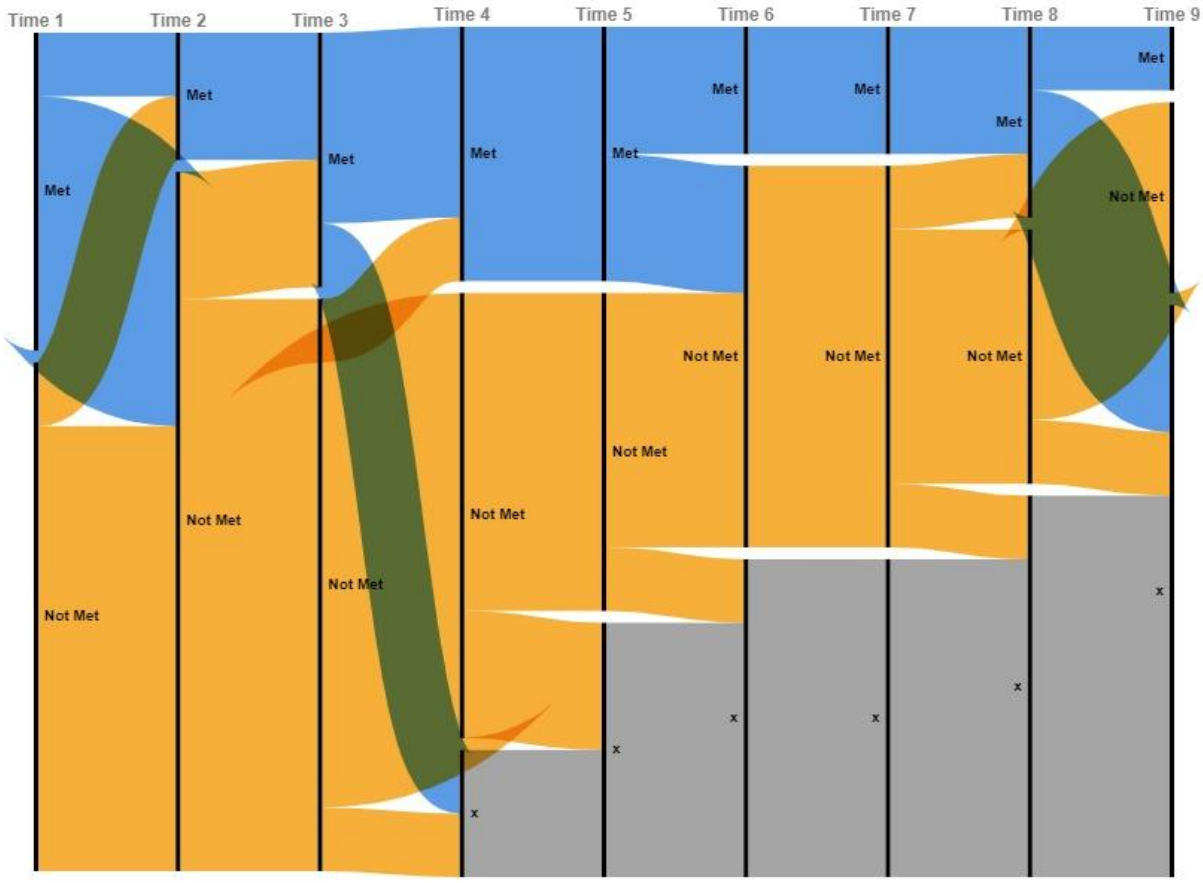

Figure 43. Average Anxiety over Five Timepoints

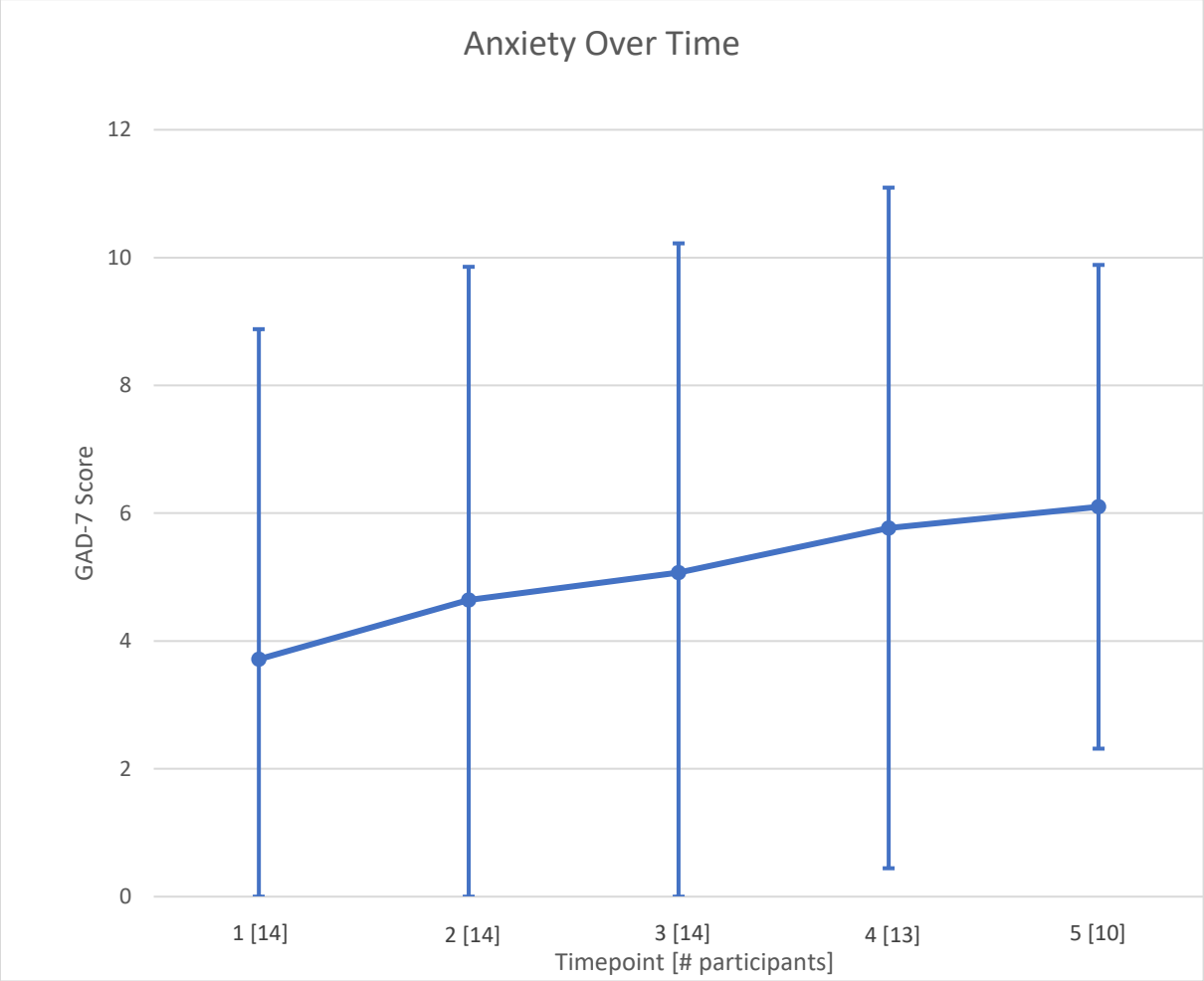

Figure 44. Percent of Adolescents with Elevated Anxiety over Five Timepoints

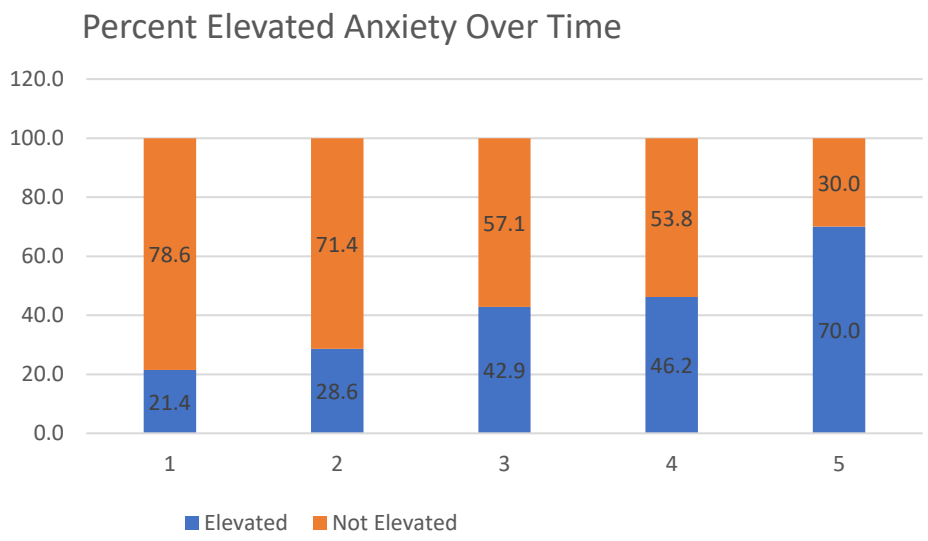

Figure 45. Individual Anxiety over Five Timepoints – Consistently Low

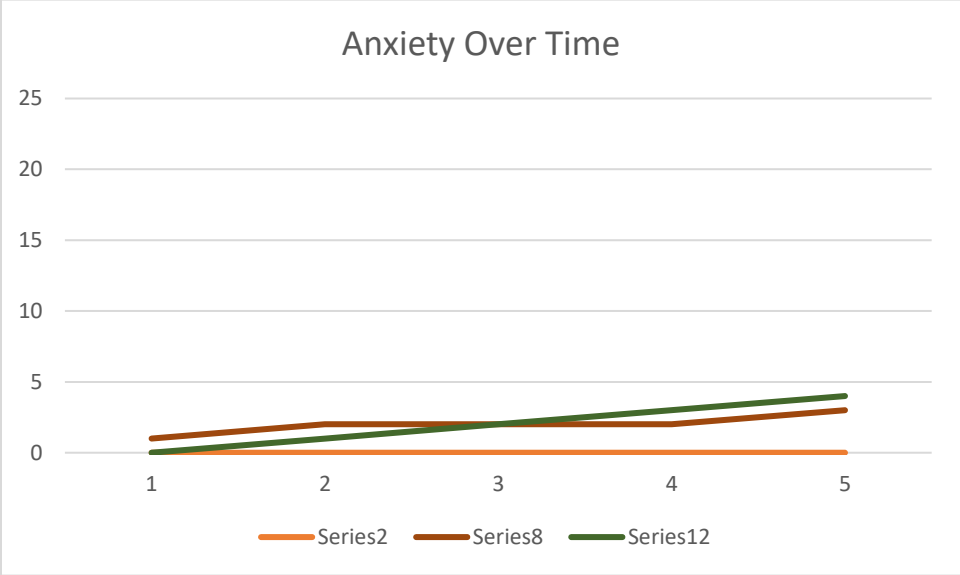

Figure 46. Individual Anxiety over Five Timepoints – Consistently High

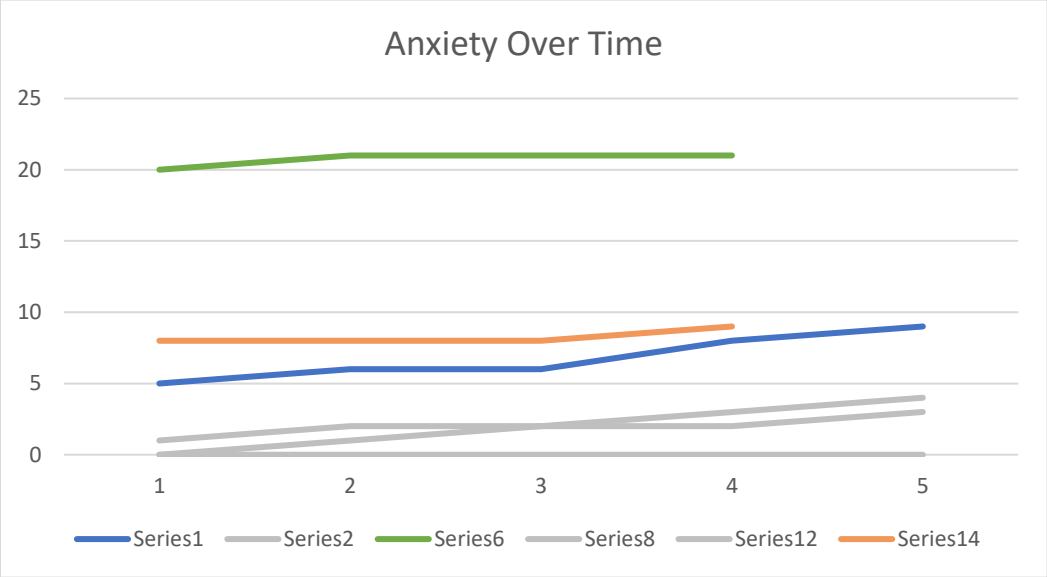

Figure 47. Individual Anxiety over Five Timepoints – Substantial Change

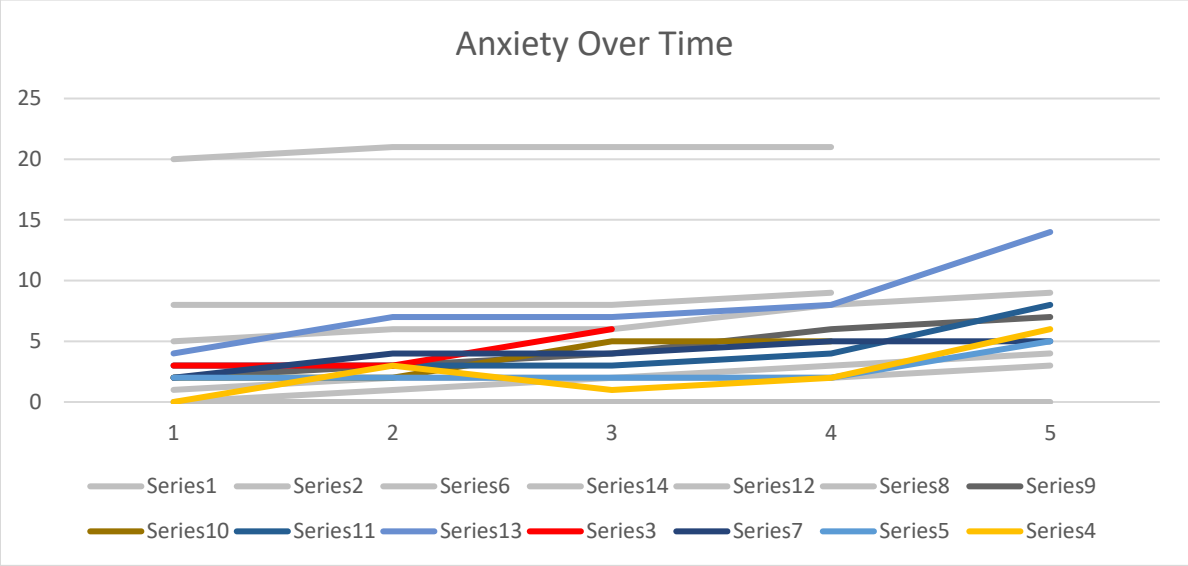

Figure 48. Percent Change in Anxiety between First and Last Timepoint

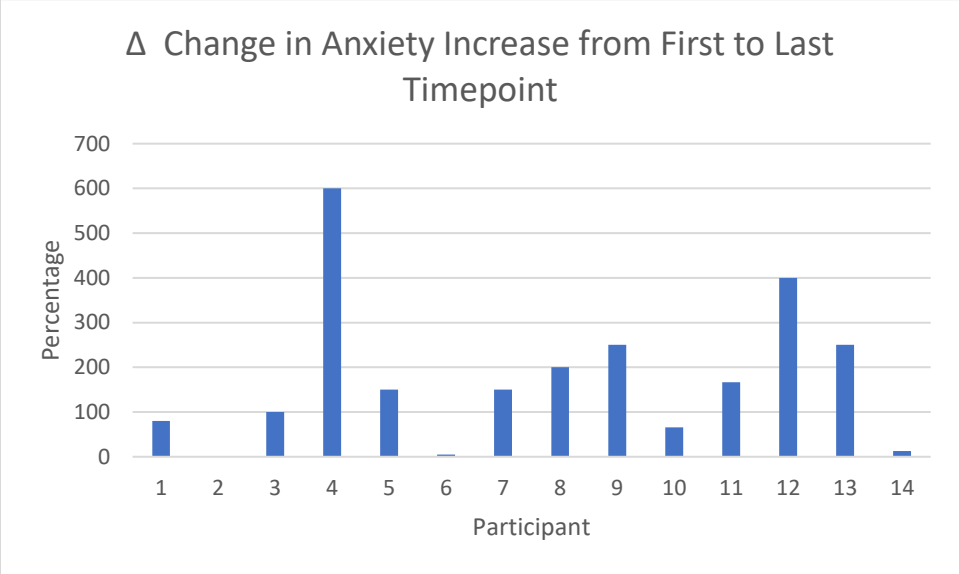

Figure 49. Individual Trajectories of Anxiety over Five Timepoints

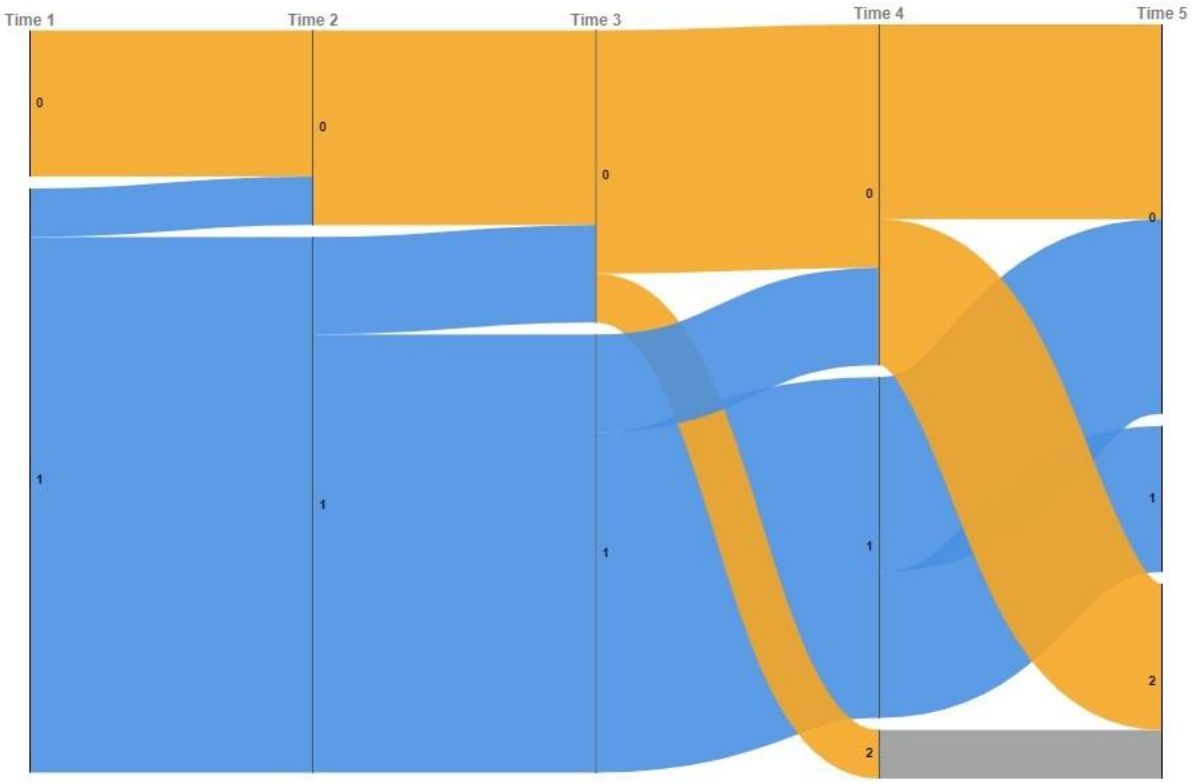

Figure 50. Male Trajectories of Anxiety over Five Timepoints

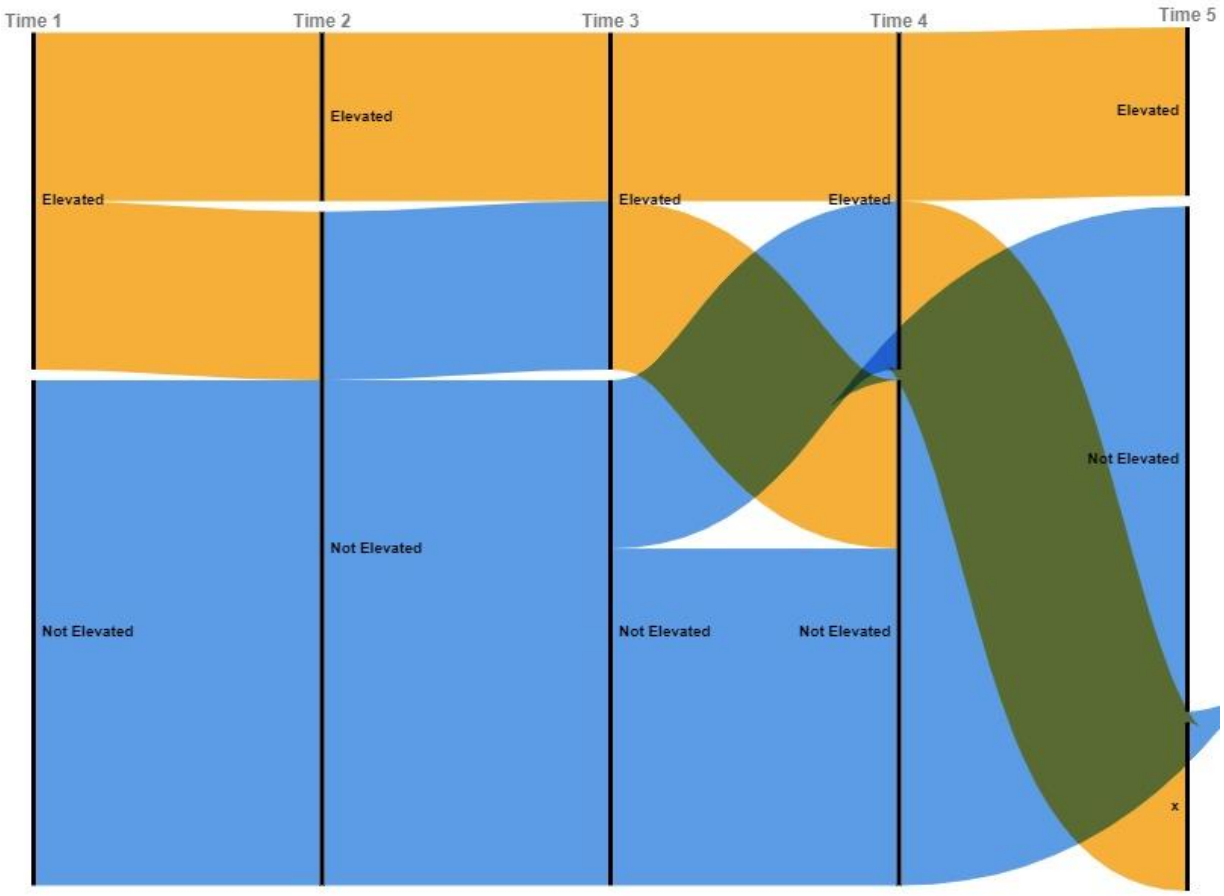

Figure 51. Female Trajectories of Anxiety over Five Timepoints