Exploring the Psychological Mechanisms Underpinning the Relationships Between Physical Activity, Perceived Stress and Mental Health in Adolescents and Young Adults.

By

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A thesis submitted to

The University of Birmingham

for the degree of

DOCTOR OF PHILOSOPHY

School of Sport, Exercise and Rehabilitation Sciences

College of Life and Environmental Sciences

University of Birmingham

December 2023

Abstract

The overarching aim of this thesis was to more comprehensively examine the relationship between physical activity (PA), stress, and mental health in adolescents and young people, by using a range of sophisticated analytical techniques to investigate factors explaining the relationship. Chapter 1 provides an overview of literature related to PA and stress. In order to examine the overarching thesis aims and to address some of the issues highlighted in Chapter 1, Chapter 2 used path analysis to examine potential factors explaining the relationship between PA and stress in adolescents. Specifically, the hypothesised model examined whether the relationship between PA and stress was indirect via self-esteem, stress appraisals, and distress tolerance. During the course of the PhD, the COVID-19 pandemic was declared, which allowed for the examination of the association between PA, stress, and mental health under these novel and unprecedented circumstances. Chapter 3 of the thesis aimed to examine the extent to which PA could protect against any negative impact of Coronavirus concerns on stress and indicators of mental health and wellbeing during lockdown. Building on the earlier cross-sectional work in the thesis demonstrating the indirect relationship between PA and stress via self-esteem, stress appraisals and distress tolerance, Chapter 4 aimed to understand the association between PA and stress further by investigating how the variables explaining the indirect relationship (identified in Chapter 2) related to PA and stress longitudinally. Over a 4-month period, data were collected at three timepoints (which also happened to occur during different levels of COVID-19 restrictions) and were analysed using Multilevel Modelling analysis. Finally, Chapter 5 provided a scoping review of existing literature to determine the relationship between PA, as well sedentary behaviour, and stress over a variety of differing time frames, ranging from concurrent associations to assessing PA and stress over the course of a year.

The thesis concludes with a discussion of the collective findings from the body of research, along with highlighting the implications and presenting considerations and suggestions for future research. This thesis represents a novel contribution to the literature and contributes to the understanding of the association between PA and stress, presenting how additional factors can alter these associations using a range of methodological and analytical approaches.

Acknowledgements

Firstly, I would like to thank my supervisors Jet and Sarah. I can't have always been easy to work with, but you stuck with me through the highs and the lows, for which I am grateful. Thank you for the endless feedback on drafts and getting annoyed with reviewers in solidarity with me. I have appreciated your collective ability to bring humour to our meetings, even when I was struggling to see the bright side and your encouragement to get me through to this finished thesis. Thank you both for everything.

I would also like to thank Vicky, Mark and Yoonjin. Thank you for the opportunity to work with you all on the SMS'S Study. Thank you for working with and round me to make sure that I had time to write my thesis, your support during the final push has taken so much pressure off me and I really appreciate everything you have done.

Thanks, must also go to Vikki – The PhD Life coach. You have made me feel validated, supported, and have challenged me to think in different ways. I cannot thank you enough for everything you do.

Next, I would like to thank my Mum and Dad. Words cannot begin to describe how grateful I am to you both for everything. For my entire life, you have unconditionally loved and supported me in every way possible and I would not be the person I am today without you. I could easily write an entire thesis detailing every way you are both the best parents anyone could ever wish for, but for the sake of keeping the inevitable tears to a minimum, I will just finish here by saying I love you both endlessly.

I would also like to take this opportunity to thank Jack for all the tech support, constantly fixing my broken laptop and keeping up the never-ending supply of motivational cute animal videos. Also, to Sam, thank you for proofreading for me when I was at the point

where I couldn't even see words anymore, and for making me laugh so hard I sound like a kettle.

To Abi, Jen, Jess, Katie, and Vikki, you are the best support network and friends a girl could ask for. You have cheered me on, celebrated every win with me, picked me up from every struggle, been my shoulder to cry on and always been there for me with kind words and encouragement. You have all listened to me complain with patience and love and I could not be more grateful for everything you do.

Rob, you have loved me endlessly and supported me through it all. You have looked after me, made me laugh, celebrated my wins with me and held me through the hard times. I can't always have been easy to live with, I know I get grumpy when I'm stressed or tired (so all the time really!) but I appreciate you putting up with me. I could not ask for a better partner, and I am so lucky to have you. I love you.

Basil, Bella, Benji, Dotty, Maisie, Medi, Whiskey and Woolfy, while you are dogs and can't read this acknowledgement, your enthusiasm to provide cuddles and emotional support went a long way to helping keep me sane during the PhD process, so deserves to be recognised in this section.

Finally, I would like to thank everyone who has supported me, offered advice or kind words throughout the duration of my PhD. While I may not have mentioned you by name, know that I am so grateful to you for everything.

Publications and Conference Presentations

Publications

1) **Wright, L. J.,** Veldhuijzen van Zanten, J. J., & Williams, S. E. (2023). Examining the associations between physical activity, self-esteem, perceived stress, and internalizing symptoms among older adolescents. *Journal of Adolescence*, 95(6), 1073-1287
2) **Wright, L. J.,** Williams, S. E., & Veldhuijzen van Zanten, J. J. (2021). Physical activity protects against the negative impact of coronavirus fear on adolescent mental health and well-being during the COVID-19 pandemic. *Frontiers in psychology*, *12*, 580511.
3) **Wright, L. J.,** Williams, S. E., & van Zanten, J. J. V. (2023). Associations between physical activity, sedentary behaviour, and stress using ecological momentary assessment: A scoping review. *Mental Health and Physical Activity*, 100518

Communications not part of this thesis

1) Yoon Jin Kim, Victoria Goodyear, Mark Griffiths, **Laura Wright.** Young people, social media and online harms in community-based sport: A systematic review. PROSPERO 2023 CRD42023444400 Available from: https://www.crd.york.ac.uk/prospero/display_record.php?ID=CRD42023444400

Conference Presentations (Oral)

1) **Wright, L. J.,** Veldhuijzen van Zanten, J. J., & Williams, S. E. (2021). Examining the Mechanisms Underlying the Relationships Between Physical Activity, Perceived Stress, Anxiety and Depressive Symptoms in Adolescents. DSEP Annual Conference, 30/11/2021, Liverpool.

Awards

2nd Place Best Student Oral Presentation for “Examining the Mechanisms Underlying the Relationships Between Physical Activity, Perceived Stress, Anxiety and Depressive Symptoms in Adolescents”

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Chapter 1

General Introduction

Stress

Stress has been in the collective consciousness of society for decades and has been seen to be highly prevalent across the lifespan. It has been found that up to 45% of adolescents report feeling stressed (Roy et al., 2015), and 60% of young people (18-24-year-old) report feeling stressed due to pressure to succeed (Mental Health Foundation, 2018a). This increase in stress prevalence continues further into adulthood with 74% of adults feeling so stressed that they feel unable to cope in the past year (Mental Health Foundation, 2018a). Therefore, it is important that we find ways by with we can support people to be able to cope with stress.

Stress can be induced by both physical and psychological stimuli. Physical stress for example can come in the form of exercise (Mastorakos et al., 2005) or extreme temperatures (Lloyd & Havenith, 2016), whereas psychological stress can come in the form of life events but also daily hassles (Segerstrom & O'Connor, 2012). Both physical and psychological stress cause physical reactions such as increased breathing, heart rate and adrenaline, preparing the body to be able to cope with the presenting stress (O'Connor et al., 2021). In addition to physical responses, there are also psychological responses to stress such as feeling overwhelmed, tense and worried (Mind, 2022). The term stress is often used interchangeably for both physical and psychological stress, which can make it difficult to conceptualise stress.

Given the difficulty in conceptualising stress due to the different types of stress stimuli and responses, it is perhaps unsurprising there is no single definition of stress. While early efforts such as "stress is the nonspecific response of the body to any demand made upon it" (Selye, 1974, p. 137) attempt to define stress, this is a very broad definition as it focuses on nonspecific actions and demands, encompassing everything and yet not

narrowing into the stress experience. While as described above stress can be physical, when considering stress, it is largely the psychological components of stress that tend to be at the forefront of thought, largely due to the detrimental effects on mental health and well-being (discussed below) and as evidenced above the high prevalence of stress across society. Psychological stress is also becoming a public health issue, with effects on public services such as the NHS (NHS Digital, 2022)and stress related ill-health being a leading cause of lost work days (HSE, 2023) Therefore, for this thesis, the focus will be on psychological stress. One definition that seems to encompass psychological stress is posed by Fink (2016), who suggests psychological stress is the feeling when demands of a situation outweigh the individual's ability to cope with these demands. This definition is more specific than that provided by Selye (1974), and allows for individualisation of the stress response based on a person's perceptions of a situation or stressor, and better encompasses the idea of psychological stress. Therefore, for the purposes of this thesis when defining stress, the focus will be upon psychological stress, using Fink (2016)'s definition.

Responses to Stress

Stressful stimuli can be acute or chronic by nature. Acute (or short term) stress can be defined as a single instance of stress (Chu et al., 2021), which is short in duration (often 60 minutes or under) and could be in response to an external stimuli, such as in preparation for an important exam. Chronic (or long term) stress, can be defined as the prolonged exposure to stress (Chu et al., 2021) and could relate to a number of long term stimuli such as sustained pressure at school or work, major life changes or illness. The body reacts to both acute and chronic psychological stress in a number of ways. First, some of the physiological responses will be briefly described, with psychological consequences of stress to be discussed later.

In reaction to psychological stress, the hypothalamic-pituitary-adrenocortical axis (HPA) and the sympathetic-adrenal-medullary (SAM) system are activated by psychological stress (Cohen et al., 2007). This activation induces the release of cortisol and catecholamines, which subsequently influence other bodily functions including anti-inflammatory responses and regulation of the cardiovascular system, such as increase in heart rate and blood pressure. These acute responses to stress are beneficial for the individual, by preparing the individual to react to a situation. Acute stress for example can lead to improvements in concentration (Degroote et al., 2020), and response time (Shields et al., 2019), as well as improved performance in sporting activities (Jones & Hardy, 1989). However, prolonged activation of the HPA axis and the SAM system, for example as a result of chronic psychological stress, can interfere with the physiological processes controlled by the HPA and SAM systems, increasing the risk of both physical and psychiatric disorders (Cohen et al., 2007). It is perhaps unsurprising therefore, that stress has been linked to a large number of physical health conditions, including but not limited to, increased prevalence of cardiovascular disease (Kivimäki & Steptoe, 2018) as well as stomach ulcers and sleep disfunction (Chu et al., 2021), all of which have a negative impact on the health of the individual. In addition to physiological consequences, exposure to stress can result in engaging in various negative behaviours including the consumption of more unhealthy and less healthy foods (Hill et al., 2022) and increased alcohol consumption (Keyes et al., 2011) as a way to cope with the stress that the individual is under. Stress has also been seen to be associated with decreased physical activity (Stults-Kolehmainen & Sinha, 2014) with all of these behaviours having additional negative consequences for general health. These negative implications for general health have wider reaching implications, with associated

implications of eating unhealthily, being physically inactive and drinking too much alcohol putting additional strain on an already stretched NHS and other public health resources.

Psychological Responses to Stress

In addition to physiological and behavioural response of psychological stress exposure, there are also psychological responses to both acute and chronic stress exposure. For example, stress has been seen to be associated with increased irritability and angry outbursts in relation to experienced acute stressors (Repetti & Wang, 2017). Meta-analysis has concluded that acute psychological stress has also seen to been to impair memory retrieval (Shields et al., 2017). Acute psychological stress has also been seen to promote increased effort and proactive coping (Jamieson et al., 2018), suggesting that experiencing acute psychological stress is not always a negative. Chronic psychological stress can have a negative influence on indicators of well-being. For example, student participants with higher levels of perceived stress have been reported to be less happy than those with lower stress (Schiffrin et al., 2009). Similarly, it has been found that higher levels of perceived stress are associated with lower life satisfaction (Puri et al., 2016). As well as negative implications for well-being, chronic psychological stress has been seen to have negative consequences for mental health.

The term mental health is often used synonymously for mental illness (Manwell et al., 2015), however this is problematic. By not making a distinction between mental health and mental illness, mental health is often regarded as negative within society. However, this interpretation lacks many of the facets of mental health, with mental health not just being mental illness, but also encompassing ideas of mental wellness, ability to function and ability to cope with daily stressors (World Health Organization, 2004). One definition however that appears to capture the complex nature of mental health comes from Galderisi

et al. (2015, pp. 231-232), who suggest that “mental health is a dynamic state of internal equilibrium”. An internal equilibrium presents the idea of a psychological balance within the individual, with “dynamic” encompassing different stages of life, such as adolescence or retirement, that may demand changes to the equilibrium (Galderisi et al., 2015, pp. 231-232). Mentally healthy people still experience both positive and negative emotions. The presence of any negative emotion is not automatically enough to make a person mentally unhealthy. It is when negative emotions consistently outweigh the positive, damaging the internal equilibrium, that a person may become mentally unhealthy. This lack of equilibrium could result in negative states of mental health, such as anxiety and depression. It is this with this definition that mental health is a dynamic state of equilibrium in mind that mental health will be discussed within this thesis. The term psychological well-being is also used in the literature and throughout this thesis. Within this thesis, psychological well-being will be defined as the elements of mental health that are not specifically mental health conditions/problems. While these elements also come under the general umbrella of mental health, it is for clarity and distinction that they will be referred to as psychological well-being.

Anxiety can be defined as a mental health condition, characterised by prolonged periods of intense and excessive worry and fear, often manifesting as physiological symptoms such as panic attacks (World Health Organisation, 2023). It has been previously found that 6 in 100 people in any given week are diagnosed with generalised anxiety disorder (McManus et al., 2016), as this is just one potential presentation of an anxiety disorder, the number of diagnoses is likely to be higher. In a recent survey, 20% of UK adults surveyed reported feeling anxious most or all of the time (Mental Health Foundation, 2023). While this figure does not necessarily represent diagnoses of anxiety disorders, it is still a

concerning figure, highlighting the prevalence of non-clinical anxiety in the UK. Depression is a mental health condition, characterised by prolonged periods of low mood, lack of interest and pleasure in activities and feelings of emptiness (World Health Organisation, 2020) It has previously been found that 3 in every 100 people receive a diagnosis of depression (McManus et al., 2016), with a recent survey suggesting that around 16% of adults report moderate to severe depressive symptoms (Office for National Statistics, 2023). These figures, although non-clinical, also add to the evidence that depression and depressive symptoms are prevalent and problematic in the UK.

Anxiety and depression can already be evident early in life. A large number of young people experience mental health conditions, with nearly one third of 16-24 year olds reporting symptoms of anxiety or depression (Office for National Statistics, 2020). Children and adolescents are also at risk, with research suggesting that 1 in 6 experience a mental health condition (Newlove-Delgado et al., 2021). People experiencing either anxiety or depression are likely to have issues with social outcomes including avoidance of social activities, reduced friendship quality, loneliness and social withdrawal (Achterbergh et al., 2020; Etkin et al., 2022) which all have negative impacts on the individual.

Stress is likely to contribute to the prevalence of both anxiety and depression. A survey by the Mental Health Foundation (2018a) found that adults who reported feeling stressed, also reported feeling symptoms of anxiety (61%) and depression (51%). Research has also found that exposure to stress is a risk factor to the development of anxiety and depression (Kalin, 2020). In addition to anxiety and depression, those who have experienced stress also reported self-harm, suicidal thoughts and feelings as well as loneliness (Mental Health Foundation, 2018a). Given the high prevalence of stress, which as discussed at the beginning of this chapter, is prevalent across the lifespan, combined with the negative

mental health consequences associated with stress, makes stress a key area to address to support mental health, particularly anxiety and depression.

In England in 2021/22, 13.8% of local NHS funding allocation was spent on mental health services. Despite this investment, people can be left waiting up to 229 days for access to talking therapies and support (Baker & Kirk-Wade, 2023), with this delay having the potential to cause mental health conditions to worsen. In addition to these waiting times, the NHS has seen an increase in referrals for talking therapies by 24.5%, from 1.46 million in 2020-1 to 1.81 million in 2021-22 (NHS Digital, 2022), putting demand on available resources. Issues surrounding mental health also have an effect on other areas of society, with approximately half of all cases of time taken off work due to ill health, being related to stress, anxiety or depression, with a total of 17.1 million working days being lost to stress, depression or anxiety in 2022/23 (HSE, 2023).

Therefore, it is essential to help reduce the burden of mental health issues, both for individuals and society as a whole. One potential way to help reduce the burden of mental health issues could be to intervene early, prior to the need to access mental health care or services. Due to the apparent influence that stress can have in relation to mental health as described above, reducing the impact of stress could be a beneficial way of providing early intervention for mental health.

Altering the Impact of Stress

There are many potential ways to alter the impact of stress on individuals and thus the influence it can have on mental health. A number of methods have focussed on trying to reduce the stress, for example spending time in nature (Kondo et al., 2018) or removing the source of the stress. While these examples are useful and may remove or reduce stress to a degree, it is not always possible or appropriate to completely remove all stress from life. For

example, while it may be possible to remove some work-based stressors (e.g., by delegating tasks), it may not be possible to remove stressors such as family illness. Additionally, it may not be desirable to remove all sources of stress. Some highly positive experiences in an individuals' life, such as having and raising children, developing and maintaining long term relationships and a dream career, can all also induce stress (Crum et al., 2020). However, these are types of stress that help an individual achieve and flourish in the type of life they want through personal growth, making these stresses essential and even desirable for an individual's development (Crum et al., 2020). Therefore, instead of trying to remove stress entirely, it would be beneficial to find ways to lessen the potential negative impact of stress when it does occur, in order to reduce the negative effect, it could have on mental health and well-being.

One way to reduce the negative impact of stress could be to change the way that stress is appraised. In their widely cited and highly regarded Transactional Model of Stress and Coping (TMSC), Lazarus and Folkman (1984), posit that how someone copes with stress is dependent on how they appraise it. The TMSC suggests that in the face of a stressful situation, the individual performs an evaluation of the situation, examining it as either an opportunity for growth/gain, which can be referred to as a challenge appraisal, or as the risk of harm/loss, which can be referred to as a threat appraisal. The appraisal of the situation as a challenge or a threat is proposed to depend on the resources available to an individual (Lazarus & Folkman, 1984). This is supported by the biopsychosocial (BPS) model (Blascovich & Tomaka, 1996). The BPS model suggests that the appraisal of task demands is weighed up against an individual's perceived available resources, with this process occurring either consciously or subconsciously (Blascovich & Mendes, 2000). When an individual perceived that their resources meet or exceed the demands of a situation they appraise the task as a

challenge and when perceived resources do not meet or exceed the demands of a situation it is appraised as a threat (Blascovich & Mendes, 2000). Key factors proposed to influence the perceived resources an individual has (and thus whether they enter a challenge or threat state) include dispositions such as a person's confidence (i.e., greater confidence typically being associated with greater levels of perceived resources; (Blascovich et al., 2004). The degree to which a challenge or threat appraisal is experienced determines the individuals ability to cope, with those experiencing a challenge appraisal more able to better cope with situational demands, where those experiencing a threat appraisal are not as able to cope with the demands (Nicholls et al., 2012). To this end, research in adults involved in sports has shown that a challenge appraisal is associated with both lower levels of perceived stress and higher proactive coping, whereas a threat appraisal has been seen to be associated with higher perceived stress and lower proactive coping (Beevor et al., 2023). Additionally, challenge appraisal has been seen to be associated with improved performance in various contexts than compared with threat appraisal (Hase et al., 2019). Therefore, it would be beneficial to facilitate a challenge appraisal within individuals to help cope with stressful situations, so it is important to find a way to push a person towards a challenge appraisal.

The TMSC benefits from being applicable on an individual level by focusing on how an individual interacts with the environment to create stress, and not focusing solely on the environment or stressor(Biggs et al., 2017)This allows for differences in what is considered to be a stressor and how the stressor is coped with. Additionally, the TMSC is dynamic in nature, allowing for each stressor to be repeatedly appraised, depending on the resources has available to them at the time of the stressor presentation(Biggs et al., 2017). The TMSC is widely cited and respected and has been instrumental in the development of the stress

and coping literature (Biggs et al., 2017). The TMSC also provides a base for other theories to potentially be integrated, for example, the TMSC emphasises the importance of resources, therefore theories relating to development of resources could be linked to the TMSC. Therefore, this thesis will use the TMSC to underpin the suggestion that altering the impact of stress could be done through how stress is appraised.

The Potential Role of Self-Esteem

In order to help facilitate a challenge appraisal as opposed to a threat appraisal, it is important to increase an individuals' available resources. According to Juth et al. (2008), self-esteem magnifies the perception an individual has of their available resources. Self-esteem can be defined as an individuals' appraisals of themselves, including subjective opinions on their own self-worth and self-respect, (Sedikides & Gress., 2003) ultimately culminating in how positive or negative a person feels about themselves (Sonstroem, 1998). Self-esteem has been seen to be relatively stable, with slow development across the lifespan, leading self-esteem to often be considered as a trait disposition (Abdel-Khalek, 2016). However, some research suggests that self-esteem can be affected by short term fluctuations in response to threats to components such as self-worth (Heatherton & Wyland, 2003). Additionally, systematic reviews and meta-analyses indicate that it is possible to apply interventions such as cognitive behavioural therapy and physical activity to actively increase self-esteem (Liu et al., 2015; Niveau et al., 2021). Therefore, although self-esteem is often seen to be largely stable, it is important to acknowledge that it can undergo changes in response to individual situation or intervention.

Benefits of high self-esteem include that those possessing higher self-esteem have been seen to be more confident in their abilities to succeed in a challenging situation (Pruessner et al., 1999). Furthermore, self-esteem has the potential to influence an

individual's confidence – a proposed predictor of perceived resources (Blascovich & Mendes, 2000) – with self-esteem having been seen to positively predict levels of self-confidence (Coudevylle et al., 2011). Linking back to the TMSC, this literature suggests that self-esteem magnifies the perception of available resources (Juth et al., 2008) and thus higher levels of self-esteem are likely to be associated with greater levels of perceived resources, meaning and individual is more likely to appraise stressful situations as a challenge. In support of this notion, from a physiological perspective, greater self-esteem has been seen to be associated with lower cortisol and autonomic stress reactivity (Seeman & Lewis, 1995), both of which are more reflective of a challenge rather than a threat appraisal (Meijen et al., 2020). Based on the literature described above, facilitating a challenge appraisal could be accomplished through greater resources, with perceived resources being inflated by self-esteem, making self-esteem a key variable in altering the impact of stress.

Self-esteem has also been seen to be associated with a higher ability to tolerate distress (Abdullah et al., 2020), a key factor in helping to reduce overall stress. Self-esteem has been seen to be directly associated with stress, for example, one study showed that low self-esteem was associated with higher reports of stressful thoughts and more severe perceptions of stress in response to stressful experiences (Juth et al., 2008). Additionally, a meta-analysis of longitudinal studies found that low self-esteem predicted both anxiety and depression (Sowislo & Orth, 2013), showing the importance of self-esteem for promoting mental health. Therefore, it would be beneficial to find ways to increase self-esteem in order to both directly improve stress and mental health, but also to increase resources and facilitate a challenge appraisal, with a challenge appraisal being associated with lower stress.

As discussed above, stress has been found to be associated with both higher anxiety and higher depression, so finding a way to combat stress, such as through increased self-esteem or more facilitative (challenge) stress appraisals would be highly beneficial. One way that has been previously seen to be associated with self-esteem, reduced stress, and improved mental health is physical activity.

Physical Activity

Physical activity (PA) can be defined as any body movements that result in the expenditure of energy, above and beyond that of a resting rate (Caspersen et al., 1985). Physical activity can be performed at different intensities. Intensities of PA are divided into categories based upon the metabolic equivalent of the task (MET), which is based upon the energy expenditure used to perform PA (Bull et al., 2020). Light intensity PA is defined as activity that is performed at a rate of between 1.5 and 3 METs, which is equivalent to a rate of perceived exertion (RPE) of 2-4 on a scale from 0-10 (0 being low exertion). This rate of exertion is characterised by a non-substantial increase in heart rate and breathing. An example of light intensity PA is slow walking (Bull et al., 2020). Moderate intensity PA refers to activities performed at between 3 and <6 METs, equating to an RPE of 5-6 out of 10 (Bull et al., 2020). This moderate PA is characterised by breathing becoming more difficult than usual, such as light lifting or regular paced cycling (Craig et al., 2003). Vigorous intensity PA is defined as PA that is performed at 6 or more METs with a RPE of 7-8 out of 10 (Bull et al., 2020). Vigorous PA is characterised by high physical effort and breathing becoming much harder than normal, with activities including vigorous cycling or heavy lifting (Craig et al., 2003).

Exercise is a specific type of PA, and is defined as planned, structured PA that has an aim such as actively seeking to improve or maintain physical fitness (Caspersen et al., 1985).

Consequently, while all exercise could be classed as a form of PA, not all PA is exercise. While investigating both PA and exercise have their benefits, PA captures both lifestyle activities and exercise, making it more all-encompassing for examination. Additionally, examining relationships between PA and stress and well-being may be beneficial for the development of any future intervention for reducing stress. While structured exercise may seem intimidating, and following a structured exercise plan may seem unattainable, particularly to those who are largely inactive, focusing on increasing (light) PA may seem a more feasible start point. Therefore, this thesis will focus on the relationship between PA and stress.

Physical Activity and Physical and Mental Health

There is ample evidence for the health benefits of PA, including reduced risk for physical health conditions, e.g., cardiovascular disease, type 2 diabetes, colon cancer, and hypertension (Warburton & Bredin, 2019). Evidence even suggests that there is no minimum PA threshold to obtain these health benefits, that just moving more would have beneficial effects (Warburton & Bredin, 2017). Especially for those with low levels of PA, increasing light intensity PA is associated with reduced risks for cardiometabolic health issues and mortality (Chastin et al., 2019). These health benefits are reflected in UK PA guidelines: adults are recommended to undertake at least 150 minutes of moderate-intensity PA per week for optimal health benefits, while also stating that 'some is good, more is better' to recognise the benefits of any type of PA for health (Department of Health and Social Care, 2019).

In addition to the positive benefits for physical health, PA has been found to be associated with psychological health. Physical activity has been found to be associated with a reduction in many negative mental health conditions, including anxiety and depression. A

recent review of systematic reviews highlights the benefits of PA for both anxiety and depression in the general population, people with diagnosed mental health conditions and people with chronic health conditions (Singh et al., 2023). Medium effects for anxiety and depression reductions were found across all included populations, with all intensities of PA, particularly higher intensities, being beneficial (Singh et al., 2023). In addition, Wipfli et al. (2008) found that exercise was as effective for reducing anxiety as cognitive behavioural therapy (CBT) – a common method for treating anxiety.

Similarly, in a systematic review and meta-analysis into PA and depression, Gianfredi et al. (2020), found that based on the analysis of data from studies using a range of designs, PA was associated with lower depression with a review of evidence from randomised control trials finding that exercise was as effective for depression as antidepressant medication compared with control groups in non-severe depression (Recchia et al., 2022). Rebar et al. (2015), supported the findings outlined above in their meta-meta-analysis, with PA being found to reduce anxiety and depression in non-clinical populations. Collectively, these findings highlight the benefits of PA for reducing anxiety and depression. It is therefore not surprising that the NHS recommends PA as a treatment for both anxiety and depression (NHS, 2022a, 2022b). .

However, when suggesting the use of PA for mental health benefits, it is important to consider the PA domain. Physical activity can be completed across many different domains, for example during leisure time, commuting or at the workplace. It is important to consider the domain of PA when examining any relationship between PA and mental health as some domains of PA may yield better mental health outcomes. For example, in their meta-analysis White et al. (2017) found that while leisure time PA and PA for transport were both positively associated with mental health, leisure time PA and school sport were

inversely associated with mental ill health. However, PA in the workplace was found to be positively associated with mental ill health, while no associations were found between household PA or physical education classes and mental health. Therefore, the domain of PA is important to consider, when examining the PA and mental health relationship.

Physical activity is also cited to have influences on positive elements of psychological well-being, including increased happiness (Zhang & Chen, 2019), subjective vitality (Dodge et al., 2022), and life satisfaction (An et al., 2020). Physical activity is also associated with increased self-esteem. In their systematic review into PA and mental health in children and adolescents, Lubans et al. (2016) propose three hypotheses for how PA relates to mental health. These are the neurobiological hypothesis, which proposes that PA enhances mental health through changes in brain function and structure; the behavioural hypothesis, which suggests that PA leads to behaviours, such as improved sleep, that are associated with better mental health, and the psychosocial hypothesis. The psychosocial hypothesis suggests that PA is related to better mental health through a range of psychosocial determinants, with a key determinant being self-esteem. While Lubans et al. (2016) present evidence that PA is associated with self-esteem through other factors such social connectedness and self-perceptions, they also highlight a direct relationship between PA and increased self-esteem, highlighting the importance of PA for self-esteem.

Examining the Association between Physical Activity and Stress

Physical activity has also been found to be associated with lower stress, with PA also used as a way of managing stress. Indeed, when interviewing a group of physicians, PA was specifically cited as a way in which participants managed their stress post work (Lemaire & Wallace, 2010). In support of this, in their systematic review and meta-analysis of the PA, and mental health literature, Rodriguez-Ayllon et al. (2019) present a range of research

involving pre-schoolers, children and adolescents (ages 2 through to 18). Cross-sectionally, a total of 4 studies examining cross-sectional associations between PA and stress were examined, with all 4 studies finding PA was associated with reduced stress (Rodriguez-Ayllon et al., 2019). However, despite these findings all supporting a beneficial relationship between PA and stress, the cross-sectional evidence is not unequivocal. For example, when examining the relationship between PA and stress in college students, Hubbs et al. (2012) found that there was no association. Similarly, Chacón-Cuberos et al. (2019) also found no association between PA and academic stress. While these are not an exhaustive set of examples of the different types of PA and stress relationship, these studies do highlight that the PA and stress relationship is not as simple as PA is beneficial for stress.

Additionally, in their systematic review on stress and PA, Stults-Kolehmainen and Sinha (2014) present evidence indicating that the relationship between PA and stress is bidirectional, with PA predicting stress and stress predicting PA. When examining data collected at a single time point (encompassing cross-sectional, retrospective and qualitative data), Stults-Kolehmainen and Sinha (2014) found equivocal results. Of the studies utilising cross-sectional studies, 67% reported that higher stress was associated with lower levels of PA. Of the remaining 33% of cross-sectional studies, 26% found no association between stress and PA and 14% found a positive association between stress and PA (Stults-Kolehmainen & Sinha, 2014). All studies utilising qualitative or retrospective methods however, showed that stress was associated with reduced PA (Stults-Kolehmainen & Sinha, 2014).

Studies have also examined the PA and stress relationship longitudinally. In their review in children and adolescents, Rodriguez-Ayllon et al. (2019) included 2 studies utilising longitudinal analysis. One study spanned 5 years, with PA being reported yearly and stress

only being reported at the final assessment at the end of the 5 years, whereas the other study took place over the course of a year, with a PA measurement being taken at time one, and a stress measurement at time two. Both studies found that higher levels of PA predicted lower levels of stress at the final time point (Rodriguez-Ayllon et al., 2019). Similarly, when examining studies with multiple time points ranging from 2 weeks to years in the future Stults-Kolehmainen and Sinha (2014) found in approximately 77% of all studies included that stress was associated with lower PA. However, approximately 15% and 18% respectively found either no association or a positive association between stress and PA (Stults-Kolehmainen & Sinha, 2014), also showing that although the most common relationship between stress and PA is negative, this is not consistent.

Improving stress through the use of PA has also been the target of interventions. A randomised control trial in adults examining the effect of PA on stress, however reflected benefits. Participants receiving a 24-week aerobic (heart rate at between 50% and 75% of max) and weight training activity intervention, reporting significantly less stress than adults in a control group not receiving the PA programme (Atlantis et al., 2004). However, a non-randomised intervention examining Tai-Chi for stress reduction, found that there was no significant difference in stress between pre- and post-intervention (Lee et al., 2013). The difference in findings between these two interventions could be as a result of the lack of randomisation in the study by Lee et al. (2013). Additionally, there are also differences in the type of PA used across the two interventions, with Tai-Chi used by Lee et al. (2013) typically being at a much lower intensity than the aerobic activity offered by Atlantis et al. (2004).

Other interventions have examined the effect of different intensities of PA on stress. For example, in two interventions examining vigorous intensity PA, one found an effect of

vigorous PA on decreased stress (Norris et al., 1992), whereas the other found no effect (Rotheram-Borus et al., 2016). Interventions examining moderate-vigorous PA, again had differing results, for example with one intervention found moderate-vigorous PA found decreased stress (Baghurst & Kelley, 2014) and where another found no effect (Khalsa et al., 2012). An intervention examining moderate PA and stress was also been found to reduce stress (Norris et al., 1992). While there is evidence from cross-sectional, longitudinal and intervention studies that there can be a relationship between PA and lower stress, this is far from consistent. This could be as a result of the intensity of the PA, or potentially a factor that is not being measured within the studies that is altering or driving the relationships.

One potential reason for the inconsistent associations seen when examining the PA and stress relationship is the way in which the relationships are examined. One issue with the way in which PA and stress is examined is the lack of consideration for variables that could underpin the relationship. It is possible that a relationship between PA and stress only exists as the result of another variable. For example, as discussed earlier, reappraising stress through a challenge appraisal, driven by self-esteem, has the potential to alter how stress is viewed and thus the impact of stress on mental health and well-being. Additionally, it is possible that PA only relates to stress when that stress is having a negative impact on a persons' mental health and well-being. For example, as mentioned earlier, some forms of stress, such as raising children may be seen as positive (Crum et al., 2020), thus PA may not have an impact on stress or stress appraisals in this instance. Examining additional variables such as stress appraisals and how these variables may function within the PA and stress relationship would be beneficial to more thoroughly understand the PA and stress relationship as a whole.

One potential way to examine how these variables may influence the associations between PA and stress is through path analysis. Path analysis allows for the inclusion of multiple variables in addition to the main relationship of interest, allowing for the examination of multiple direct and indirect effects simultaneously (Byrne, 2010). Path analysis also allows for the creation of a visual interpretation of the proposed relationships in the format of a path model, (Byrne, 2010), providing clarity on not just whether variables are associated, but how these variables are associated and how they work together in a sequential manner. For example, based on the assumption that there are additional factors, such as challenge and threat appraisals, underpinning the PA and stress relationship, a path model allows for these factors to be examined at the point in the relationship they are proposed to function.

Another limitation of previous studies examining PA and stress research (or a factor not considered when interpreting the findings) is how stress and PA are measured. Studies often use measures that are a reflection over a period of time (e.g., over the course of a month) of overall stress and overall PA, taken at a single time point. However, it is known that both PA and stress fluctuate over time (Shang et al., 2018; von der Embse & Mankin, 2021). These fluctuations in PA and stress cannot be observed using the reflective measurements described above, potentially meaning that existing associations are not captured. To properly examine these potential fluctuations in PA and stress, relationships between the two need to be examined in a more sophisticated manner.

One potential way to do this is through multilevel analysis. Multilevel analysis not only allows for the examination of relationships over time, but it also allows for the examination of both between- person (deviation from a group mean) and within-person (deviation from individual mean) relationships simultaneously (Hoffman, 2015). Between-

person analysis examines the relationships in more general terms, for example if overall levels of PA are related to the overall levels of stress (Hoffman, 2015). Between-person associations are generally the relationships traditionally seen when examining PA and stress relationships (as described above). Within-person analysis allows the researcher to capture how the PA and stress relationship functions on an individual level, so it can examine whether a person doing more PA on a given day relates to their stress levels of that given day (Hoffman, 2015). Multilevel analysis also allows for an exploration of other factors that can influence the associations between PA and stress (Hoffman, 2015).

Examining the PA and stress relationship in the more sophisticated way described above (path analysis and multilevel analysis), allows for a more meaningful, comprehensive understanding of the PA and stress relationship above and beyond classic analyses. When utilising these techniques to examine the PA and stress relationship, it is also important to consider populations in which examining these relationships would be particularly beneficial in order to appropriately measure any potential mechanisms for example. One key population that could benefit from reducing stress is adolescents and young people.

Adolescents and Young People

As previously mentioned, stress is prevalent across the lifespan. Adolescents, defined by the World Health Organisation (2018) as those aged 10-19-years-old, are a population that suffer from stress. As previously mentioned, up to 45% of adolescents report feeling stressed (Roy et al., 2015). Similarly, 60% young people (aged 18-24- years-old) have also reported feeling so stressed that they cannot cope (Mental Health Foundation, 2018a). These statistics are perhaps not surprising as both adolescents and young people experience many different sources of stress. For example, adolescents have a lot of academic pressures including school and GCSE and A level examinations (Chamberlain

et al., 2011; Roome & Soan, 2019), as well as developing a sense of self and identity. Young adults have the added stresses of starting university or employment and leaving home for the first time (van Sluijs et al., 2021), with these conditions meaning they can no longer rely on parents or caregivers as much for support with daily living tasks such as cooking.

As previously stated, stress can have a negative impact on mental health, with the same being true for adolescents and young people (Gianfredi et al., 2020; Rodriguez-Ayllon et al., 2019; Stults-Kolehmainen & Sinha, 2014). In fact, it was estimated that globally, more than 13% of adolescents were living with a diagnosed mental health condition (Keeley, 2021), with UK statistics in those aged 17-24 suggesting a 22% prevalence rate for mental health conditions (Newlove-Delgado et al., 2022). During the month of August in 2023, nearly 415,000 people were in contact with children and young people's NHS mental health services, with the majority of these being under the age of 18 (NHS England, 2023), showing the sheer demand on mental health services for this age group. A large scale, global meta-analysis has suggested that almost 50% of first occurrences of mental health problems emerge before the age of 18 (Solmi et al., 2022). As it has been found that 75% of all mental health conditions emerge before the age of 24 (Mental Health Foundation, 2018a), it is essential to help prevent mental health conditions before they occur. This could potentially be done through helping to manage the impact of stress on this age group.

Physical Activity, Self-Esteem, Stress and Mental Health in Adolescents and Young People

As discussed above, PA has been seen to be associated with reduced stress, and lower mental health problems such as anxiety and depression. These associations can also be seen in adolescents and young people. In their review of reviews into PA and adolescent mental health, Biddle et al. (2019) found that PA interventions show a moderate effect size for the reduction of depression and varied but significant effect sizes for reductions in

anxiety. Additionally, Rodriguez-Ayllon et al. (2019)'s review found that in adolescence, PA is associated with significantly lower stress. It is also important to note the role that PA in adolescence could play in preventing mental health problems. Evidence from a 20 year cohort study states that being persistently active from time point 1 (aged 9-15) through to a follow up 20 years later resulted in at least a 50% reduction in risk of developing depression (McKercher et al., 2014). Similarly, a meta-analysis including children, adolescents and young adults found that higher levels of self-reported PA were protective against later anxiety (measured at least 1 year later) (Schuch et al., 2019). Combined, these findings demonstrate the potential protective nature of PA from both anxiety and depression. This further emphasises the benefits of PA for adolescents and young adults in order to improve mental health and reduce the associated public health issues such as NHS waiting times and further mental health problems later in life.

Despite the evidence presented above that shows the benefits of participating in PA for self-esteem, stress and mental health problems in adolescence and young adulthood, evidence suggests that this population may not be may not be sufficiently physically active. It is recommended that adolescents should participate in 60 minutes of moderate intensity PA per day (NHS, 2021b), but evidence suggests that less than 50% of under 18-year-olds are meeting PA guidelines (Sport England, 2021), with there being suggestion that 80% of adolescents globally not being sufficiently active (van Sluijs et al., 2021). Generally young adults appear to be better at meeting PA guidelines of at least 150 minutes per week (across 4-5 days) (NHS, 2021a), with one survey suggesting 76% of students aged 16-24 reported that they met PA guidelines (ukactive Research Institute, 2020). However, as discussed above, 60% of this age group report being highly stressed (Mental Health Foundation,

2018a), suggesting that it may not be PA alone that is beneficial for stress, and there could be other factors underpinning the PA and stress relationship.

As discussed above, PA has been found to be associated with increased self-esteem. For example, in their review, Lubans et al. (2016) found that PA was associated with increased self-esteem, both directly, and indirectly through factors such as increased self-perceptions. Self-esteem has also been found to be associated with elements of mental health. Orth et al. (2008) found that low self-esteem is predictive of depression in adolescents and young adults when examined longitudinally between the ages of 15/16 through to 21. Similar findings have also been evidenced in clinical adolescent populations where high levels of self-esteem at baseline, predict lower levels of anxiety and depression 3 years later (Henriksen et al., 2017). Low self-esteem has also been seen to be associated with higher perceived stress in 18–24-year-olds (Piekarska, 2020). There is also evidence in adolescence that individuals with low self-esteem are more vulnerable to the negative effects of stressful situations (Orth et al., 2009). Thinking back to the TMSC, self-esteem is also likely to play a role in the development of resources (Juth et al., 2008) necessary to adopt the challenge appraisal associated with lower perceived stress in university students (Beevor et al., 2023). These associations demonstrated above suggest that self-esteem could play an important role in the development of good mental health. The evidence suggests that PA is beneficial for self-esteem, and self-esteem is beneficial for stress, anxiety and depression. However, to my knowledge, there is no evidence that links PA, self-esteem, stress, and mental health, despite self-esteem appearing to be a key variable that could explain the PA, stress, and mental health relationships.

Therefore, it would be beneficial to examine the PA and stress relationship within this population to understand how this relationship, and any underpinning factors may be associated with stress.

Summary, Aims and Overview of the Thesis

The evidence presented in the present chapter highlights the negative impact that stress can have on mental health and well-being and the subsequent impact poor mental health has on both the individual, as well as on society as a whole. It also details how stress is appraised may be associated with lower levels of stress and better mental health (and could also explain the relationship between PA and stress levels). Additionally, it is clear that adolescents and young people experience many sources of stress and that this stress has a negative impact upon them and their mental health. With 75% of all mental health conditions emerging before the age of 24 (Mental Health Foundation, 2018a), research in this population is vital and findings could help to act as a preventative measures for reducing the incidence of mental health conditions. While there is evidence that there is a relationship between PA, stress, and mental health, the findings are not consistent. These inconsistencies in the literature could be a result of how the PA and stress relationship is examined, or the influence of other variables explaining the relationship which are overlooked. To be able to develop future interventions that aim to use PA to improve stress and subsequent mental health, it is important to first understand how the PA and stress relationship functions. Therefore, the overarching aim of this thesis was to conduct an innovative examination of the relationship between PA and stress and associations with mental health in adolescents and young people, by exploring potential factors underpinning the relationship by using a variety of sophisticated analytical techniques.

In order to address these aims, both empirical research and a review of the existing literature was undertaken. To begin, Chapter 2 investigated a series of potential mechanisms explaining the PA and stress relationship in adolescents, as well as the subsequent association of stress with the mental health outcomes of anxiety and depressive symptoms. Drawing on the stress appraisal and coping literature, a theoretical model was developed based on existing frameworks, proposing that more PA would be related to lower perceived stress through higher self-esteem, greater perceived resources and challenge appraisal tendencies, lower threat appraisal tendencies, and more distress tolerance. The model was tested using path analysis, with cross-sectional data from 244 adolescent participants aged 15-19.

During the completion of the research presented in this thesis, the unprecedented COVID-19 pandemic struck. As a result of the pandemic, a novel series of conditions were experienced by individuals, including the implementation of stay at home orders and closing of sports and PA facilities (UK Government, 2020), which resulted in different opportunities for PA and lower levels of PA in the populations targeted by this thesis (López-Valenciano et al., 2021; Rossi et al., 2021). In addition, the pandemic provided its own unique set of challenges in respect to this thesis, for example the inability to engage face to face with participants. However, the pandemic did provide a novel set of circumstances, acting almost as a naturally occurring intervention, allowing for the examination of the PA and stress relationship under these unique conditions.

Based on the onset of the COVID-19 pandemic, Chapter 3 sought to examine the extent to which PA was associated with adolescent mental health alongside a novel and stressful life event (i.e., the COVID-19 pandemic). Specifically, the study aimed to examine the extent PA could protect against any negative impact of Coronavirus concerns on mental

health and well-being during lockdown. A secondary aim was to investigate any effect of gender on these variables. Cross-sectional data was collected from 165 adolescent participants from the United Kingdom (UK) in May 2020 during the first wave of the COVID-19 pandemic with the most stringent restrictions. Hierarchical liner regressions were utilised to address these research aims.

Chapter 4 looked to extend on the findings of Chapter 2 and 3 by examining the PA and stress relationship longitudinally, with measurements of PA and stress being taken at different levels of COVID-19 restrictions during wave 2 of the COVID-19 pandemic between October 2020 and January 2021. Chapter 4 also aimed to re-examine similar proposed factors to Chapter 2, i.e., self-esteem, stress appraisals, to see if these relationships were also present during longitudinal examination. These aims were addressed using multilevel analyses of data from 90 participants aged 18-24.

Chapters 2 and 3 examined the PA and stress relationship at one time point, whereas Chapter 4 examined the PA and stress relationship over the course of a few months. However, as previously mentioned, PA and stress both fluctuate within and between days, making it necessary to examine the relationship in a way that can capture these fluctuations. Chapter 5 presents a scoping review investigating the PA and stress relationship, with the inclusion of the sedentary behaviour (SB) and stress relationship. The specific aims of the Chapter were to establish what, if any, concurrent (a measurement of PA/SB and stress, taken at the same time, reflecting the same time period e.g., daily averages), and prospective (associations between PA/SB or stress at one time point, with stress or PA/SB at a later time point, e.g., the association between stress measured on the hour, and PA measured 30 minutes later) relationships between PA/SB and stress (and vice versa) exist. To address these aims, studies included within the review had to utilise an

618 ecological momentary assessment methodology, a method collecting multiple assessments
619 of data in real time (Shiffman et al., 2008), to collect data on the PA/SB and stress
620 relationship. This methodology allows for the examination of between and within-person
621 associations (as explained above in relation to multilevel analysis) as well as concurrent and
622 prospective associations.

Chapter 2

Examining the Associations Between Physical Activity, Self-Esteem, Perceived Stress, and Internalizing Symptoms in Older Adolescence.

This chapter is published under the following reference:

Wright, L. J., Veldhuijzen van Zanten, J. J., & Williams, S. E. (2023). Examining the associations between physical activity, self-esteem, perceived stress, and internalizing symptoms among older adolescents. *Journal of Adolescence*, 95(6), 1073-1287.

Abstract

In older adolescence, stress has been found to be prevalent. It has been seen that higher physical activity relates to lower stress levels, which in turn relate to fewer anxiety and depressive symptoms (internalising symptoms). However, how these associations function is not fully understood. Physical activity is strongly associated with greater self-esteem in adolescents. As greater self-esteem is thought to aid better coping with stress and has been seen as beneficial for mental health in adolescents, physical activity may be associated with lower stress and better mental health through self-esteem and more adaptive stress appraisals. Therefore, the aim of the study was to examine the relationships between physical activity, self-esteem, stress, and mental health. A cross-sectional design was employed, and path analysis was implemented. Physical activity, self-esteem, stress appraisals, distress tolerance, perceived stress, anxiety, and depression, were assessed using online questionnaires from 244 adolescent participants from the United Kingdom (aged 15-19, M = 16.75 [SD = .82], 145 female). Path analysis revealed that physical activity was associated with lower perceived stress through increased self-esteem, adaptive appraisals, and higher distress tolerance (total standardised indirect effect; p = .007 (-.25 – -.11). Moreover, lower perceived stress was associated with lower anxiety (standardised direct effect; p <.001 (2.65 – 4.0) and depressive symptoms (standardised direct effect; p <.001 (.33-.63). Findings suggest that higher physical activity could be an effective in improving mental health in older adolescents, due to its association with perceived stress through higher self-esteem and more adaptive appraisals of stress.

Key Words: Mental Health, Stress, Adolescence, Stress Appraisals, Self-Esteem, Path Analysis

Introduction

Adolescence is an incredibly stressful time, characterised by periods of change (e.g., puberty, changing schools), academic pressures (e.g., examinations), as well as beginning the transition into adulthood (Byrne et al., 2007; Pascoe et al., 2020). Worryingly in the UK, an estimated 20-45% of adolescents report feeling stressed (Roy et al., 2015). Older adolescence is defined by the World Health Organisation (2018) as those adolescents who are between the ages of 15 and 19 years old. This particular age group are likely to be at risk of elevated stress levels due to added academic pressures from GCSE and A-level examinations, applying for university or post-education employment, and establishing an identity (Chamberlain et al., 2011; Roome & Soan, 2019). Indeed, research demonstrates that older adolescents report higher perceived stress than their younger counterparts (Tully et al., 2009). The prevalence of stress in these adolescents has only been exacerbated in recent years by the COVID-19 pandemic (Paschke et al., 2021) due to factors such as school closures, cancelled examinations, social isolation resulting from stay-at-home restrictions, as well as fear of the COVID-19 virus (Alimoradi et al., 2022; McCluskey et al., 2021; Wright et al., 2021), with older adolescents reporting higher posttraumatic stress reactions than younger adolescents (Schwartz et al., 2021).

Stress is a predictor of poor mental health such as increased anxiety (Schneider et al., 2021) and depression (Hammen, 2005), meaning the exacerbated stress experienced in older adolescence is likely a key contributor to the prevalent levels of poor mental health observed in this population. Globally approximately 14% of older adolescents are predicted to have a mental health disorder (UNICEF, 2021) and UK based adolescents (17-19) have seen increases in probable mental health conditions from 1 in 10 17-19 year olds in 2017, to as many as 1 in 4 17-19 year olds in 2022 (Newlove-Delgado et al., 2022). Additionally, as

discussed in the thesis introduction, adolescents make up a large proportion of those accessing mental health care services (NHS England, 2023). A large scale meta-analysis suggests that nearly 50% of all first instances of mental health problems occurs before the age of 18 (Solmi et al., 2022), making it vitally important to intervene in an adolescent population. Considering it is not always possible to remove stressors, it is vital to identify ways to help older adolescents cope with stress to lead to better well-being and reduced mental health problems such as decreased anxiety and depression.

The literature presents many theories and frameworks to explain how better coping with stress arises. One of the most prevalent and well supported frameworks is Lazarus and Folkman (1984) Transactional Model of Stress and Coping (TMSC), which proposes that how someone copes with stress is determined by how they appraise it. The TMSC proposes that when an individual is confronted with a stressful situation, they evaluate the potential for either growth/gain or harm/loss (Lazarus & Folkman, 1984). Harm or loss is described as threat appraisal while growth or gain refers to challenge appraisal. The TMSC (Lazarus & Folkman, 1984) suggests that while challenge and threat appraisals are not mutually exclusive, the degree to which someone experiences a challenge or threat appraisal can determine how they cope, with stress appraisaed as a challenge leading to more adaptive coping (Nicholls et al., 2012). In contrast, a threat appraisal is associated with more debilitative coping, lower distress tolerance (i.e., lower ability to tolerate distress) and higher perceived stress (Nicholls et al., 2012). Consequently, challenge appraisals are thought to be associated with greater distress tolerance and lower percieved stress (Lee et al., 2018; Trotman et al., 2018).

The TMSC proposes an indivdual experiencing a challenge appraisal is likely to feel more capable of drawing on available resoruces (Lazarus & Folkman, 1984). The contextual

model of stress and coping proposes that the appraisal of stressful events is influenced by three factors: 1) the nature of the event, 2) the social context that the event occurs, and 3) stable aspects of the self (DeLongis & Holtzman, 2005). Self-esteem (i.e., how positive a person feels about themselves; (Sonstroem, 1998) is a stable aspect of the self that has been proposed to be a key resource that individuals use when exposed to stressful situations (Taylor & Stanton, 2007). In support, research has demonstrated associations between self-esteem, and secondary appraisals of stress (the extent the stress exceeds perceived resources; (Juth et al., 2008). Specifically, Juth et al. (2008) explained "self-esteem thus appears to serve to magnify the perception of available resources, their perceived effectiveness or potency, or itself functions as a resource during secondary appraisal" Furthermore, individuals with higher levels of self-esteem are likely to possess greater confidence in their ability to succeed in a challenging situation (Pruessner et al., 1999) and a more positive sense of self or greater self-esteem has been associated with lower autonomic and cortisol stress reactivity (Seeman & Lewis, 1995) – these characteristics are reflective of appraising stressful scenarios as a challenge rather than a threat (Meijen et al., 2020). Collectively, this research suggests that adolescents displaying greater self-esteem are likely to exhibit greater perceived resources and be more likely to appraise stressful scenarios they encounter as a challenge rather than a threat, which in turn relates to being better able to cope with and tolerate stress. In support of this proposal, adolescent research shows that higher self-esteem is associated with a greater distress tolerance (Abdullah et al., 2020), and greater distress tolerance is associated with lower perceived stress (Ozcan, 2019). Therefore, based on the TMSC, it can be proposed that higher levels of self-esteem will be associated with lower perceived stress through more adaoptive stress appraisals and greater distress tolerance. As such, identifing factors associated with greater

738 self-esteem in adolesents appears to be highly beneficial for trying to elicit more adaptive
739 appraisal and coping with stress. This is likely to relate to lower anxiety and depressive
740 symptoms (Lee et al., 2018; McHugh et al., 2014).

741 One activity that has been consistently linked to higher self-esteem in adolescents is
742 engagment in physical activity (PA). Lubans et al. (2016) stated that while a wealth of
743 litearture desmonstrates the relationship between PA and mental health and well-being in
744 children and adolescents, the underlying mechanisms have yet to be established.
745 Conseuqently, they conducted a systematic review of the literature after presenting a
746 conceptual model proposing 3 hypotheses for how PA could benfit adolescent and young
747 people's mental health and well-being. The three proposed hypotheses were: (1) the
748 neurobiological hypothesis (PA enhances cognition and mental health via changes in brain
749 structural and functional composition), (2) the behavioural hypothesis (PA leads to changes
750 in behaviors that are related to better mental health such as improved sleep), and (3) the
751 psychosocial hypothesis (PA relates to better mental health via psychosocial determinants).
752 Results of the systematic review showed the strongest evidence for the psychosocial
753 hypothesis with PA being associated with greater self-esteem. Although this was in part
754 through mechanisms such as self-perceptions and social connectedness, evidence from the
755 review also indicated direct effects from PA to increased self-esteem independent of other
756 mechanisms (Lubans et al., 2016). The positive relationship between PA and self-esteem has
757 also been evidenced in another systematic reviews in adolescents (Biddle et al., 2019), with
758 research suggesting improved self-esteem being experienced following just one single bout
759 of exercise (Wood et al., 2013). Therefore, PA appears an important behaviour likely to be
760 associated with greater self-esteem and better mental health and well-being.

Lubans et al. (2016) psychosocial hypothesis suggests adolescent PA relates to greater self-esteem which reflects better mental health and well-being. Drawing on the TMSC (Lazarus & Folkman, 1984), it can also be proposed that this greater self-esteem, arising from PA, may also relate to better mental health through enabling adolescents to more adaptively appraise and cope with the day to day stress they encounter. However, to our knowledge, research has not yet examined whether Lubans et al.'s (2016) psychosocial hypothesis of PA can be integrated with the TMSC (Lazarus & Folkman, 1984). Therefore, the aim of the present study was to integrate these two theories and examine the indirect relationship between PA, perecived stress, and anxiety and depressive symtoms in an adolescent population via self-esteem, perceived resources, challenge and threat appraisals, and distress tolerance.

Hypothesised Model

The full hypothesised model is presented in Figure 2.1a. Based on the aforementioned theories in the liteature, physical activity was hypothesised to positively relate to self-esteem, which was in turn expected to be positively associated with perceived resources, challenge appraisal, and distress tolerance, while being negatively associated with threat appraisal and perceived stress. Resources were predicted to be negatively associated with threat appraisal and positively associated with challenge appraisal, while threat appraisal was hypothesised to be negatively associated with distress tolerance and positively with perceived stress, and challenge appraisal positively associated with distress tolerance and negatively with perceived stress. Distress tolerance was predicted to be negatively associated with perceived stress (Ozcan, 2019), anxiety and depressive symptoms (McHugh et al., 2014), while perceived stress was expected to be positively associated with anxiety and depressive symptoms (O'Connor et al., 2010). Due to the often co-morbid

785 nature of anxiety and depression (Aina & Susman, 2006) it is likely that there are similarities
786 in how PA relates to both of these constructs. In order to examine any subtle differences in
787 the proposed mechanisms through which PA relates to anxiety and depressive symptoms,
788 the proposed model was tested separately with anxiety and depressive symptoms as
789 outcome variables (see Figure 2.1a).

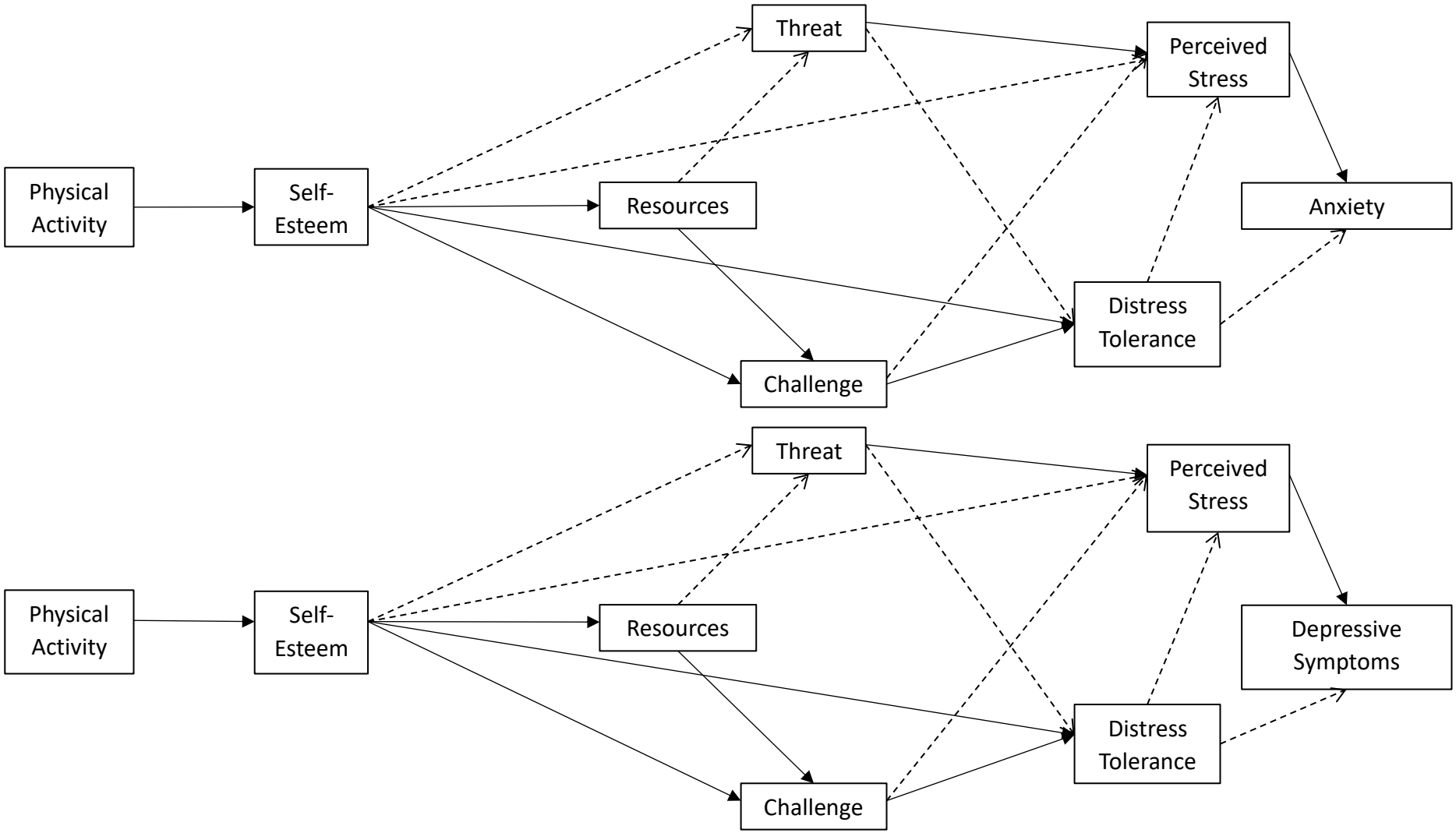

Figure 2.1a: Hypothesised models for the relationships between physical activity and anxiety and physical activity and depressive symptoms. Note: solid lines indicate a predicted positive relationship and dashed lines indicate a predicted negative relationship. For visual simplicity, age and gender control variables and the correlation between challenge and threat appraisal are not depicted.

Methods

Participants

In total, 273 participants aged 15-19 in UK school year 11 and above were recruited via emails to schools and other adolescent targeted organisations (e.g., youth orchestras, sports clubs, youth groups, cadets, youth theatres etc.) across the United Kingdom (UK) as well as social media posts from the research team. Emails were sent by the research team to over 300 schools and organisations throughout England and Wales with the aim of recruiting a diverse sample of adolescents that didn't focus on just one type of person (e.g., those playing sport). The study gained ethical approval from the University Ethics Committee. All participants provided consent, and where appropriate (i.e., if the participant was under 16 years old), a parent/guardian gave informed consent prior to participating in the study.

Questionnaires

Physical Activity

A single item was used to measure PA, whereby participants were asked to select the level which represented their usual level of PA (Jurca et al., 2005). Participants selected the level of PA from five possible levels (1-5), with higher numbers indicating higher levels of PA. Level 1 indicated "Inactive or little activity other than usual daily activities"; Level 2: "Regularly (≥5 d/wk) participate in physical activities requiring low levels of exertion that result in slight increases in breathing and heart rate for at least 10 minutes at a time"; Levels 3-5 were phrased as participation in "aerobic exercises such as brisk walking, jogging, or running at a comfortable pace, or other activities requiring similar levels of exertion" with level 3 being for 20 – 60 minutes per week, level 4: 1-3 hours per week and level 5 for 3 hours+ per week. This item has been used as part of a test of non-exercise estimation of

cardio-respiratory fitness (CRF), where it was found that it provided a good indication of CRF when compared to actual exercise testing (Jurca et al., 2005). Similar single-item measures of PA have been found to be reliable and valid assessments of PA in adolescents, including when compared with objective accelerometer data (Scott et al., 2015).

Self-Esteem

A 4-item version of the Rosenberg Self-Esteem Scale (Guddal et al., 2019) was used to assess self-esteem. Participants were asked to rate each item (e.g., "I have a positive attitude towards myself") on a 4-point Likert scale from 1 (strongly disagree) to 4 (strongly agree). Two items were negatively worded so were reverse scored before summing all items to give an overall self-esteem score (range 4-16), with a higher score indicating a higher level of self-esteem. The 4-item version of the Rosenberg Self-Esteem Scale has been previously used in adolescents and has good internal reliability (Guddal et al., 2019), and was strongly correlated with the full scale (Tambs & Røysamb, 2014), with the full scale having good validity (Rosenberg, 1965). In the present study the questionnaire demonstrated good internal reliability with a Cronbach alpha of .78.

Resources, Challenge and Threat Appraisals

The stress appraisal measure for adolescents (Rowley et al., 2005), was used to measure perceived resources, challenge appraisal and threat appraisal tendencies. The measure consists of 3 subscales: challenge appraisal (4 items, e.g., "I have the ability to overcome stress"), threat appraisal (7 items, e.g., "I perceive stress as threatening") and resources (3 items, e.g., "I have the resources available to me to overcome stress"). Participants were asked to rate the extent to which they generally think or feel each statement when encountering a stressful event. Responses were made on a 5-point Likert scale from 0 (not at all) to 4 (a great amount). Scores for each subscale were then averaged,

with a higher score indicating a greater tendency towards a challenge, or a threat appraisal, and greater resources. Adequate reliability has been found for all subscales and the questionnaire has been validated for an adolescent population (Rowley et al., 2005). In the present study the questionnaire demonstrated good internal reliability for challenge and threat with the Cronbach alpha's being .85 and .80 respectively. The resources subscale demonstrated acceptable reliability with the Cronbach alpha being .67.

Distress Tolerance

The Distress Tolerance Scale (DTS; (Simons & Gaher, 2005) is a 15-item scale, measuring individual components of and an overall level of distress tolerance. The DTS is comprised of 4 subscales: tolerance (3 items, e.g., "Feeling upset or distressed is unbearable to me"), appraisal (6 items, e.g., "I can tolerate being distressed or upset as well as most people"), absorption (3 items, e.g., "When I feel distressed or upset, all I can think about is how bad I feel"), and regulation (3 items, e.g. "I'll do anything to avoid feeling distress or upset"). Participants rated the extent to which they agreed with each statement. Ratings are typically made on a 5-point Likert scale from 1 (strongly agree) to 5 (strongly disagree). However, for continuity with other questionnaires in the pack, the scoring was reversed to 1 (strongly disagree) to 5 (strongly agree). Subscale means were then calculated. For the present study, a higher order (overall) distress tolerance factor was used to provide an overall representation of distress tolerance. This higher order distress tolerance subscale was calculated by taking the mean of all subscale scores. The higher order subscale and has been found to be a valid and reliable measure of general distress tolerance (Simons & Gaher, 2005). Higher scores represent higher distress tolerance. The DTS has been found to be reliable in adolescents (Wolitzky-Taylor et al., 2015). In the present study the

questionnaire demonstrated excellent internal reliability with the Cronbach alpha's being .90.

Perceived Stress

The 10-item version of the perceived stress scale (PSS; (Cohen et al., 1983) assessed how stressed participants had felt in the past month. Participants were asked to read and respond to each item (e.g., "How often have you felt nervous and stressed?") on a 5-point Likert scale from 0 (never) to 4 (very often). Items that were positively worded (e.g., How often have you felt that you were on top of things?) were reverse scored. A mean of all items was calculated, with a higher overall score indicating higher levels of perceived stress. In adolescent populations, the PSS has been reported to have good internal reliability (Carlozzi et al., 2010) and has been validated for both younger (Yarcheski & Mahon, 1999) and older (Cohen et al., 1983) adolescents. In the present study the questionnaire demonstrated good internal reliability with the Cronbach alpha's being .85.

Anxiety and Depressive Symptoms

The 14-item Hospital Anxiety and Depression Scale (HADS; (Zigmond & Snaith, 1983) was used to measure general anxiety (7 items, e.g., "Worrying thoughts go through my mind") and depressive symptoms (7 items, e.g., "I feel as if I am slowed down") experienced in the past month. Each item is scored from 0-3. Each subscale is summed, with scores ranging from 0-21, where a higher score indicates higher levels of anxiety and depressive symptoms. The HADS provides valid and reliable anxiety and depressive symptoms scores in an adolescent population (White et al., 1999). In the present study the questionnaire demonstrated good internal reliability for anxiety and acceptable internal reliability for depression with the Cronbach alpha's being .80 and .69 respectively.

Procedures

Schools and organisations willing in supporting the research distributed information sheets explaining the nature of the study and the links to participate to adolescents and their parents to give them the opportunity to take part. Prior to consenting to take part, participants were given the opportunity to contact the researchers with any questions they had. Questionnaires were completed either through an online questionnaire platform (SmartSurvey) or using paper hardcopies. If participants aged 16 and above decided they wanted to take part, they could access the study consent form and questionnaire pack online directly by clicking a link from the online information sheet. Participants aged 15 also had to gain consent from a parent/guardian to take part in the study, with the link for the questionnaire being sent to the adolescent to complete via an email address provided by their parent/guardian. Participants who completed the pack via hardcopy were provided with a copy of the consent form and questionnaire pack by their school to complete in their own time before returning to the school (the consent form also contained the parental consent form to be completed by parents of adolescents under 16). The hardcopy questionnaires and consent forms were then collected from the schools by the researchers. The questionnaire pack contained items relating to demographic information, PA, self-esteem, stress appraisals, distress tolerance, perceived stress, anxiety, and depressive symptoms. The questionnaire pack took approximately 30 minutes to complete, and data were collected between November 2019 and March 2020.

Data Analysis

Analysis was conducted using SPSS (IBM, Version 26) and AMOS (IBM, Version 26). Data were screened and cleaned to check for missing values and outliers. Four participants were removed due to not being in Year 11 or above. Three participants who had not

completed at least one entire questionnaire, were deemed to have not completed the study sufficiently and were removed from all analyses. A further three participants did not complete the questionnaire pack correctly and were excluded. Path analysis was used to examine the models as this allowed for the examination of both direct and indirect effects and on observed data and is an approach used successfully in previous cross-sectional data (Harvey et al., 2022). Examining direct and indirect effects with cross-sectional data is appropriate in this case as the aim was to establish the existence of the hypothesised relationships and not whether they were causal (Cain et al., 2018). To examine indirect effects and obtain their confidence intervals and significance values, a full data set is required to enable bootstrapping to provide this information (IBM, 2018). Therefore, assuming any missing data of remaining participants was missing completely at random, this would be imputed to ensure a complete data set. To establish if missing data was missing completely at random, Little's MCAR test was run (Little, 1988). Little's MCAR indicated that less than 5% of the data was completely missing at random, so the expectation maximisation method was used to complete the data set (Tabachnick & Fidell, 2013). Inspection of the Mahalanobis distance at $p < .05$ identified 19 multivariate outliers, which were removed from the analysis. Therefore, the final sample size was 244, with all having complete data.

Descriptive statistics on the final sample were generated, and Pearson correlations were run to examine the extent to which PA was associated with the other model variables (i.e., self-esteem, resources, challenge appraisal, threat appraisal, distress tolerance, perceived stress, anxiety, and depressive symptoms). In order to develop the final hypothesised models for both anxiety and depressive symptom multiple versions of each model were tested using the variables of interest. The first version of the models began with

the basic proposed relationships of PA-stress-anxiety/depressive symptoms. Additional variables were added at each version of the models based on the TMSC and the psychosocial hypothesis, to ensure the added variables made good theoretical sense. At each iteration of the model, the goodness of model fit was tested using the chi-square statistic (χ^2). Due to a non-significant value rarely being found, additional fit indices were used. The root mean square error of approximation (RMSEA) and the standardised root mean square residual (SRMR) were used to indicate absolute fit (values of .06 and ≤.08 respectively indicating adequate fit). The comparative fit index (CFI) and Tucker-Lewis Index (TLI) were also used to indicate incremental fit (values >.90 indicate adequate fit and >.95 indicating excellent model fit; (Hu & Bentler, 1999). Mediation analysis was used to explore indirect effects (Hayes, 2018). Bootstrapping was performed at 2000 samples with confidence intervals at 95%. In addition to examining the model fit indices, the AMOS (IBM, Version 26) software also makes suggestions as to what additional relationships could improve the fit of the model. If these suggestions also made theoretical sense with reference to the TMSC and the psychosocial hypothesis, these suggestions were incorporated into the next version of the model. The final iterations of the hypothesised models predicting anxiety and depressive symptoms were tested using the same approach and fit criteria. These models as highlighted in Figure 2.1a were chosen based on a combination of model fit and theoretical backing. Both models controlled for age and gender and standardized estimates were reported for direct and total indirect effects. Specific indirect effects were also examined and reported as unstandardized estimates. Estimates are unstandardized as these are measured from unstandardised path coefficients so cannot produce standardized estimates (Crowson, 2021).

To determine the extent to which the relationships between PA and stress, and between PA and anxiety/depressive symptoms were indirect via self-esteem, stress appraisals, and distress tolerance, both models were also tested with additional direct pathways from PA to perceived stress and from PA to anxiety/depressive symptoms (Figure 2.1b). Non-significant pathways between PA and stress and PA and anxiety/depressive symptoms would suggest the relationship to be operating through self-esteem, stress appraisals, and distress tolerance.

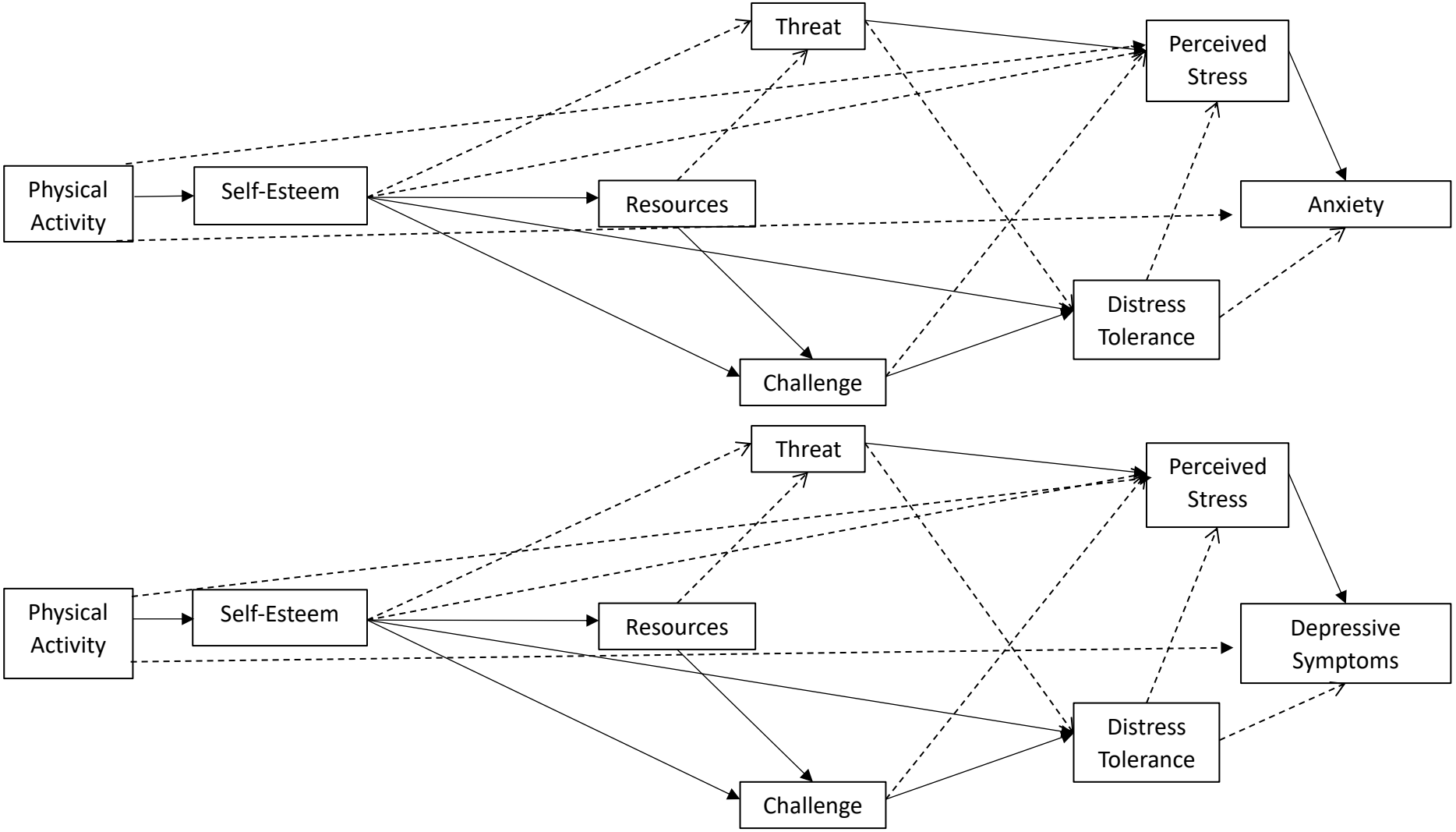

Figure 2.1b: Hypothesised models for the relationships between physical activity and anxiety and physical activity and depressive symptoms, including direct pathways from physical activity to perceived stress, anxiety, and depressive symptoms. Note: solid lines indicate a predicted positive relationship, and dashed lines indicate a predicted negative relationship. For visual simplicity, age and gender control variables and the correlation between challenge and threat appraisal are not depicted.

Results

Participant Characteristics

A final sample of 244 participants from school years 11 – 14 participated in the study (for breakdown of participant characteristics, please see Table 2.1). Participants came from a total of 41 different schools located in the North, South, East, and West of England as well as Wales. Schools' participants attended included private, state, and grammar.

Table 2.1: Participant Characteristics

Characteristic	Frequency
Age (M = 16.5; SD = 0.82)	
15	4 (1.6%)
16	101 (41.4%)
17	95 (38.9%)
18	39 (16%)
19	5 (2.0%)
Gender	
Male	97 (39.8%)
Female	145 (59.4%)
Unspecified	2 (0.8%)
School Year	
11	15 (6.1%)
12	128 (52.5%)
13	89 (36.5%)
14+	3 (1.2%)
Not specified	9 (3.7%)

Means and standard deviations for PA, self-esteem, perceived resources, challenge appraisal, threat appraisal, distress tolerance, perceived stress, anxiety, and depressive symptoms are reported in Table 2.2. Correlation coefficients between all model variables were all found to be significant and are reported in Table 2.2 along with the p values and 95% confidence intervals.

Table 2.2: Means, standard deviations and Pearson's correlations between all model variables.

		Correlations Coefficient (95% CI) and p value							
	Mean (SD)	Physical Activity	Self-Esteem	Resources	Threat	Challenge	Distress Tolerance	Perceived Stress	Anxiety
Physical Activity	3.50 (1.42)	-	-	-	-	-	-	-	-
Self-Esteem	10.98 (2.92)	.32 (.20, .43)	-	-	-	-	-	-	-
Resources	2.88 (0.70)	.15 (.03, .27), p = .016	.40 (.29,.50)	-	-	-	-	-	-
Threat	2.26 (0.75)	-.21 (-.33, -.09),	-.48 (-.57,-.38)	-.31 (-.42, -.19)	-	-	-	-	-
Challenge	2.25 (0.88)	.30 (.18, .41),	.63 (.55, .70)	.49 (.38, .58)	-.54 (-.63, -.45)	-	-	-	-
Distress Tolerance	2.98 (0.74)	.14 (.01, .26), p = .029	.47 (.36, .56)	.35 (.24, .46)	-.60 (-.68, -.51)	.53 (.43, .56)	-	-	-
Perceived Stress	2.24 (0.63)	-.26 (-.37, -.14),	-.63 (-.70, -.54)	-.38 (-.49, -.27)	.64 (.56, .71)	-.69 (-.75, -.61)	-.61 (-.68, -.52)	-	-
Anxiety	9.73 (4.20)	-.14 (-.26, -.02), p = .026	-.54 (-.62, -.44)	-.30 (-.41, -.18)	.61 (.52, .68)	-.54 (-.62, -.44)	-.60 (-.67, -.51)	.69 (.62, .75)	-
Depressive Symptoms	5.64 (3.25)	-.16 (-.28, -.04), p = .011	-.40 (-.50, -.29)	-.34 (-.45, -.23)	.38 (.26, .48)	-.35 (-.45, -.23)	-.34 (-.45, -.23)	.48 (.38, .57)	.42 (.31, .52)

Note: Unless stated otherwise, $p < .001$

Hypothesised Model for Anxiety

To test the hypothesised model in predicting anxiety, regression paths were drawn from PA to self-esteem, and from self-esteem to resources, challenge appraisals, and threat appraisals. Regression paths were also drawn from resources to challenge and threat appraisals. Challenge and threat appraisals then had regression paths drawn to distress tolerance and perceived stress, with distress tolerance having a regression path into perceived stress. There was also a direct pathway to perceived stress from self-esteem. Finally, perceived stress and distress tolerance then each had a regression path to anxiety. Due to the relationship between challenge and threat appraisals, a correlation was also included between their variances similar to previous research (Williams & Cumming, 2012). The hypothesised model is displayed in Figure 2.2. The model was found to be a good fit to the data, χ^2 (12) = 28.06, p = .005, CFI = .98, TLI = .93, SRMR = .03, RMSEA = .07 (90% CI = <.04 – .11). Furthermore, all paths within the model were significant (p's <.05) except for the path between self-esteem and distress tolerance (p = .074). The model indicated that PA positively predicted self-esteem, which was positively associated with greater resources and more adaptive stress appraisals (i.e., lower threat appraisals and higher challenge appraisals). The more adaptive stress appraisals were then associated with greater distress tolerance and lower levels of perceived stress. These in turn predicted lower levels of anxiety. Furthermore, total indirect effects were identified as being significant including an indirect effect between PA and perceived stress (p = .007) and PA and anxiety (p = .007). All specific indirect effects were found to be significant. See Figure 2.2 for the final model and all standardised direct effects while Table 2.3 contains all standardised total indirect effects. The specific indirect effects through the different potential pathways when examined in isolation are also reported in Appendix 1.

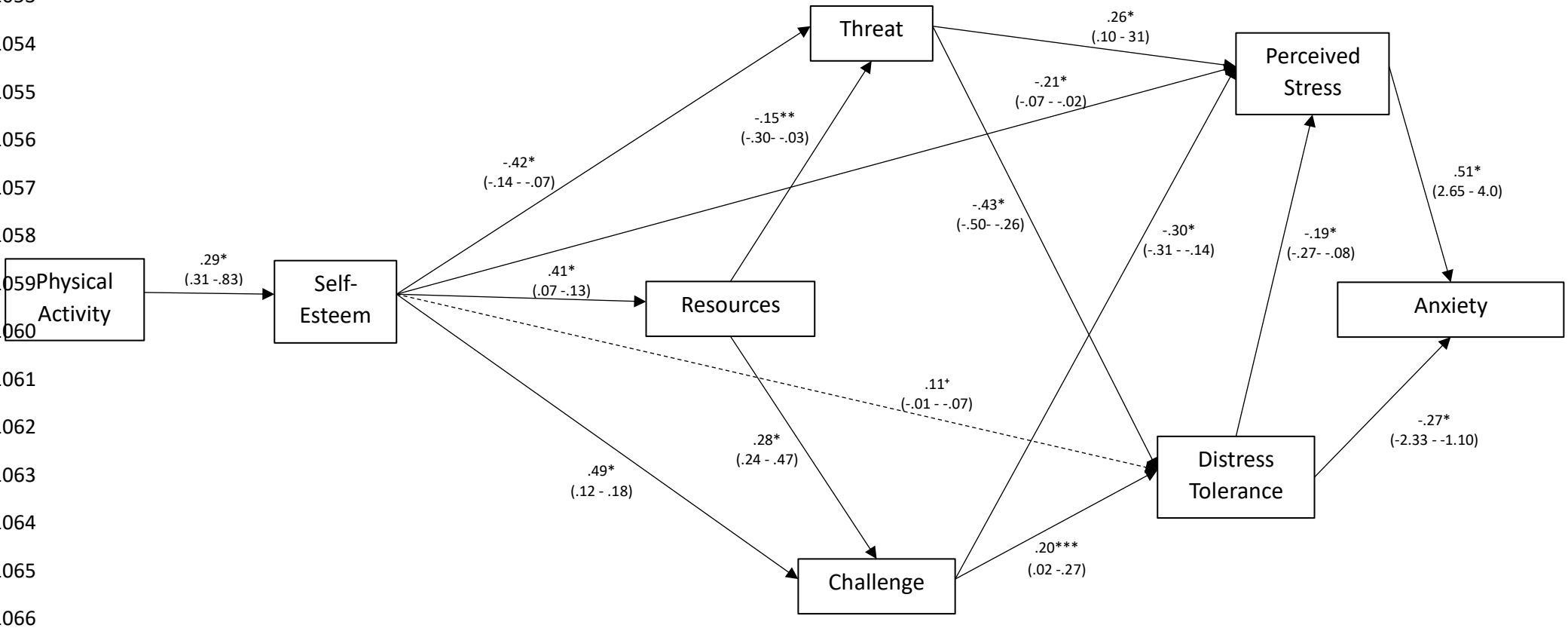

Figure 2.2: Final model for the relationship between physical activity and anxiety.
Note: * p <.001, ** p = .019, *** p = .003, + = p = .072. Solid lines indicate a significant relationship, dashed lines indicate a non-significant relationship. For visual simplicity, age and gender control variables, error terms and the correlation between challenge and threat are not presented in this model. Regression weights standardised.

Table 2.3: Standardised estimates (95% confidence intervals) and p values of the anxiety model for total indirect effects

	Resources	Threat	Challenge	Distress Tolerance	Perceived Stress	Anxiety
Physical Activity	.12 (.09 - .19) *p* = .006	-.14 (-.21 - -.07) *p* = .006	.17 (.11 - .25) *p* = .006	.13 (.08 -.19) *p* = .005	-.17 (-.25 - -.11) *p* = .007	-.12 (-.18 - -.07) *p* = .007
Self-Esteem		-.06 (-.12 - -.03) *p* = .015	.115 (.08 - .17) *p* = .005	.32 (.23 -.42) *p* = .009	-.38 (-.47 - -.31) *p* = .005	-.42 (-.48 - -.33) *p* = .013
Resources				.12 (.05 -.17) *p* = .011	-.14 (-.19 - -.09) *p* = .004	-.11 (-.15 - -.06) *p* = .009
Threat					.08 (.03 - .13) *p* = .005	.29 (.22 - .38) *p* = .006
Challenge					-.04 (-.08 - -.01) *p* = .006	-.22 (-.30 - -.15) *p* = .007
Distress Tolerance						-.09 (-.16 - -.04) *p* = .009

Note: Predictor Variables are in the left-hand column, Outcome Variables are across the top of the table

Hypothesised Model for Depressive Symptoms

The proposed regression pathways for the hypothesised model in predicting depressive symptoms were the same as those in the anxiety model, but with depressive symptoms taking the place of anxiety as the outcome variable (i.e., the regression pathways from perceived stress and distress tolerance were drawn to depressive symptoms; see Figure 2.3). The model was found to be a good fit to the data, χ^2 (12) = 22.43, p = .033, CFI = .99, TLI = .96, SRMR = .03, RMSEA = .06 (90% CI = <.02 – .10). Like the anxiety model, PA was a positive predictor of self-esteem which was positively associated with the more adaptive stress appraisals, which in turn were associated with higher distress tolerance and lower levels of perceived stress. Lower levels of perceived stress then predicted lower levels of depressive symptoms. The pathways between self-esteem and distress tolerance (p =.074) and distress tolerance and depressive symptoms, however, was found to be non-significant (p = .243), but all other pathways were significant (p's <.05). Total indirect effects were found between PA and perceived stress (p = .007) and PA and depressive symptoms (p = .007), (see Figure 2.3 for standardised direct effects and Table 2.4 for all standardised total indirect effects). Specific indirect effects were also all found to be significant, except where the pathway contained a direct path between distress tolerance and depressive symptoms (see Appendix 1 for the specific indirect effects).

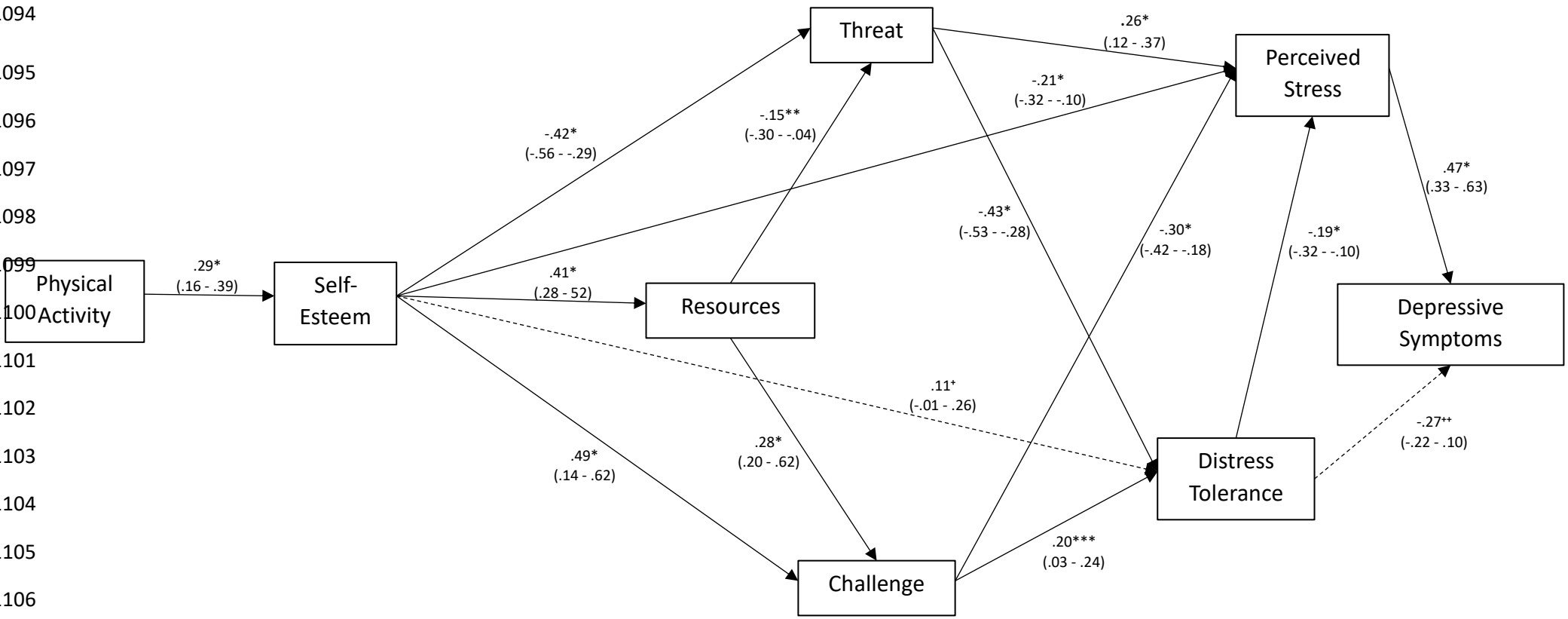

Figure 2.3: Final model for the relationship between physical activity and depressive symptoms.
Note: * p <.001, ** p = .019, *** p = .003, + = p = .072, ++ p = .246. Solid lines indicate a significant relationship, dashed lines indicate a non-significant relationship. For visual simplicity, age and gender control variables, error terms and the correlation between challenge and threat are not presented in this model. Regression weights standardised.

Table 2.4: Standardised estimates (95% confidence intervals) and p values of the depressive symptoms model for total indirect effects

	Resources	Threat	Challenge	Distress Tolerance	Perceived Stress	Depressive Symptoms
Physical Activity	.12 (.09 - .19) *p* = .006	-.14 (-.21 - -.07) *p* = .006	.17 (.11 - .25) *p* = .006	.13 (.08 - .19) *p* = .005	-.17 (-.25 - -.11) *p* = .007	-.09 (-.14 - -.05) *p* = .007
Self-Esteem		-.06 (-.12 - -.03) *p* = .015	.115 (.08 - .17) *p* = .005	.32 (.23 - .42) *p* = .009	-.38 (-.47 - -.31) *p* = .005	-.32 (-.39- -.24) *p* = .015
Resources				.12 (.05 - .17) *p* = .011	-.14 (-.19 - -.09) *p* = .004	-.08 (-.12 - -.05) *p* = .004
Threat					.08 (.03 - .13) *p* = .005	.20 (.14 - .28) *p* = .034
Challenge					-.04 (-.08 - -.01) *p* = .006	-.17 (-.26 - -.13) *p* = .005
Distress Tolerance						-.09 (-.15 - -.03) *p* = .003

Note: Predictor Variables are in the left-hand column, Outcome Variables are across the top of the table

Direct Pathways between Physical Activity, Stress, Anxiety and Depressive Symptoms

Anxiety and depressive symptoms models were rerun with the addition of direct pathways from PA to perceived stress and PA to anxiety or depressive symptoms (dependent on the model being run, see Figure 2.1b). The models for both anxiety (χ^2 [10] = 26.76, p = .003, CFI = .98, TLI = .93, SRMR = .03, RMSEA = .08 [90% CI = <.05 – .11]) and depressive symptoms (χ^2 [10] = 20.60, p = .024, CFI = .99, TLI = .94, SRMR = .03, RMSEA = .07 [90% CI = <.02 – .11]) were found to be a good and similar fit to the data as the hypothesised models. However, the direct pathways from PA to perceived stress (p = .792), PA to anxiety (p = .393), and PA to depressive symptoms (p = .303), were all non-significant.

Discussion

The aim of the present study was to integrate Lubans et al. (2016) psychosocial hypothesis and Lazarus and Folkman (1984)'s TMSC and examine the psychological pathways underlying the relationships between PA, stress, and mental health problems (in the form of anxiety and depressive symptoms) in older adolescents. The specific models tested examined the extent to which PA was associated with stress and anxiety or depressive symptoms indirectly via self-esteem, stress appraisals, and distress tolerance. All hypothesised pathways in both hypothesised models were supported (except the pathway from self-esteem to distress tolerance [both models] and distress tolerance to depressive symptoms) and the data provided a good fit for both models. Physical activity was positively associated with self-esteem, which in turn was positively associated with perceived resources and challenge appraisal, and negatively associated with threat appraisal and perceived stress. Resources were positively associated with challenge appraisal and negatively associated with threat appraisal. Challenge appraisal was then positively associated with distress tolerance and negatively associated with perceived stress, with the

reverse found for threat appraisal. Distress tolerance was negatively associated with perceived stress and anxiety, perceived stress was positively associated with anxiety and depressive symptoms.

Bivariate correlations in the present study demonstrated that greater levels of PA were associated with lower levels of stress, anxiety, and depressive symptoms, supporting existing literature (Biddle et al., 2019; Hammen, 2005; O'Connor et al., 2010). However, when alternate models which included direct relationships between PA and perceived stress, and PA and anxiety and depressive symptoms were tested, these relationships were non-significant. Collectively these findings support the notion that PA is indirectly related to perceived stress, and anxiety/depressive symptoms through self-esteem and the associations self-esteem has with stress appraisals, and perceived stress, as well as the relationship between perceived stress and anxiety or depressive symptoms.

The findings of the present study provide support for the psychosocial hypothesis presented by Lubans et al. (2016). Physical activity was seen to be positively associated with self-esteem, suggesting PA is associated with better mental health through greater self-esteem. In addition, although the present study was cross-sectional, results appear to offer some support to the TMSC (Lazarus & Folkman, 1984). Lazarus and Folkman (1984) proposed that personal characteristics such as self-esteem are likely to influence resource appraisals which determine challenge and threat appraisals, and in turn these can impact coping with stress. Although the findings in the present study are correlational, they do suggest the importance of self-esteem being associated with more adaptive stress appraisals in lower perceived stress and internalising symptoms.

Collectively the results from the present study appear to support the integration of Lubans et al.'s (2016) psychosocial hypothesis and the TMSC by Lazarus and Folkman (1984).

Specifically, the relationship between PA and perceived stress operated indirectly through self-esteem and stress appraisals. The direct association between greater self-esteem and lower perceived stress also supported previous literature (Abdullah et al., 2020). The fact that perceived stress was associated with lower anxiety and depressive symptoms suggests an extension of Lubans et al. (2016)'s psychosocial hypothesis. Rather than physical activity leading to better mental health by being associated with greater self-esteem, the present study suggests in that the higher self-esteem may also lead to improved mental health through more adaptive stress appraisals and lower perceived stress. Given the prevalence of stress in older adolescents and the impact that stress can have on adolescent mental health, higher levels of self-esteem arising from physical activity to protect against stress and the negative impact it can have on mental health seems like a logical hypothesis. The present study suggests this could be somewhat through higher self-esteem being associated with appraising stress more adaptively. However, it is important to note that this is merely a suggestion. The present findings are limited in being correlational meaning future research needs to test this hypothesis causally.

While the current study took a psychological perspective to investigate how physical activity relates to better mental health in adolescents, it is important to note that there are likely to be other in direct effects to consider. A wealth of literature has evidenced other benefits of PA that may play a role in improving mental health. For example, research has shown that PA interventions are associated with physiological outcomes indicative of more adaptive responses to stress such as decreased levels of the stress hormone cortisol (De Nys et al., 2022; Moraes et al., 2018) or more attenuated blood pressure (Chen et al., 2022; Farah et al., 2021). Additionally, in their systematic review, Lubans et al. (2016) provide some evidence for other avenues including neurobiological mechanisms in which PA could

enhance mental health through changes in functional composition and structure of the brain for example (Davis et al., 2011; Hillman et al., 2014). Consequently, while the present study suggests self-esteem, more adaptive stress appraisals, and lower perceived stress are one explanation for how PA is related to better mental health, it is important for future research to investigate some of the other likely indirect effects explaining the PA mental health relationship.

Additionally, the context in which PA is performed has the potential to strengthen or weaken the relationship between PA and self-esteem, perceived stress, and internalising symptoms in different ways. For example, previous research has suggested that the increases in self-esteem post-PA are greater when PA is performed in green space (Barton et al., 2012). Additionally, individual characteristics can also influence the PA and self-esteem relationship. When examining adolescents participating in various levels of sport, individuals having a goal-orientation was more beneficial than a win-orientation, and more important than athletic ability level in the PA improving self-esteem (Findlay et al., 2009). It has also been seen that those who are autonomously or intrinsically motivated to be physically active have higher self-esteem than those who are more externally motivated (Wilson & Rodgers, 2002). Therefore, future work should consider the different personal and situational factors that may impact the effect of PA on self-esteem, perceived stress, and internalising symptoms and establish how PA could be tailored best to have the most positive impact in the context of these factors.

Strengths and Limitations

One key strength of the present study was the use of path analysis to explore multiple relationships between variables and indirect pathways simultaneously. This allowed for a more comprehensive understanding of how the variables relate and

contribute to each other. An additional strength of the study is the large and varied sample of adolescents recruited from various types of school (e.g., private and state schools) and organisations (e.g., sports clubs, music societies, youth theatre, cadets etc), with representation in the sample from across the country. It is not possible however to calculate an exact response rate, as many organisations or schools (e.g., school contacts) did not always respond to the researchers' contact emails, but survey responses were received from participants associated with some of these organisations or schools suggesting information about the study must have been circulated to the adolescents and their parents if under 16. The use of social media as a recruitment method also broadened the reach of the survey, but it is not possible to determine the exact number of responses gained as a result.

Limitations of the study include the use of a cross-sectional design which cannot infer causation. While the use of cross-sectional data in path analysis is often debated, as the intention of the study was to examine the existence of the relationships in the hypothesised model, not whether these relationships are causal, cross-sectional data is appropriate (Cain et al., 2018). In providing support for the proposed relationships, findings expand on existing suggestions from the literature e.g., Lazarus and Folkman (1984) and Lubans et al. (2016), laying the foundations for future research to test these associations in a more causal manner. A further limitation is the use of a self-report single item measure of PA, however, single item self-report measures of PA have previously been found to be a reliable and valid measure of PA in adolescent populations (Scott et al., 2015). Despite this, future research should re-examine these relationships using an objective measure of PA such as accelerometer data. An additional limitation is the slightly low reliability score for the resources subscale in the stress appraisal measure for adolescents' (.67), and the depressive symptoms subscale from the HADS (.69) which mean results for these scales

must be interpreted with caution. However, the resources subscale only has three items which is likely to have contributed to the slightly low reliability score and the depression subscale of the HADS has been extensively validated and previously found to be reliable in this population (White et al., 1999; Zigmond & Snaith, 1983). It must also be noted that the bivariate correlations presented between PA and other model variables are all significant, despite low effect sizes. While this demonstrates the study had sufficient power to detect significant associations, the size of some of the associations were not as meaningful as others.

Implications and Applications of the Findings

The findings of the present study highlight important relationships between PA, self-esteem, perceived stress, and anxiety and depressive symptoms. As PA is a relatively cheap and accessible method to potentially facilitate improvements in self-esteem and subsequent stress and mental health, it is likely to be an important tool and focus of mental health and self-esteem interventions. While there are other potential interventions available that have seen success in increasing self-esteem, such as mindfulness-based interventions (Randal et al., 2015) or therapeutic options such as rational emotive behaviour therapy (Sælid & Nordahl, 2017), it is often seen that adolescents fail to access mental health support (Radez et al., 2021). This can be for a variety of reasons including perceived stigma and embarrassment, lack of access to professional services, or negative perceptions of mental health practitioners, including perceived lack of confidentiality (Radez et al., 2021). Therefore, potential interventions that do not require accessing mental health services or professionals, such as PA, that can be completed when convenient and in a way that is enjoyed, could be more easily used by adolescents to increase their self-esteem.

The findings from the present study highlight a novel integration of two existing theories, Lubans et al. (2016) psychosocial hypothesis and Lazarus and Folkman (1984)TMSC. To the best of my knowledge, this set of relationships underpinning the overall PA and stress relationship has not been investigated previously. The presented associations between PA, self-esteem, appraisals, and stress provide key contributions to the PA and stress literature that could begin to explain some of the inconsistent relationships found between PA and stress that are described earlier in this thesis, while also providing the foundation for further exploration into the relationships between the presented variables.

Future Research Directions

Addressing some of the limitations in the present study's cross-sectional design, it would be beneficial for future research to investigate how the relationships between PA, stress, and anxiety/depressive symptoms change over time and whether different types and levels of perceived stress change the relationships. Examining these relationships overtime could help provide focus to potential interventions, for example at what point before a pre-determined stressor (e.g., an exam) would PA need to be implemented for best effects. Given that research has found associations between longer sedentary time and poorer mental health in adolescents, including higher depression and anxiety and lower self-esteem (Hoare, Milton, Foster, Allender, et al., 2016), it is important future research consider the effects of sedentary behaviour on these variables.

Future research could also examine if the present study findings are applicable to younger adolescents. With the World Health Organisation (WHO) defining adolescence as the period from age 10-19 (World Health Organisation, 2018), the current study does not address the 10-14 portion of this age group. As Rodriguez-Ayllon et al. (2019) note, PA has different associations with mental health in different developmental periods, and with

UNICEF (2021), suggesting up to 13.5% of adolescents in this age group experience a probable mental health condition, it is important to see if the findings from this study in older adolescents apply to younger adolescents. Additionally, although the World Health Organisation (2018), identifies older adolescence as ages 15-19 years old, this is still quite a large age range. Future research could break down this age group further to examine the relationships between smaller age brackets, or how relationships change over time within the 15–19-year-old period. Similarly, future research should look to extend the findings of the current study into young adults (18-24). Approximately 75% of all mental health issues begin before the age of 24 (Kessler et al., 2005), with this age group experiencing numerous stress-evoking life transitions (e.g., moving away from home for the first time, whether this is to university or work, and having to take on the responsibility of becoming adults). Therefore, it is essential to extend the current research into this next age bracket, to see whether similar mechanisms are in pay to explain PA's benefits on mental health.

Conclusions

In conclusion, the present study examined the relationships between PA, stress, anxiety, and depressive symptoms in older adolescents. Findings demonstrated that PA is associated with increased self-esteem, adaptive stress appraisals and higher distress tolerance, which were associated with reduced stress, which in turn was related to lower anxiety and depressive symptoms. Collectively this research provides an insight into how PA may relate to lower stress and better mental health in older adolescents through increased self-esteem which is associated with more adaptive stress appraisal. Future research should further examine these relationships assessing PA objectively and investigate how the PA/stress relationship changes over time.

Chapter 3

Physical Activity Protects Against the Negative Impact of Coronavirus Fear on Adolescent Mental Health and Well-Being During the COVID-19 Pandemic

This chapter is published under the following reference:

Wright, L. J., Williams, S. E., & Veldhuijzen van Zanten, J. J. (2021). Physical activity protects against the negative impact of coronavirus fear on adolescent mental health and well-being during the COVID-19 pandemic. *Frontiers in psychology*, *12*, 580511.

Abstract

The severity of the Coronavirus pandemic has led to lockdowns in different countries to reduce the spread of the infection. These lockdown restrictions are likely to be detrimental to mental health and well-being in adolescents. Physical activity can be beneficial for mental health and well-being; however, research has yet to examine associations between adolescent physical activity and mental health and well-being during lockdown. The aim of the present study was to examine the effects of adolescent perceived Coronavirus prevalence and fear on mental health and well-being and investigate the extent to which physical activity can be a protective factor against these concerns. During United Kingdom lockdown restrictions, 165 participants (100 female, aged 13–19) completed an online questionnaire assessing perceived Coronavirus prevalence and fear, physical activity, and indicators of mental health and well-being (stress, anxiety, depression, fatigue, vitality, and perceived health). Separate hierarchical multiple linear regression analyses (with age, gender, perceived Coronavirus prevalence, and fear entered in step 1, and physical activity in step 2) were run to predict each well- being outcome. Regression analyses indicated that in general, while Coronavirus fear was a negative predictor, physical activity was a positive and stronger predictor of enhanced mental health and well-being outcomes. Findings suggest that physical activity during the Coronavirus pandemic can counteract the negative effects of Coronavirus fear on adolescent mental health and well-being. Therefore, physical activity should be promoted during lockdown to support good mental health and well-being.

Keywords: anxiety, COVID-19, exercise, fatigue, stress, youth

Introduction

The first cases of the COVID-19 Coronavirus (SARS-CoV-2) were discovered in Wuhan Province of China at the end of December 2019, and by 11th March 2020 the World Health Organisation declared this new Coronavirus a pandemic (World Health Organization, 2020). To combat the spread of the virus, unprecedented regulations were put in place for people displaying symptoms (self-isolation) or having been in contact with people with symptoms (quarantine), and most countries applied community-wide restrictions on movement and daily activities (commonly referred to as lockdowns). For example, during the UK lockdown, people were only allowed to leave the house for basic necessities (e.g., seeking medical attention, food shopping), to go to work if this was essential and could not be done from home, and to exercise once a day (UK Government, 2020). While these measures were deemed necessary to limit the spread of the Coronavirus, such restrictions are likely to have a negative impact on mental health.

Quarantine and larger scale lockdowns leads to separation from loved ones, fear over the health of oneself, family, and friends, and a need to cope with the new situation (Cava et al., 2005). All these things can influence mental health and well-being. Indeed, research shows that restrictions during previous epidemics and pandemics have led to increased stress (and even post-traumatic stress disorder), depression, anxiety, emotional exhaustion, and fear (Brooks et al., 2020; Jiménez-Pavón et al., 2020; Xiang et al., 2020). Individuals also experienced numerous stress-evoking factors during lockdown and quarantine such as fear of infection and death, loss of social contacts, confinement, helplessness, as well as experienced stress, depression, anxiety, panic attacks, and even suicidality (Brooks et al., 2020; Jiménez-Pavón et al., 2020; Xiang et al., 2020). Emerging studies relating to the COVID-19 Coronavirus pandemic observe similar patterns, in that

large proportions of healthcare workers and the general public surveyed have reported symptoms of depression, anxiety, and distress (Huang & Zhao, 2020; Lai et al., 2020; Rodríguez-Rey et al., 2020). In addition to these reported symptoms, research in frontline health care workers also indicates high levels of both physical and psychological fatigue (Sasangohar et al., 2020), and vitality was seen to be reduced in personal trainers (Bratland-Sanda et al., 2020), suggesting an impact on psychological well-being that needs to be further investigated.

Specifically, fears and concerns surrounding pandemics during lockdowns and quarantine (e.g., fear of infection, fear of becoming ill) can have a particularly negative impact on mental health and well-being. Research shows that fear of becoming ill was evident in over 20% of people who had been quarantined during severe acute respiratory syndrome (SARS) epidemic (Reynolds et al., 2008). In line with this, perceived severity of the current Coronavirus, as well as being in close contact with someone diagnosed with the Coronavirus have both been found to be associated with increased stress, anxiety, and depression in adults (Rodríguez-Rey et al., 2020). Furthermore, fear of the current Coronavirus was associated with higher levels of anxiety in the general population (Harper et al., 2020). This research suggests that concerns about the current Coronavirus are likely to be detrimental to mental health and well-being.

Most research relating to the COVID-19 Coronavirus has focused on adult populations, with less attention to adolescent populations. This is somewhat surprising given the high prevalence of mental health problems in adolescents (Sadler et al., 2018). Furthermore, lockdown restrictions leading to sudden school closures, a switch to online and more independent learning, and the cancelation of end of year final exams were all likely to contribute to stress and anxiety. Adolescents were also confined to home,

organised sports and group physical activity stopped and they were no longer able to socialise in person with others outside their household. It is therefore not surprising that initial Coronavirus pandemic research in adolescents found a high prevalence of depressive and anxiety symptoms (Chen et al., 2020; Zhou et al., 2020). Therefore, it is important that effective strategies are identified to promote mental health and well-being to protect adolescents against the negative effects of the Coronavirus.

One effective way to enhance mental health and well-being is physical activity. More physically active individuals exhibit lower levels of stress, anxiety, depression, and fatigue as well as greater vitality and well-being in adults and adolescents (Biddle et al., 2019; Gianfredi et al., 2020; O'Connor & Puetz, 2005; Petruzzello et al., 1991; Rodriguez-Ayllon et al., 2019; Stults-Kolehmainen & Sinha, 2014). Physical activity can have a beneficial effect, equal to or greater than, a range of common mental health treatments, such as cognitive behavioural therapy for anxiety (Wipfli et al., 2008), and is comparable to antidepressant medication for depression (Dinas et al., 2011). Importantly, it is not only more physical activity that can improve mental health. A sudden decrease in physical activity can negatively impact on depressive symptoms, anxiety, fatigue, and energy levels (Weinstein et al., 2017). In sum, there is ample evidence that being and staying physically active results in benefits for mental health and well-being.

Previous research suggests that during the Coronavirus pandemic, physical activity could contribute to better mental health and well-being in adolescents. Moreover, physical activity's importance has been acknowledged by governments in several countries, by allowing physical activity to be one of the few reasons people could leave their homes during lockdown. Despite this, lockdown restrictions make physical activity more challenging, with research suggesting reduction in adult physical activity levels during the

Coronavirus compared to pre-Coronavirus (Ammar et al., 2020). However, research conducted during the Coronavirus pandemic on adults has shown that physical activity is related to better mental health, such as lower levels of depression, stress, and anxiety (Rodríguez-Rey et al., 2020). Additionally, self-reported reductions in physical activity since the onset of the Coronavirus have been associated with higher stress, depression, and anxiety (Stanton et al., 2020). Conversely, in a sample of less physically active individuals, those who report engaging in more physical activity during lockdown restrictions report lower anxiety than those who report being less physically active during lockdown (Lesser & Nienhuis, 2020).

When investigating physical activity, mental health, and well-being, it is important to take gender differences into consideration. For example, there is evidence that males are more physically active than females (Bann et al., 2019). Furthermore, females tend to report higher levels of anxiety, depression, and stress than their male counterparts (Murray et al., 2011; Sadler et al., 2018). In addition, in the context of Coronavirus, there is evidence for higher stress and anxiety levels in females (Fitzpatrick et al., 2020; Lai et al., 2020; Mazza et al., 2020). Consequently, when examining the associations between physical activity and mental health and well-being, it is important to investigate the impact on gender.

In sum, although there is substantial evidence of the detrimental effects of quarantine and lockdown on mental health and well-being, less is known about the factors impacting mental health and well-being in adolescents. While concerns related to the Coronavirus may adversely affect mental health, physical activity is likely to be beneficial. However, this is yet to be examined in an adolescent population. Therefore, the present study aimed to examine the effects of Coronavirus concerns on mental health and well-being in adolescents and the extent to which physical activity can protect against the

negative impact of these Coronavirus concerns on mental health and well-being during lockdown. A secondary aim was to investigate the effect of gender on these variables.

Methods

Participants

In total 100 female and 65 male participants aged between 13 and 19 years old (*M* = 15.90, *SD* = 1.48) took part in the study, 94.6 % identified their ethnicity as white. Participants were recruited predominately through emails to schools, sports clubs, and other organisations targeted at adolescents (e.g., Scouts) across the UK. The study was also advertised via the social media of the research team All participants lived in England. None of the participants reported as having tested positive for COVID-19. The study obtained ethical approval from the University ethics committee, and all participants, and where appropriate, a parent/guardian, provided informed consent. Power analyses showed that a sample of 165 participants would allow for the detection of a small to medium effect with power at .90 (Faul et al., 2009).

Procedures

Data collection took place from 1st May 2020 to the 25th May 2020 in the UK using an online questionnaire platform (SmartSurvey). Participants then completed an online questionnaire pack including the demographic information, and measures to assess perceived fear and prevalence of the Coronavirus, physical activity, perceived stress, anxiety, depression, fatigue, vitality, and general health. Coronavirus restrictions and school closures had been in place for 5 weeks at the onset of data collection and remained unchanged during data collection.

Questionnaires

All questionnaires were phrased so that the time period they related to was during the last month, which coincided with the period of the UK lockdown restrictions.

Coronavirus Inventory

The Coronavirus inventory was developed for the present study by modifying the Swine Flu Inventory (SFI) items (Wheaton et al., 2012).The SFI is a 10-item questionnaire which assessed things such as individuals' concerns about the spread of H1N1 influenza, perceptions of likelihood of contracting the infection, and severity of the infection. Items were modified in the present study to refer to the Coronavirus that causes COVID-19 rather than H1N1 influenza, and any reference to the US was altered to refer to the UK (e.g., "How quickly do you believe contamination from Swine Flu is spreading in the U.S.?" was modified to "How quickly do you believe the Coronavirus is spreading in the U.K.?"). Small wording modifications were also made to ensure items were understandable by an adolescent population. Two further items "to what extent has the threat of the Coronavirus influenced your well-being" and "to what extent has the threat of the Coronavirus increased your stress levels" in order to better tap some of our variables of interest, namely stress and well-being and how they relate to the threat of the Coronavirus (see Appendix 2 for all items). Participants rated the extent to which they agreed with each item on a 5-point Likert scale ranging from 0 (very little) to 4 (very much).

To reduce the items to a number of meaningful factors, principle axis factoring with oblimin rotation was conducted on the 12 items (Tabachnick & Fidell, 2013). The initial solution identified four factors with eigenvalues ranging from 1.02 to 3.92, collectively accounting for 63.67% of the variance. However, one item (item 6) failed to load onto any factor and one item (item 8) cross loaded highly on more than one factor. These two items were removed from the second iteration which revealed three factors. The third factor

consisted of only two items which poorly loaded on their subscale (items 9 and 10). These two items were dropped for the third run which yielded a final two factor solution with eigenvalues of 1.34 and 3.25, accounting for 57.36% of the variance. Each factor consisted of four items and factor loadings were all above .45 (Tabachnick & Fidell, 2013). One factor contained items assessing perceived prevalence and likelihood of becoming infected with the Coronavirus (e.g., "How likely do you think it is that you could become infected with the Coronavirus?*"*). This subscale was named *perceived Coronavirus prevalence*. The other factor contained items tapping concerns about the coronavirus and impact it could have on health and well-being (e.g., "If you did become infected with the Coronavirus, to what extent are you concerned that you will be severely ill?"). This subscale was named *Coronavirus fear*. The final 8 items and their factor loadings are reported in Table 3.1, Cronbach alpha coefficient values demonstrated good reliability for Coronavirus concerns (.78) and slightly low reliability for perceived Coronavirus prevalence (.68). Mean scores for each subscale were calculated so a higher score indicated a greater perceived Coronavirus prevalence or Coronavirus fear.

Table 3.1. Coronavirus Inventory Factor Loadings for a Two-Factor Solution

Item	Coronavirus Fear	Coronavirus prevalence
To what extent has the threat of the Coronavirus increased your stress levels?	.817	
To what extent are you concerned about the Coronavirus?	.690	
To what extent has the threat of the Coronavirus influenced your well-being?	.679	
If you did become infected with the Coronavirus, to what extent are you concerned that you will be severely ill?	.483	
How quickly do you believe the Coronavirus is spreading in the UK?		.634
To what extent do you believe that the Coronavirus is prevalent in the UK?		.601
How likely do you think it is that you could become infected with the Coronavirus?		.546
How likely is it that someone you know could become infected with the Coronavirus?		.495

Physical Activity

Physical activity was measured using a single item in which participants selected which level represented their physical activity (Jurca et al., 2005). The question asked participants to rate their usual pattern of activity. In the present study this was altered to ask participants their usual pattern of activity in the last month. Participants selected one of five possible levels with each increasing level indicating a higher amount of physical activity (Level 1: “Inactive or little activity other than usual daily activities; Level 2: “Regularly (≥5 d/wk) participate in physical activities requiring low levels of exertion that result in slight increases in breathing and heart rate for at least 10 minutes at a time”; Level 3-5: participation in “aerobic exercises such as brisk walking, jogging, or running at a comfortable

pace, or other activities requiring similar levels of exertion" for 20 – 60 minutes per week (level 3), 1-3 hours per week (level 4) or over 3 hours per week (level 5)). The item has been used as an element of a non-exercise estimate of cardio-respiratory fitness (CRF) which was found to be a good estimation of CRF when compared to actual exercise testing (Jurca et al., 2005). Single item physical activity measures have been found to provide reliable and valid assessments of physical activity in adolescents (Scott et al., 2015).

Perceived Stress

The 10-item Perceived Stress Scale (PSS;(Cohen et al., 1983) assessed how stressed individuals felt over the past month. Participants read each item (e.g., "How often have you felt nervous and "stressed"?") and respond on a 5-point Likert scale from 0 (never) to 4 (very often). Positively worded items are reverse scored, and a mean score is calculated of all items so that a higher score indicates a higher level of perceived stress. The PSS has been reported to have good internal reliability in adolescent populations (Carlozzi et al., 2010). The present study demonstrated good internal reliability (α = .88).

Anxiety and Depressive Symptoms

The Hospital Anxiety and Depression Scale (HADS; (Zigmond & Snaith, 1983) assessed general levels of anxiety (7 items, e.g. "I get sudden feelings of panic") and depressive symptoms (7 items, e.g. "I feel as if I am slowed down"), with items being scored on a scale of 0-3. Each subscale is summed with scores ranging from 0 to 21, with higher scores indicating higher levels of anxiety or depressive symptoms. A score of 8-10 indicates mild anxiety/depressive symptoms, a score of 11-15 indicates moderate anxiety/depressive symptoms where a score of 16 or above indicates severe anxiety/depressive symptoms. The HADS has been validated for use in adolescents to assess anxiety and depressive symptoms

(White et al., 1999). The present study demonstrated good internal reliability for anxiety (α = .84) and depression (α = .81).

Fatigue

The 20-item Multidimensional Fatigue Inventory (MFI-20; (Smets et al., 1995) was used to measure general fatigue (e.g. "I feel tired"), physical fatigue (e.g. "Physically I feel only able to do a little"), reduced activity (e.g. "I get little done"), mental fatigue (e.g. "It takes a lot of effort to concentrate on things"), and reduced motivation (e.g. "I don't feel like doing anything"). Each subscale consisted of 4 items. Participants rated the extent to which they agree or disagree with each item on a 5-point Likert scale from 1 (yes, that is true) to 5 (no, that is not true). Positively worded items were reverse scored and scores for each subscale were summed to create a total score for each subscale with higher scores representing greater fatigue The MFI-20 is a valid and reliable measure to assess fatigue (Smets et al., 1995), used successfully in adolescent populations (Vantieghem et al., 2018). The present study demonstrated good internal reliability for all subscales (α ≥ .75).

Vitality

The Subjective Vitality Scale (SVS; (Ryan & Frederick, 1997) is a 5-item questionnaire (e.g. "I feel I have a lot of energy") assessing how energetic a person feels. Participants rate the extent to which they agree with each statement on a 7-point Likert scale from 1 (not at all true) to 7 (very true). Items are then averaged with higher scores indicative of greater vitality. The SVS has been found to be a valid and reliable measure of vitality in adolescents (Reinboth et al., 2004). The current study demonstrated a good internal reliability (α = .89).

General Health

Perceptions of general health was measured using a single item taken from the Short Form Health Survey-12 (Ware Jr et al., 1996). Participants rated their perceived health on a

5-point scale: poor, fair, good, very good, excellent. This single item measure for perceived health has been found to be as valid and reliable as a multi-item scale (Macias et al., 2015) and has also been used effectively in adolescents (Herman et al., 2015).

Data Analysis

All data was analysed using SPSS (IBM, Version 26). First, data were screened and cleaned to check for missing data and outliers. As Little's MCAR test showed less than 5% of data were missing at random ($p > .05$), the expectation maximisation method was used to complete the data set (Tabachnick & Fidell, 2013). Inspection of the Mahalanobis distance at $p < .001$ identified no multivariate outliers so all data were retained for the analysis. Descriptive statistics were generated for males and females and a series of one-way ANOVAs conducted to examine gender differences in all relevant outcomes. Pearson correlations were then run to examine the relationships between perceived Coronavirus prevalence, Coronavirus fear, and physical activity, with each other as well as the mental health and well-being outcomes (i.e., perceived stress, anxiety, depressive symptoms, different fatigue subscales, vitality, and perceived general health). Finally, separate hierarchical multiple linear regressions were run to predict each well-being outcome. To determine the extent to which perceived Coronavirus prevalence and Coronavirus fear predicted each well-being outcome, these two variables were entered in step 1 along with control variables gender and age. Then physical activity was added at step 2 to determine if it was an independent predictor of each mental health and well-being outcome. The alpha level was set at .05 for all analyses and standardized beta values are reported for all regression analyses.

Results

Participant Characteristics

Means and standard deviations of perceived Coronavirus prevalence, Coronavirus fear, physical activity, and mental health and well-being outcomes for both males and females are reported in Table 3.2. One-way ANOVAs revealed that males reported significantly lower Coronavirus fear, perceived stress, anxiety, general fatigue, physical fatigue, and mental fatigue, as well as higher vitality and general health. No gender differences were seen for depressive symptoms, perceived Coronavirus prevalence, or reduced activity. There was no significant difference in physical activity levels between male and female participants. The mean score for anxiety in female participants falls into the "mild anxiety" category based on the HADS scale (i.e., a score of 8-10 (Zigmond & Snaith, 1983)) with 65% of females being classified as displaying at least mild anxiety.

Correlational Analyses

Correlation analysis between perceived Coronavirus prevalence, Coronavirus fear, physical activity, and well-being outcomes are displayed in Table 3.3. Perceived Coronavirus prevalence was associated with higher levels of Coronavirus fear, but physical activity was not associated with either perceived Coronavirus prevalence or Coronavirus fear. Coronavirus fear was associated with higher levels of perceived stress, anxiety, depressive symptoms, general fatigue, reduced activity, mental fatigue, and reduced motivation, and was associated with lower levels of vitality and general health. Coronavirus prevalence was not associated with any of the well-being outcomes. Higher levels of physical activity were associated with lower levels of perceived stress, depressive symptoms and all five fatigue subscales, as well as higher levels of vitality and perceived general health.

Table 3.2. Mean (SD) of perceived Coronavirus prevalence, Coronavirus fear, physical activity, and wellbeing outcomes for male and female participants.

	Male Mean (SD)	Female Mean (SD)	F value	p value
Perceived Coronavirus prevalence	2.39 (0.876)	2.57 (0.67)	2.17	.143
Coronavirus Fear	1.62 (0.96)	2.19 (0.97)	14.44	<.001
Physical Activity	3.41 (1.35)	3.42 (1.3)	<0.01	.958
Perceived Stress	1.85 (.691)	2.32 (0.67)	18.73	<.001
Anxiety	6.62 (3.55)	9.35 (4.71)	16.13	<.001
Depressive symptoms	5.17 (3.78)	6.27 (3.92)	3.23	.074
Vitality	3.94 (1.40)	3.28 (1.32)	9.66	.002
General Health	3.44 (0.906)	3.08 (1.13)	4.59	.034
General Fatigue	11.33 (3.28)	12.66 (3.96)	5.11	.025
Physical Fatigue	8.79 (3.53)	10.25 (3.91)	5.99	.015
Reduced Activity	11.67 (4.31)	11.88 (4.54)	0.09	.763
Mental Fatigue	12.33 (3.55)	13.92 (3.74)	7.45	.007
Reduced Motivation	11.52 (3.97)	12.39 (4.09)	1.87	.173

Note: degrees of freedom: 1,164, F value relates to gender differences ANOVA.

Table 3.3 Correlations between perceived Coronavirus prevalence, Coronavirus fear, physical activity, and wellbeing outcomes

	Perceived Coronavirus prevalence	Coronavirus Fear	Physical Activity
Perceived Coronavirus prevalence	1		
Coronavirus Fear	.41**	1	
Physical Activity	.01	-.09	1
Perceived Stress	.10	.40**	-.26**
Anxiety	.11	.47**	-.15
Depressive symptoms	-.10	.17*	-.31**
Vitality	.02	-.18*	.34**
General Health	-.05	-.25**	.33**
General Fatigue	.07	.24**	-.38**
Physical Fatigue	.11	.25**	-.58**
Reduced Activity	<-.01	.07	-.54**
Mental Fatigue	.01	.20**	-.23**
Reduced Motivation	.09	.19*	-.32**

*Note: *p <.05, **p <.001*

Multiple Linear Regressions

Results of the multiple linear regression analyses are reported in tables 3.4 and 3.5. Step one of these analyses explored the independent associations between Coronavirus fear and perceived coronavirus prevalence with the different measures of mental health and well-being, while correcting for age and gender, with physical activity being added as a predictor at step two. Results for all regressions, except when predicting depressive symptoms, showed perceived Coronavirus prevalence was not independently associated with any mental health and well-being outcomes.

Step 1 and Step 2 of the regressions predicting stress, anxiety, and depressive symptoms accounted for a significant portion of the variance (except anxiety step 2).

Coronavirus fear was a significant predictor in step 1 and 2, with higher levels predicting more perceived stress, anxiety, and depressive symptoms. Physical activity was a significant negative predictor for stress and depressive symptoms, with higher levels of physical activity predicting lower levels of these outcomes.

The regressions for the fatigue subscales showed step 1 accounted for a significant portion of the variance and Coronavirus fear was a significant positive predictor of these subscales (with the exception of reduced activity and reduced motivation). Step 2 accounted for a significant proportion of the variance and physical activity was a significant negative predictor of all 5 fatigue subscales. Furthermore, Coronavirus fear became a nonsignificant predictor in all regressions except general fatigue.

Step 1 and Step 2 of the regressions predicting vitality and general health accounted for a significant proportion of the variance. In step 1 and step 2, Coronavirus fear was a significant negative predictor of general health but not vitality. In step 2, physical activity was a positive predictor of both variables so that higher levels of physical activity were associated with greater vitality and perceived health.

Table 3.4. Regressions between perceived Coronavirus prevalence and fear, physical activity, stress, anxiety, depressive symptoms, vitality, & general health

	Perceived Stress		Anxiety		Depressive Symptoms		Vitality		General Health	
Step One	ΔR^2=.23, F =11.72[a], p <.001		ΔR^2=.27, F =14.59[a], p <.001		ΔR^2=.08, F =3.35[a], p =.012		ΔR^2=.11, F =4.89[a], p =.001		ΔR^2=.09, F =4.18[a], p =.003	
	ß	p	ß	p	ß	p	ß	p	ß	p
Gender	.25	.001	.19	.010	.11	.187	-.23	.004	-.13	.114
Age	.13	.071	.05	.504	.06	.445	-.18	.021	-.14	.059
Perceived Coronavirus Prevalence	-.09	.263	-.11	.136	-.21	.014	.12	.144	.08	.366
Coronavirus Fear	.36	.000	.47	<.001	.23	.009	-.16	.068	-.24	.006
Step 2	ΔR^2=.05, F =10.55[b], p =.001		ΔR^2=.01, F =2.50[b], p =.12		ΔR^2=.08, F= 15.87[b], p <.001		ΔR^2=.10, F =20.62[b], p <.001		ΔR^2=.09, F =17.20[b], p <.001	
Gender	.25	.001	.19	.009	.11	.142	-.24	.002	-.13	.080
Age	.11	.096	.04	.564	.04	.575	-.16	.030	-.13	.083
Perceived Coronavirus Prevalence	-.07	.340	-.10	.162	-.19	.020	.10	.203	.06	.485
Coronavirus Fear	.33	.000	.45	<.001	.19	.022	-.12	.154	-.20	.016
Physical Activity	-.22	.001	-.11	.116	-.29	<.001	.32	<.001	.30	<.001

Note: [a]: degrees of freedom are 4,161, [b]: degrees of freedom are 1,160

Table 3.5. Regressions between perceived Coronavirus prevalence and fear, physical activity, and fatigue.

	General Fatigue		Physical Fatigue		Reduced Activity		Mental Fatigue		Reduced Motivation	
Step One	ΔR^2=.10, F =4.50[a], p =.002		ΔR^2=.09, F =3.86[a], p =.005		ΔR^2=.04, F =1.66[a], p =.16		ΔR^2=.07, F =3.21[a], p =.015		ΔR^2=.04, F =1.75[a], p =.14	
	ß	p	ß	p	ß	p	ß	p	ß	p
Gender	.14	.074	.14	.072	.04	.670	.17	.034	.07	.418
Age	.17	.023	.10	.173	.19	.018	.05	.550	.06	.476
Coronavirus Prevalence	-.04	.601	<-.01	.984	-.05	.569	-09	.292	.01	.902
Coronavirus Fear	.22	.012	.21	.017	.07	.417	.19	.030	.16	.064
Step 2	ΔR^2=.12, F =25.36[b], p <.001		ΔR^2=.31, F =83.40[b], p <.001		ΔR^2=.28, F =65.15[b], p <.001		ΔR^2=.04, F =7.94[b], p =.005		ΔR^2=.09, F =17.02[b], p <.001	
Gender	.15	.043	.16	.016	.05	.491	.18	.026	.07	.345
Age	.15	.032	.07	.258	.16	.021	.03	.659	.04	.617
Coronavirus Prevalence	-.02	.798	-.04	.598	-.01	.853	-.07	.365	.03	.705
Coronavirus Fear	.17	.034	.14	.055	<.01	.952	.16	.058	.13	.139
Physical Activity	-.35	<.001	-.56	<.001	-.22	<.001	-.21	.005	-.31	<.001

Note: [a]: degrees of freedom are 4,161, [b]: degrees of freedom are 1,160

Discussion

This study aimed to examine the extent to which Coronavirus prevalence and Coronavirus fear predicted adolescents' mental health and well-being during lockdown, and the extent to which physical activity can protect against the negative impact of these Coronavirus concerns on mental health and well-being. Despite perceived Coronavirus prevalence and fear being associated with each other, higher Coronavirus fear was associated with higher levels of stress, anxiety, depressive symptoms, and fatigue, as well as lower vitality and general health, which is in line with research in adults (Brooks et al., 2020; Harper et al., 2020; Rodríguez-Rey et al., 2020). Perceived Coronavirus prevalence was only significantly associated with lower depressive symptoms. The seemingly surprising negative relationship between perceived Coronavirus prevalence and depressive symptoms could perhaps be explained by behavioural disengagement (Horwitz et al., 2011): adolescents with higher depressive symptoms may not engage with media related to Coronavirus, making them less aware of its prevalence. Collectively, the findings demonstrate that Coronavirus fear is a more consistent predictor of poorer mental health compared to perceived Coronavirus prevalence. This is similar to research in adult populations demonstrating fear of the current Coronavirus to be associated with higher anxiety and depressive symptoms, and fear of infection during periods of quarantine from other viruses to be associated with stress (Brooks et al., 2020; Harper et al., 2020). By extending these relationships into other indicators of health and well-being, the results of the present study suggest that it is not the prevalence of the Coronavirus but rather the fear of the impact it could have on health which is associated with poorer adolescent mental health.

An important novel finding of the current study is that physical activity counteracted the negative impact of Coronavirus fear on mental health and well-being in adolescents.

Moreover, the size of the beta weights in the regressions predicting depression, vitality, perceived health, and fatigue (particularly physical fatigue and reduced activity) demonstrate that physical activity was a stronger predictor than Coronavirus fear. Indeed, physical activity is suggested to impact mental health in different ways, and some of these pathways might be especially relevant during the Coronavirus pandemic (Matias et al., 2020; Mikkelsen et al., 2017). For example, physical activity can have an immediate positive effect on mood and feelings of energy (Liao et al., 2017) and physical activity can be a distraction from negative thoughts and stress related to the Coronavirus fear (Mikkelsen et al., 2017). Physical activity can also bring a structure or daily routine to life, which is likely to be heavily disturbed as a result of the lockdown. As such, it can provide a sense of control and mastery, which can also impact on well-being (Mikkelsen et al., 2017).

The associations between physical activity and more positive mental health and well-being may in part be due to the environment of the activity. Although physical activity location was not assessed in the current study, in other studies during the Coronavirus, outdoor physical activity has been reported in over 90% of individuals (Lesser & Nienhuis, 2020). During the data collection in the present study, physical activity was one of the few reasons adolescents could leave the house. Furthermore, data from May-July 2020 indicates that more adolescents were being active outdoors, with the number of people going for a walk and cycling for fun or fitness being higher compared with the same period in 2019 (Sport England, 2021). Consequently, it could be suggested that a number of the study participants may have been doing most of their physical activity outdoors. Outdoor physical activity is generally associated with lower depression, tension, anger, and confusion compared to indoor physical activity (Bowler et al., 2010; Dunton et al., 2015), and has been associated with improved emotional well-being, including in adolescents (Pasanen et al.,

2014). Moreover, adults who spent more time doing physical activity outdoors during the current Coronavirus displayed better well-being (described as “flourishing”(Lesser & Nienhuis, 2020)). Therefore, the simple act of being able to leave the confinements of the house to exercise may have had an additional benefit to mental health. However, data also suggests an increase in adolescent participation in gym and fitness during this same time compared with 2019 (Sport England, 2021). Considering that public gyms were closed as part of lockdown restrictions, it is likely that these gym and fitness activities were undertaken at home (e.g., live streamed workouts). Given that the location of the physical activity was not assessed in the present study, these suggestions are purely speculative.

Although physical activity significantly predicted lower perceived stress, Coronavirus fear was the strongest independent predictor of stress. This is not surprising given that literature shows infection fear can induce stress during periods of quarantine or lockdown (Brooks et al., 2020). A bi-directional relationship between stress and physical activity has been reported, with stress leading to less physical activity and less physical activity leading to more stress (Stults-Kolehmainen & Sinha, 2014) . Importantly, the present study shows that despite the strong association between Coronavirus fear and perceived stress, physical activity was still a significant negative predictor of stress. Interestingly, during the SARS outbreak in Hong Kong in 2003, especially those who experienced more stress at home and worry about the virus reported to have increased their time spend being physically active (Lau et al., 2005; Lau et al., 2006). Therefore, it is possible that physical activity is also used by adolescents as a way to cope with the stress of the COVID-19 Coronavirus and to have a sense of control over their health.

A somewhat surprising result from the present study was that physical activity was not associated with anxiety. This contradicts work outside of pandemic settings, where

higher levels of physical activity are associated with lower anxiety in children and adolescents (Ahn & Fedewa, 2011). During the current Coronavirus pandemic, the associations between physical activity and anxiety appear complex. Similar to the present study, other Coronavirus related studies have shown no association between anxiety and physical activity (Zhang et al., 2020), and no difference in anxiety between those who are active and non-active (Lesser & Nienhuis, 2020; Zhang et al., 2020). However, other studies have shown that those who are more physically active during the pandemic displayed lower levels of anxiety (Antunes et al., 2020). It is difficult to know why the relationship between physical activity and anxiety appears to be inconsistent during the current Coronavirus, but it may be that anxiety experienced during this time is different in nature to the anxiety typically experienced in the absence of such pandemics. During disease outbreaks, a number of people experience clinical levels of fear and anxiety (Taylor, 2019), and recent research suggests that individuals can experience specific dysfunctional Coronavirus anxiety (Lee et al., 2020). Although findings in the current study do not suggest specifically high levels of anxiety compared to non-pandemic situations, anxiety may be caused by other factors which influence its associations with physical activity. Other studies during the Coronavirus pandemic have shown a reduction in physical activity compared to pre-Coronavirus is associated with higher anxiety, and inactive people who became more active during the Coronavirus displayed lower anxiety than those who become less active (Lesser & Nienhuis, 2020), suggesting it could be the change in physical activity that is more closely associated with anxiety in such times. However, further research is needed to fully understand the relationship between physical activity and anxiety during lockdowns due to pandemics.

Coronavirus fear, perceived stress, and anxiety were all significantly higher in females, which is in line with Coronavirus research in adult populations (Fitzpatrick et al., 2020; Lai et al., 2020; Mazza et al., 2020). As adolescent females have been found to have higher levels of stress and anxiety (Murray et al., 2011; Sadler et al., 2018) under regular circumstances, it is perhaps expected that their levels would also be higher under a pandemic scenario. The present study suggests that females may also display greater fear associated with the Coronavirus. In addition, general, physical, and mental fatigue were higher, and vitality lower in females, which has been reported before in adults (Engberg et al., 2017), but not during the Coronavirus pandemic. To our knowledge, this is the first study to find this in adolescents. Interestingly, there was no gender difference in physical activity. This is perhaps surprising given that a number of studies report males displaying significantly higher levels of physical activity compared with females (Bann et al., 2019). However, other studies (albeit in college students) have also found no gender differences in certain types of physical activity during lockdown (Zhang et al., 2020). Thus, commonly reported gender differences in adolescent physical activity (Bann et al., 2019), could be influenced by lockdown restrictions – indeed, research suggests that most individuals report experiencing a reduction in physical activity compared to pre-lockdown (Stanton et al., 2020).

The findings of the study indicate the clear benefits of physical activity to help to counteract the negative mental implications of Coronavirus fear in adolescents. The data suggests positive benefits for mental health with physical activity in adolescents. UK physical activity guidelines recommend adolescents to participate in 60 minutes of moderate to vigorous physical activity per day (Department of Health and Social Care, 2019). Although the measure of physical activity used in the current study does not allow for

comparison of levels of physical activity against the physical activity guidelines, it does confirm with general physical activity guidelines that being more physically active is associated with better (mental) health.

Despite its novel contributions, the study is not without limitations. First, the cross-sectional design cannot imply causation. The study also uses a self-report single item measure of physical activity; however, this method has been previously validated (Jurca et al., 2005; Scott et al., 2015). Third, our measure of Coronavirus prevalence and fear was designed for the purpose of the study and has thus not been extensively validated. However, items underwent exploratory factory analysis based on the recommendations in the literature and the results support the existence of two separate subscales (Tabachnick & Fidell, 2013). Finally, our sample's ethnicity was predominately white. Given the reported ethnicity differences in risk of mortality relating to the Coronavirus (Price-Haywood et al., 2020), it would be interesting to explore these associations in a wider range of ethnicities.

In conclusion, the present study found that while Coronavirus fear was associated with higher levels of stress, anxiety, depressive symptoms, fatigue, and lower vitality and general health, physical activity was an independent predictor of lower stress, depressive symptoms, and fatigue, and higher vitality and perceived health. Moreover, physical activity was often a stronger predictor than Coronavirus fear. Therefore, this was the first study to show that physical activity during the Coronavirus pandemic can counteract the negative effects of fear of the Coronavirus on adolescent mental health and well-being. Findings highlight the significance of physical activity during the Coronavirus pandemic and emphasise the importance of governments letting individuals continue to leave the house for physical activity during periods of lockdown.

Chapter 4

Longitudinal Associations between Physical Activity and Stress in University Students

Abstract

In Chapter 2, it was found that physical activity (PA) was indirectly associated with lower stress through self-esteem and challenge and threat appraisals. Research has also suggested that proactive coping could play a role in the PA and stress relationship. However, the research presented in Chapter 2 was only conducted at one time point, so it is as yet unknown whether this relationship is consistent when measured overtime. It is also unknown if PA intensity makes a difference in the relationship with stress or if proactive coping has any influence on the associations. This study therefore aimed to explore longitudinal associations between PA intensities and stress, and to examine whether the added variables of self-esteem, stress appraisals and proactive coping made a difference to the associations. Data was collected at three time points across the course of a university semester, during different levels of COVID-19 lockdown. Participants completed a questionnaire pack at each time point containing questions about their PA, perceived stress, self-esteem, stress appraisals and proactive coping. Date was analysed using multilevel analyses. PA intensities (other than moderate intensity) were significantly associated with stress at a between-person level when independently entered into the model, however there was no significant within-person association. When the additional variables of self-esteem, challenge appraisal, threat appraisal and proactive coping were added to the model, no significant associations were found. Self-esteem, challenge appraisal, threat appraisal and proactive coping were found to be independently significantly associated with stress. No significant interaction effects were found. Findings suggest that while PA intensity was associated with stress when entered independently into the model, when additional variables were added this was not the case. This could have been due to the conditions of

COVID-19 or the overall time frame. Future research should focus on different time frames to more fully understand how time can influence the PA and stress relationship.

Key Words: Multilevel analysis, stress, longitudinal, young adult

Introduction

Young adults (aged 18-24) are particularly prone to stress with this time of life being associated with periods of transition, such as moving away from home for the first time, going to university, and the associated pressures to succeed and meet expectation (Kumaraswamy, 2013; Pascoe et al., 2020; Ramón-Arbués et al., 2020). Indeed 60% of 18–24-year-olds reported feeling so stressed due to pressures to succeed that they felt overwhelmed or unable to cope (Mental Health Foundation, 2018b). As stress as has been found to be associated with characteristics reflective of poor mental health such as increased anxiety (Schneider et al., 2021) and depression (Hammen, 2005), the high levels of stress experienced by young adults can be highly problematic.

Stress and poor mental health can be increased from certain life events. One worldwide phenomenon that could be considered a life event to most young adults is the COVID-19 pandemic. The COVID-19 pandemic aggravated mental health issues. Measures needed to contain the virus, such as lockdowns and reduced social contacts, have been suggested to increase stress, anxiety, and depression (Rodríguez-Rey et al., 2020). Indeed, increases across facets of poor mental health including stress, depression, and anxiety have been reported since the start of the COVID-19 pandemic, with some evidence that this increase in poor mental health, takes current levels to higher than pre-pandemic levels (Kauhanen et al., 2023). In a post pandemic survey, it was estimated that 22% of 17-24 year-olds have a probable mental health condition in the United Kingdom (UK) (Newlove-Delgado et al., 2022), emphasising the need for methods to help decrease mental health issues in young adults. One potential way to improve mental health is by reducing perceived stress and providing methods to help cope with stress that does occur. It has been suggested that one potential way to achieve this is through physical activity (PA).

PA is largely supported to be beneficial for physical and mental health outcomes, for example improved outcomes in diabetes and prevention of cardiovascular disease (Anderson & Durstine, 2019), and reduced depression (Gianfredi et al., 2020) and anxiety (Wipfli et al., 2008). Evidence shows that PA can influence stress (Mikkelsen et al., 2017), but stress can also influence PA (Stults-Kolehmainen & Sinha, 2014), suggesting a relationship that is bi-directional in nature. Cross-sectional studies as presented in reviews by Stults-Kolehmainen and Sinha (2014) and Rodriguez-Ayllon et al. (2019) largely support this notion of a bi-directional relationship between PA and stress, with Stults-Kolehmainen and Sinha (2014) reporting that around two thirds of cross-sectional studies found higher stress was associated with lower levels of PA. Rodriguez-Ayllon et al. (2019) found that higher levels of PA were associated with lower stress when examined cross-sectionally. Similarly, as evidenced in Chapter 3, in adolescents surveyed during the height of the COVID-19 pandemic, physical activity was seen to be a negative predictor of stress similar to pre-pandemic associations between these variables. Additionally, Vogel et al. (2022) found that those who were more physically active during a lockdown reported being less stressed as well as using PA specifically to manage their stress.

Beyond these cross-sectional findings between PA and stress, when looking at longitudinal associations, Stults-Kolehmainen and Sinha (2014) also found that higher levels of stress were associated with lower levels of PA. However there was also some evidence that higher stress could result in higher levels of subsequent PA which was suggested to be a type of behavioural activation – potentially a coping strategy to deal with the higher levels of stress (Stults-Kolehmainen & Sinha, 2014). These studies reviewed included a mix of intervention, observational, and diary type studies over time periods as short as 5 days to up to 10 years, with factors such as age and gender influencing the relationship. The review

found that studies examining large (n>100), mixed gender samples of older adults were more likely to find higher stress being associated with lower PA.

Although findings appear to be similar when comparing cross-sectional and longitudinal associations between PA and stress, examining these relationships longitudinally has some advantages, such as the ability to examine both between (deviation from group mean) and within-person (deviation from personal mean) associations. By using a combination of between and within-person measures, it allows the researcher to examine whether any associations are driven by general levels (between-person) or temporal deviations at an individual level (within-person), allowing for comprehensive analysis and discovery of directional relationships. However, researchers do not often utilise the ability to examine between and within-person associations, and instead often focusing on just the between-person associations. There is some evidence suggesting that when examining within-person associations, PA is associated with lower subsequent stress (Schultchen et al., 2019) and stress is associated with lower subsequent PA (Do et al., 2021). Additionally, there is evidence in that individual characteristics, beyond regularly controlled for covariates (e.g., age, gender), can influence the relationships between PA and stress. For example, Nägel et al. (2015) found that stress was associated with lower subsequent PA in those with low motivation to exercise, but stress was associated with higher subsequent PA in those with higher motivation to exercise. These findings suggest a need for personal characteristics and dispositions to be taken into account when examining the PA and stress relationship.

One such characteristic is self-esteem. Self-esteem (how positive a person feels about themselves; (Sonstroem, 1998) is a stable characteristic of the self and those with higher self-esteem are thought to possess the belief they are better able to cope with

challenging or stressful situations (Pruessner et al., 1999). The Transactional Model of Stress and Coping (TMSC;(Lazarus & Folkman, 1984) suggests that when an individual experiences a stressful situation, they evaluate the situation as one that either facilitates growth/gain (a challenge appraisal) or harm/loss (a threat appraisal). While Lazarus and Folkman (1984) indicate that challenge and threat states are not mutually exclusive, the way in which an individual appraises the situation can be instrumental in coping with stress. Indeed, seeing stress through a challenge appraisal is more likely to result in adaptive coping and lower stress (Nicholls et al., 2012), whereas a threat appraisal is likely to be associated with more debilitative coping and therefore higher stress (Nicholls et al., 2012). Self-esteem has been seen to be associated with lower cortisol and autonomic stress reactivity (Seeman & Lewis, 1995), both of which are reflective of a challenge rather than threat appraisal (Meijen et al., 2020), suggesting those with higher self-esteem are better placed to have a more adaptive stress appraisal.

Self-esteem therefore is likely to be an important method to aid in creating a challenge appraisal and therefore reduce subsequent stress. Therefore, increasing self-esteem is likely to be beneficial for mental health. One of the proposed hypotheses on how PA is beneficial for mental health and well-being is the psychosocial hypothesis, which states that PA is linked to psychosocial determinants of mental health (Lubans et al 2016). Self-esteem was suggested as one of these psychosocial determinants. In addition to PA and self-esteem being related through additional mechanisms such as social connectedness, Lubans et al. (2016) presented evidence for the relationship between PA and self-esteem to be direct and independent of other mechanisms. Additionally, PA is often reported to be used as a method of coping with stress (Lemaire & Wallace, 2010). This could make PA a method of proactive coping, i.e., efforts undertaken to help to help prevent or modify the stressful

outcome before it occurs (Aspinwall & Taylor, 1997). Proactive coping has also been stated to be important in the development of skills and personal resources that help to cope with stress (Aspinwall & Taylor, 1997). Therefore, by developing personal resources through proactive coping, a person's stress appraisals could be influenced towards a challenge appraisal. This suggests the importance of considering proactive coping when examining stress.

The findings in Chapter 2, provide evidence for a synthesis of Lubans et al. (2016) psychosocial hypothesis of how PA can relate to self-esteem and self-esteem's links with stress appraisals according to Lazarus and Folkman (1984) transactional model of stress and coping. The findings from the model (Chapter 2), as well as previous research (e.g., Stults-Kolehmainen and Sinha (2014) review) suggest relationships between PA and stress through these mechanisms (i.e., self-esteem and stress appraisals). However, the model only provides support for these relationships cross-sectionally. The model also does not consider the effect of PA intensity on the relationships presented, which is important as other research suggests that PA intensity can play a role in the PA-stress relationship. For example, Jones et al. (2017) found that while low intensity PA was associated with lower subsequent stress there was no association between moderate-vigorous PA (MVPA) and subsequent stress. Contrastingly, Gerber et al. (2014) found vigorous intensity exercise to be associated with lower stress. The contrast in findings between these two studies (one supporting vigorous PA for stress, the other not) suggests that the relationship between PA intensity and stress is complex and should be considered when examining any associations.

The findings of the previously discussed literature leads to the following questions: 1) how do the relationships underpinned by the TMSC (Lazarus & Folkman, 1984) and the psychosocial hypothesis of PA and self-esteem (Lubans et al., 2016), presented in the

Chapter 2's model hold up longitudinally, 2) what, if any, impact does proactive coping have on stress and, 3) Does PA intensity play any role in the aforementioned relationships. Therefore, the present study aimed to explore longitudinal associations between stress and different intensities of PA, as well as how predictor variables (self-esteem, challenge and threat appraisals and proactive coping) could potentially influence these associations. The study also aimed to examine if there were any interaction effects between PA intensities and other predictor variables on stress.

Hypotheses

It was hypothesised that increased PA across all intensities (walking, moderate PA, vigorous PA, and total PA) would predict lower stress at both a within and between-person level. It was also expected that higher levels of self-esteem, challenge appraisals and proactive coping would predict lower levels of stress at both a between and within-person level. Higher threat appraisal was expected to predict higher stress. It was also predicted that there would be interaction effects between all intensities of PA and predictor variables at between and within-person levels. For example, PA would interact with self-esteem to predict lower stress than PA or self-esteem independently.

Methods

Participants

In total, 297 participants were recruited. Participants were undergraduate, University of Birmingham students, (M age= 19.27, 62% female) predominately from the School of Sport, Exercise and Rehabilitation Sciences. Participants were recruited through a short advertisement video, containing details of the study and an accompanying summary sheet, provided to students completing one of two modules within the school. The summary sheet contained the contact details of the lead researcher, and interested participants were

asked to email the lead researcher for more information or to sign up to the study. Course credit was offered to students for completion of the study. To be eligible to take part in the study, participants had to be university students, aged 18-24, able to read English, and have no current self-reported medically diagnosed mental health conditions. The study gained ethical approval from the University STEM Ethics Committee.

Procedures

Participants who were interested in taking part in the study were emailed the link to the online questionnaire pack (SmartSurvey). The questionnaire pack contained the study information sheet, detailing the requirements of the study and contact details of the lead researcher in order for participants to ask any questions. Those agreeing to participate gave informed consent to take part in the study in the same online questionnaire pack. Participants completed the questionnaire pack using the online software at three time points. These time points were between 8th October – 5th November 2020 (time point 1), 18th November – 1st December 2020 (time point 2), and 12th – 21st January 2021 (time point 3). These time points were chosen to reflect different points of an academic semester, a settling in period at the start of a new semester, a settled point mid-semester, and exam season. During time point 1, although the three tier lockdown system (Brown & Kirk-Wade, 2021) was announced, the UK was largely allowed to leave the house and organised PA was allowed to take place across all tiers providing that guidance relating to distancing was observed. During time points 2 and 3, the UK was placed in a full lockdown comparable to the initial March 2020 lockdown (Brown & Kirk-Wade, 2021), which prevented groups of people gathering and gyms were closed (UK Government, 2020). At each time point, consent to participate was taken, along with an email address the participant would like the next pack sending to. The questionnaire pack contained questions relating to participants'

physical activity, perceived stress, self-esteem, stress appraisals and proactive coping (specific measures described below). The pack took approximately 30 minutes to complete.

Questionnaires

Physical Activity.

The short form International Physical Activity Questionnaire (IPAQ; (Craig et al., 2003)) was used to assess participants' physical activity levels of the last 7 days. Participants were asked how many times in the last 7 days they had completed at least 10 minutes of vigorous physical activity (e.g., fast cycling), moderate physical activity (e.g., easy swimming) and how many days they had walked. For each intensity, participants were also asked to state the duration (hours and minutes) of their average physical activity session. Total weekly minutes of activity were then calculated for each intensity as well as overall (e.g., if a person completes vigorous physical activity 3 times per week, for 30 minutes each time, total minutes = 30x3 = 90 minutes). The IPAQ scoring allows for a bout of up to 180 minutes (or 1260 minutes per week) at each time point, therefore any individual bout lengths of over this duration were truncated to the maximum of 180 minutes (Forde, 2018). Metabolic Equivalents (METS) were then calculated by multiplying the total minutes for each intensity by the appropriate MET value: 8 (vigorous physical activity), 4 (moderate physical activity) and 3.3 (walking). This would mean for example, a participant who completed 90 minutes vigorous PA (90*8 = 720), 90 minutes of moderate PA (90*4 = 360) and 480 minutes of walking (480*3.3 = 1584), would have completed a total of 660 minutes of activity per week for a total METS of 2664 (720+360+1584). METS were then standardised by dividing the calculated METS by 1000. Using the example above, this would mean vigorous METS would become 0.72 (720/1000), moderate METS would become 0.36 (360/1000), walking would become 1.58 (1584/1000), with a total standardised METS of 2.66 (2664/1000). This was

done to bring the METS scores to an equivalent value with scores from other questionnaires. The short form IPAQ has been found to be reliable and valid in similar university/college age participants (Dinger et al., 2006).

Perceived Stress

The 10-item version of the perceived stress scale (PSS; (Cohen et al., 1983), was used to assess how stressed participants had felt in the past month. Participants rated items (e.g., "How often have you felt nervous and stressed?") on a 5-point Likert scale (0 = never, to 4 = very often). Positively worded items (e.g., How often have you felt that you were on top of things?) were reverse scored. The mean of all items was calculated, with higher overall scores indicating higher levels of perceived stress. The use of the PSS in a student population has been found to be reliable and valid (Denovan et al., 2019; Roberti et al., 2006). The present study showed good reliability, with a Cronbach's alpha of > .82 at each time point.

Self-Esteem

Self-Esteem was assessed using the 4-item version of the Rosenberg Self-Esteem Scale (Guddal et al., 2019). Participants were asked to rate items (e.g., "I have a positive attitude towards myself") on a 4-point Likert scale from 1 (strongly disagree) to 4 (strongly agree). Negatively worded items were reverse scored. All items were summed to give an overall score (range 4-16); a higher score indicated higher self-esteem. The full Rosenberg Self-Esteem scale demonstrates good validity (Rosenberg, 1965), and the 4-item scale strongly correlates with the full scale (Tambs & Røysamb, 2014). Additionally, the 4-item scale has been seen to have good internal reliability (Guddal et al., 2019). The present study showed good reliability, with a Cronbach's alpha of > .73 at each time point.

Stress Appraisals

The two subscale Cognitive Appraisal Scale (CAS; (Skinner & Brewer, 2002)) is an 18-item questionnaire that was employed to measure challenge (8 items, e.g., I believe that most stressful situations contain the potential for positive benefits) and threat appraisal tendencies (10 items, e.g., I feel that difficulties are piling up so that I cannot overcome them). Participants rated items on a 6-point Likert scale from 1 (Strongly disagree) to 6 (Strongly agree). Separate subscale means were then calculated with higher scores indicating higher challenge/threat appraisal tendencies. The CAS has been used previously in participants of a similar age group and was found to be valid and reliable across both subscales (Williams & Cumming, 2012). The present study showed good reliability for both challenge and threat appraisal tendencies, with Cronbach's alpha scores of > .79 and > .93 respectively at each time point.

Proactive Coping

The Proactive Coping Scale (PCS; (Greenglass et al., 1999)) is a subscale of the Proactive Coping Inventory (PCI; (Greenglass et al., 1999)). The scale comprises 14-items (e.g., When I experience a problem, I take the initiative in resolving it). Responses to each item were made on a 4-point scale from 1 (Not at all true) to 4 (Completely true). Negatively worded items were reverse scored, and all items were summed to create an overall score. Higher scores were representative of a higher tendency towards proactive coping. The scale has previously been shown to have good internal reliability (Vernon et al., 2009) and validity (Greenglass et al., 1999), with the present study also showing good reliability. Cronbach's alpha scores of > .76 were seen at each time point in the present study.

Data Analysis

Analysis was conducted using SPSS (IBM Version 26). Data was screened and cleaned to check for missing values and outliers. To be included in the final sample, participants had

to have completed at least two of the three time points, including time point one, as well as having complete IPAQ data. Those with unrealistic IPAQ data (e.g., durations or frequencies that were too high to be true), while taking into account that participants were largely sports students so likely to be more active, were excluded from the final sample. From the 298 participants that started the study, 90 were included in the final sample. Physical activity METS were seen to be significantly higher in those that did not complete the study than those in the final sample across all intensities (vigorous PA, p =.001, moderate PA, p =.006, walking METS, p =.001, total METS, p>.001), however as unrealistically high PA was an exclusion criteria, this was to be expected. Participants excluded were seen to have broadly similar characteristics and variable scores as those presented in the results. There were no significant age (p = .65) or gender (p =.61) differences between those who were included in the final sample and those who were not. There were no significant differences in self-esteem (p =.80), challenge appraisal (p =.06) or threat appraisal (p =.49) between participants in the final sample and those who were not. Proactive coping however was found to be significantly higher (p =.002) in the participants not included in the final sample. At each time point, Little's MCAR test (Little, 1988) showed that less than 5% of the data was missing completely at random. Expectation Maximisation was therefore used to complete the data set (Tabachnick & Fidell, 2013). Imputation was completed for each time point individually to prevent imputed values being influenced by scores at other time points.

Multilevel analyses were used to examine if there were any changes in the variables over time, i.e., between time points 1, 2 and 3. A series of multilevel analyses were then completed to examine within- and between-person associations between stress, vigorous, moderate, and total PA, walking, self-esteem, challenge appraisal, threat appraisal and proactive coping. Within-person (level 1) predictors were person-mean centred, reflecting

the variation in score for each participant compared to the participants own mean. Between-person (level 2) predictors were grand-mean centred, reflecting the mean value for each participant in relation to the overall mean of the sample. Age and gender were entered as covariates in all analyses. The covariates were grand-mean centred (age), or a dummy variable was used (gender: 0 = female). The intercept in the models therefore represents the estimated stress of a female of average age.

Results

Participant Characteristics

The final sample consisted of 90 participants (mean age = 19.22 years, SD= 0.49, 60% female), of which 78 participants (87% of final sample) had completed all three time points. Mean (SD) scores for stress, PA intensities, and other predictor variables at each time point are reported in Table 4.1.

Analyses of Changes over Time

Multilevel analyses were run to establish if there were any changes in variables across the time points. It was found that total PA significantly decreased between T1 and T2 ($p < .001$), between T1 and T3 ($p < .001$), and between T2 and T3 ($p < .001$). Vigorous PA also significantly decreased between T1 and T2 ($p < .001$) and between T1 and T3 ($p < .001$) but not between T2 and T3 ($p = .348$. Self-Esteem significantly increased between T1 and T3 ($p = .031$) but did not change between T1 and T2 ($p = .462$) or T2 and T3 ($p = .077$). Stress, challenge appraisal, threat appraisal, proactive coping, moderate PA, and walking did not change over time (see Table 4.1).

Table 4.1: Estimated mean METS (SD)[minutes] of weekly physical activity, stress, and additional dependant variables at each time point.

	T1	T2	T3
Total PA	3.25 (1.73) [643]	2.27 (1.45) [514]	1.42 (1.05) [504]
Vigorous PA	1.77 (1.36) [221]	0.86 (0.91) [107]	0.96 (1.07) [103]
Moderate PA	0.50 (0.52) [125]	0.40 (0.55) [99]	0.90 (4.06) [225]
Walking	0.98 (0.90) [297]	1.02 (0.89) [308]	0.95 (0.99) [225]
Stress	1.93 (0.54)	1.93 (0.71)	1.82 (0.64)
Self-Esteem	11.94 (2.36)	12.06 (2.44)	12.35 (2.64)
Challenge Appraisal	4.48 (0.64)	4.53 (0.64)	4.46 (0.66)
Threat Appraisal	3.80 (1.07)	3.77 (1.14)	3.69 (1.16)
Proactive Coping	2.99 (0.36)	2.96 (0.40)	2.97 (0.39)

Note: PA = Physical Activity, physical activity and walking means are presented as standardised METs ((total minutes per week*METS equivalent)/1000).

Longitudinal Analyses Predicting Stress

Physical Activity Predicting Stress

Separate multilevel models were run for total, vigorous PA, moderate PA, and walking predicting stress at between and within person levels. It was found that total PA, vigorous PA, and walking predicted stress at a between-person level, but not at the within-person level, meaning that being more physically active compared to sample mean, increases the likelihood of being less stressed, but an individual being more physically active compared with their personal mean does not mean they are likely to be less stressed. Moderate intensity PA did not predict stress at either between or within-person level (see Table 4.2).

Other Predictor Variables Predicting Stress

Separate multilevel models were run for self-esteem, challenge appraisal, threat appraisal and proactive coping predicting stress. Models contained the independent variable (e.g., self-esteem) at both between and within-person levels. Self-esteem, challenge appraisal, threat appraisal and proactive coping were found to be predictors of stress at both the between and within-person levels. This means that, for example, having higher self-esteem compared to sample mean, increases the likelihood of being less stressed, and an individual with higher self-esteem compared with their personal average means they are likely to be less stressed (see Table 4.3).

Table 4.2: Associations between Physical Activity Intensity (predictor variables) and stress (outcome variables)

	Model 1 Total PA β(SE)	**Model 2** Vigorous PA β(SE)	**Model 3** Moderate PA β(SE)	**Model 4** Walking β(SE)
Fixed Effects				
Intercept	2.03	2.03	2.03	2.02
	(0.07)	(0.07)	(0.07)	(0.07)
Level 2 Predictors				
Age	-0.03	-0.02	-0.03	-0.04
	(0.05)	(0.05)	(0.05)	(0.05)
Gender	-0.33*	-0.33*	-0.32*	-0.30*
	(0.11)	(0.11)	(0.11)	(0.11)
Between-person	0.11*	0.12*	0.01	0.19*
Differences	(0.05)	(0.06)	(0.04)	(0.09)
Level 1 Predictor				
Within-person Differences	0.11	-0.05	0.02	0.05
	(0.02)	(0.03)	(0.01)	(0.03)
Model Fit				
-2 restricted LL	383.67	383.87	388.75	382.72
AIC	397.67	397.87	402.75	396.72

Note: *p <.05, *** p <.001, LL= log likelihood, AIC= Akaike's Information Criterion.

Table 4.3: Self-Esteem, Challenge Appraisal, Threat Appraisal and Proactive Coping predicting Stress.

	Model 1 Self-Esteem β(SE)	**Model 2** Challenge Appraisal β(SE)	**Model 3** Threat Appraisal β(SE)	**Model 4** Proactive Coping β(SE)
Fixed Effects				
Intercept	1.98	1.99	1.94	2.02
	(0.05)	(0.06)	(0.06)	(0.06)
Level 2 Predictors				
Age	-0.01	-0.02	0.01	0.01
	(0.03)	(0.04)	(0.04)	(0.04)
Gender	-0.20*	-0.02*	-0.11	-0.29*
	(0.81)	(0.10)	(0.10)	(0.10)
Between-person	-0.16***	-0.50***	0.31***	-0.75***
Differences	(0.02)	(0.08)	(0.04)	(0.14)
Level 1 Predictor				
Within-person Differences	-0.10**	-0.28*	0.24**	-0.33*
	(0.03)	(0.10)	(0.07)	(0.16)
Model Fit				
-2 restricted LL	316.10	348.87	338.84	376.35
AIC	330.10	362.87	352.84	380.35

Note: *p <.05, ***, p =.001, p <.001, LL= log likelihood, AIC= Akaike's Information Criterion.

Physical Activity and Covariates Predicting Stress

Separate multilevel models were run for total, vigorous PA, moderate PA, and walking predicting stress. Self-esteem, challenge appraisal, threat appraisal, proactive coping, age, and gender were included as between-person predictors in each model. Across all models, self-esteem and threat appraisal were found to be between-person predictors of stress, meaning that having higher self-esteem than the group mean is likely to result in lower stress, or that having higher threat appraisal than the group mean is likely to result in higher stress. Total PA, vigorous PA, moderate PA, walking, challenge appraisal, proactive coping, age, and gender were not found to be predictors at between or within-person level (see Table 4.4).

Interaction Effects

No significant interaction effects were found between any intensity of PA and any other predictors at any level. For example, there was no interaction found between vigorous PA and self-esteem when predicting stress.

Table 4.4: Longitudinal Analysis PA and additional variables predicting Stress.

	Model 1 Total PA β(SE)	**Model 2** Vigorous PA β(SE)	**Model 3** Moderate PA β(SE)	**Model 4** Walking β(SE)
Fixed Effects				
Intercept	1.95	1.95	1.95	1.95
	(0.05)	(0.05)	(0.05)	(0.05)
Level 2 Predictors				
Age	0.001	0.004	0.006	-0.003
	(0.03)	(0.03)	(0.03)	(0.03)
Gender	-0.14	-0.15	-0.13	-0.13
	(0.08)	(0.08)	(0.08)	(0.08)
Between-person PA	0.04	0.07	-0.02	0.08
	(0.03)	(0.04)	(0.03)	(0.06)
Self-Esteem	-0.10***	-0.10***	-0.10***	-0.10***
	(0.03)	(0.03)	(0.03)	(0.03)
Challenge Appraisal	-0.14	-0.15	-0.10	-0.13
	(0.12)	(0.12)	(0.12)	(0.12)
Threat Appraisal	0.14*	0.14*	0.15**	0.15*
	(0.05)	(0.05)	(0.05)	(0.05)
Proactive Coping	-0.02	-0.01	-0.03	-0.01
	(0.18)	(0.18)	(0.18)	(0.18)
Level 1 Predictor				
Within-person PA	-0.01	-0.05	0.02	0.05
	(0.02)	(0.03)	(0.01)	(0.03)
Model Fit				
-2 restricted LL	312.032	309.793	312.953	310.064
AIC	334.032	331.793	334.953	332.064

Note: *p <.05, ** p =.001 *** p <.001, LL= log likelihood, AIC= Akaike's Information Criterion, PA= physical activity.

Discussion

Multilevel analysis was used to examine the within- and between-person associations between PA intensities (total, vigorous, moderate, and walking), predictor variables (self-esteem, challenge and threat appraisals and proactive coping) and stress in university students over a 3-month period during varying levels of COVID-19 lockdown restrictions. It was found that walking, total PA, and vigorous PA predicted stress at a between-person level, but when covariates of self-esteem, challenge appraisal, threat appraisal, and proactive coping were included in the models, PA no longer predicted stress. Across all PA intensity models, self-esteem consistently predicted lower perceived stress at a between-person level, whereas threat appraisal predicted higher perceived stress across all models at a between-person level. Contrary to hypotheses, no interaction effects were found between PA intensities and any predictor variable at either between or within-person levels.

PA intensities (except moderate PA) were found to predict stress only at a between-person level. While a between-person association was expected based on previous research (as seen in Chapter 2), this did not extend to within-person level associations, despite prior research suggesting the existence of this association across various time frames from same day to 2 years later (Jones et al., 2017; Jonsdottir et al., 2010). The existence of between-person relationships but no within-person associations suggests that the overall levels of these intensities of PA are more consistently associated with overall levels of perceived stress, whereas fluctuations in PA at an individual level are not predictive of fluctuations in stress levels. However, it should be acknowledged that, in the current study, the fluctuations in both PA and stress were marginal, which could be a reason for the lack of within-person associations. This suggestion could account for the associations between

vigorous PA, total PA, and walking and stress at between, but not within-person level, however this warrants further investigation.

Moderate intensity PA was not found to be associated with stress at either the between or within-person level. At a within-person level, this could be due to levels of moderate PA not changing much over time, therefore there may not have been enough variation in moderate PA to see an association, similar to the other PA intensities. A moderate intensity PA intervention implemented during the COVID-19 initial lockdown found that a 6-week course of moderate intensity training reduced stress (Borrega-Mouquinho et al., 2021), indicating that moderate PA does have the potential to reduce stress. The levels of moderate PA prescribed by Borrega-Mouquinho et al. (2021) in their intervention were higher than the values reported in the present study (approx. 240 minutes per week compared with approx. 150 minutes per week in the present study), suggesting that maybe more moderate intensity activity is needed to see an effect. Similarly to the present study, high intensity activity was found by Borrega-Mouquinho et al. (2021) to reduce perceived stress, but the amount of high intensity activity was higher than in the present study (approx. 240 minutes per week compared with approx. 144 minutes per week in the present study). Unlike the present study however, Borrega-Mouquinho et al. (2021) did not find a difference in the relationships between moderate and vigorous activity and stress. This could suggest that for the present study, the metabolic expenditure is more important to the stress relationship than time spent undertaking an activity. This is supported by the finding that although on average, participants spent more time walking (approx. 277 minutes per week) than any other intensity of activity, the reported average METS are higher than those for moderate PA. However, this is just speculation, and more

research is needed to establish whether metabolic expenditure or time in an activity is more important when examining the PA and stress relationship.

It is also possible that there are differences in perceptions of what moderate PA amounts to. Where Borrega-Mouquinho et al. (2021) asked participants to exercise to an rate of perceived exertion of 4-6 out of 10, this rating is likely to differ across participants based on elements like physical ability. Some participants may actually have been completing these activities at a higher intensity than others. The same point can be made for the current study, with it not being possible to measure actual PA intensity as the PA measure used was solely self-report. Therefore, some moderate PA could actually have been incorrectly classified as vigorous PA for example, skewing the results towards a vigorous PA and stress relationship. It is important therefore for more accurate measures of PA intensity to be taken beyond self-report, for example the use of accelerometer data, to fully understand the relationship between PA intensity and stress.

Despite total PA, vigorous PA, and walking predicting stress at a between-person level, these associations were no longer evident when covariates were added to the model. Within these models, only self-esteem and threat appraisal were found to predict stress. While it is perhaps surprising that threat appraisal is a predictor of stress where challenge appraisal is not due to the close conceptual links between challenge and threat appraisals, research has found that threat appraisal is more closely associated with stress than challenge appraisal (Beevor et al., 2023), providing support for the current finding. Self-esteem has previously been found to be beneficial for stress, so this result is perhaps not surprising, with self-esteem being suggested to reduce stress through providing increased resources to enable coping with stress (Pruessner et al., 1999) and by lowering physiological elements of stress such as cortisol reactivity (Seeman & Lewis, 1995). As resources and

physiological factors are not measured in this study this is speculation, but appears a logical assertion based upon previous research. Future research could benefit from examining both the psychological and physiological elements of self-esteem and stress simultaneously to confirm these theories.

Indeed, previous research has shown that in college students vigorous exercise was found to be associated with a higher stress tolerance (Bland et al., 2014). Similarly, during the COVID-19 pandemic, it has been seen that active individuals were likely to use PA as a coping mechanism to manage stress (Vogel et al., 2022). In the present study however, proactive coping is not associated with stress when included in the model with PA intensities, but it is independently associated with stress and a between and within-person level. There is a difference however in how both proactive coping and PA are measured in the current study and by Vogel et al. (2022). Where Vogel et al report that people who are physically active (using a binary measure) are more likely to use PA as a way to cope with stress, the current study shows that displaying a more proactive coping disposition is not associated with the amount of PA, with proactive coping not being specifically measured in the context of PA. This suggest that people may need to be educated on how best to use PA as a way to cope with stress.

As shown in Chapter 2's model, associations between PA, self-esteem, stress appraisals, and stress are present at a cross-sectional, between-person level. The present study, however, ran with a number of weeks between each data collection point and did not find associations at a similar between-person level, or at a within-person level. While there may not be between or within-person associations over the presently studied time period, it is possible that there could be associations over other periods of time. For example, a study examining PA and stress 2 years apart found that those who had higher levels of light or

MVPA at time point 1, were less likely to report high perceived stress at time point 2 (Jonsdottir et al., 2010). Additionally, within the current study, although there are 3 separate time points, at each point data is collected from participants reflecting back over a week, providing only a general snapshot of the stress and PA completed in this time. This approach will not capture any associations between PA and stress over much shorter periods, e.g., between hours or over a day or two. Evidence from studies utilising ecological momentary assessment (EMA) methodology (collection of data using a repeated sampling method (Shiffman et al., 2008)), suggest that some PA intensities can predict stress at a within-person level in time frames as short as 15 minutes later (Jones et al., 2017), to 2.5 hours later (Schultchen et al., 2019) or the following day (daSilva et al., 2021). These findings could suggest that the PA/stress association is more instantaneous, something which is not captured using the current study method which asks participants to reflect back over the week. However, this is speculation and further research is needed to examine whether this is the case.

Data was collected during different stages of the COVID-19 pandemic, with varying levels of restriction at each time point. Throughout the study, COVID-19 restrictions became more strict, going from largely free movement, through to severely reduced freedoms similar to those seen during the initial March 2020 lockdown (Brown & Kirk-Wade, 2021), which prevented groups of people gathering and gyms were forced to close (UK Government, 2020). Within the study, it was seen that total PA, decreased across all three time points and vigorous PA reduced from time 1 to time 2 and 3. As moderate PA and walking did not change overtime, the overall decrease in PA was likely driven by the decrease in vigorous PA. This suggests that the lockdown acted as a natural intervention to decrease PA across our sample, by restricting PA opportunities in organised settings that can

facilitate more vigorous types of PA, such as fitness classes, gyms, or organised sports. Despite previous evidence suggesting that the COVID-19 pandemic increased stress in adults (Rodríguez-Rey et al., 2020), this was not evidenced within our sample who maintained a moderate level of stress across the all three time points. The levels of stress seen in the current sample are also comparable to the levels of stress seen in adolescents surveyed in Chapter 3 and university students completing the same stress questionnaire (PSS) prior to the pandemic (Denovan et al., 2019). This suggests that the COVID-19 pandemic may not have affected the stress levels of the current participants to the extent it did in other samples.

Self-esteem was seen to significantly increase between T1 and T3, but not between T2 and T3. While previous research has suggested that self-esteem is largely stable (Abdel-Khalek, 2016), there is evidence that suggests self-esteem can be temporarily altered by external circumstances that threaten components of self-esteem such as self-worth or self-confidence (Heatherton & Wyland, 2003). At T1, participants were either starting university for the first time, or returning after the disruption of COVID-19 to their previous year. This could have resulted in a lower-than-normal level of self-esteem, potentially due to lower self-confidence as a result of the unknown circumstance. This lower-than-normal level of self-esteem could have persisted into T2 but resolved back to normal levels at T3 after a period of settling and building self-confidence back up. This could potentially account for the increase in self-esteem from T1-T3, but not T2 – T3, however this is speculation based on evidence that self-esteem can fluctuate (Heatherton & Wyland, 2003), but may not have been the case in this sample. Future research could benefit from examining self-esteem more frequently, to examine potential fluctuations in more depth. It would also be beneficial to collect data around events occurring (such as exams or deadlines) around the

time of each measurement of self-esteem to provide the context for any fluctuation. Previous research has found that EMA has the potential to be used the measure self-esteem (Hank & Baltes-Götz, 2019), so this could be a key next step.

Strengths and Limitations

One key strength of the present study is the use of a longitudinal design which allows the examination of fluctuations of variables over time. This design also allowed for the use of both between- and within-person analysis. One limitation of the study however is that although this method allows the examination of fluctuations in variables over a longer period of time, it does not pick up much smaller fluctuations that occur during or between individual days. This could result in associations that are present on a more short-term basis being missed. Additionally, the study only has a small sample size. This could mean that the results did not have sufficient power to show small, subtle fluctuations.

The study participants were also predominantly students studying sports related courses, and who were largely very physically active. This makes it difficult to generalise the results of the study to a more general population or even a regular student population, who likely have very different PA behaviours. Therefore, results should be treated with caution when not applied to a similar sample. The findings of the current study, however, could be relevant to similar highly active students, such as student athlete populations, so still have their benefits.

Proactive coping was seen to be significantly lower in the final sample than in the total sample. Both mean values however were found to be low (final sample =2.99, total sample = 3.13 out of a possible total score of 14), and similar, suggesting that the difference being significant could be down to the difference in sample size, or potentially a type one

error due to the multiple comparisons between groups. However, this is just speculation and further research is needed to clarify this theory.

Future Research Directions

Future research could focus on examining the associations between the discussed variables over shorter time periods. One potential way to do this would be to use EMA to examine the associations between variable fluctuations within and between individual days. Research could also examine these relationships over a longer period of time, with repeated sampling over a number of years in order to establish whether attributes such as challenge and threat appraisal are more stable or if they change in relation to factors such as age. Additionally, it could be useful to re-examine the relationships presented outside of COVID-19 restrictions, allowing for more natural levels of PA to be examined.

As discussed previously, the sample was predominately students from a sports related background and were found to be highly active. It would therefore be beneficial to re-examine the relationships from the study in less active student populations. There is also scope for further research to provide comparisons between student athletes and non-student athletes to see if/where there are similarities or differences in the findings.

Conclusions

In conclusion, it was found that under the circumstances presented in this study, PA intensity (except moderate intensity) was associated with stress at a between-person (but not a within-person level) when entered independently into the model, but not when self-esteem, challenge and threat appraisal and proactive coping were added to the model. Additionally, self-esteem and threat appraisal were seen to be consistent predictors of stress at a between-person level across all PA intensities. While many of the findings were not as hypothesised, it is possible that factors such as the COVID-19 pandemic and the

timescale the variables were measured over contributed to the largely non-significant associations found. Future research could focus on examining these relationships over different time frames, including on a within-day basis using methodology such as EMA.

Chapter 5

Associations between Physical Activity, Sedentary Behaviour, and Stress using Ecological Momentary Assessment: A Scoping Review

This chapter is published under the following reference:

Wright, L. J., Williams, S. E., & van Zanten, J. J. V. (2023). Associations between physical activity, sedentary behaviour, and stress using ecological momentary assessment: A scoping review. *Mental Health and Physical Activity*, 100518.

Abstract

Physical activity (PA) and sedentary behaviour (SB) have previously been seen to be associated with stress. However, observed associations have been inconsistent in direction. Research tends to examine associations at one given time point without considering how these constructs change over time. Ecological momentary assessment (EMA) is one potential method to examine how the relationships between PA or SB and stress change over time taking variations in PA/SB and stress within and between days into consideration. This scoping review aimed to examine the concurrent and prospective relationships between PA/SB and stress and vice versa, using EMA methodology. 5 online data bases were used to search for EMA research that included measures of PA/SB and stress, where a PA/SB-stress relationship was examined. Searches were run up until February 2022. Papers were assessed for eligibility for inclusion, with 33 papers found to fit the required criteria. 28 of the included studies focussed on PA, with 2 focussing on SB, and 3 on both PA and SB. Studies used a mix of between- and within-person analyses as well as examining associations over concurrent and/or prospective time frames. Taking into consideration analyses and time frame, results were inconclusive, with approximately half of the studies finding no association. Overall findings appear to be mixed. However, some evidence on a within-person level suggests that stress is associated with subsequent lower levels of PA, as well as PA being associated with lower levels of subsequent stress. Future research should investigate the impact of the way stress is quantified, different intensities of PA and the context of both PA and SB in order to get a better understanding of the associations between PA/SB and stress. In addition, more detailed studies are needed to explore personal and contextual factors that could influence these associations is warranted.

Keywords: Exercise, Physical Inactivity, Mental Health, Distress, Experience Sampling.

Introduction

Stress is highly prevalent in society, with a survey suggesting that 74% of UK adults felt so stressed that they were unable to cope (YouGov, Mental Health Foundation, 2018). Stress can be defined as the response to a situation when the demands of that situation exceed an individuals perceived ability to cope (Fink, 2016). It can include life events or person centred stresses (Segerstrom & O'Connor, 2012). Although stress can at times be beneficial, such as improving performance, effort, and proactive coping (Jamieson et al., 2018), there is also ample evidence that both acute and chronic stress can have a negative impact on physical and mental well-being, such as cardiovascular disease (Kivimäki & Steptoe, 2018; Song et al., 2019) and depression (Hammen et al., 2009; Parrish et al., 2011). Therefore, it is important to find ways to reduce the negative implications of stress in order to sustain good mental and physical health and well-being.

As discussed throughout this thesis, physical activity (PA) has long been promoted for the promotion of positive physical health outcomes such as the prevention of cardiovascular disease and improved outcomes in type 2 diabetes mellitus (Anderson & Durstine, 2019). PA has also been seen to be associated with improved mental health, such as reduced anxiety (Wipfli et al., 2008) and depression (Gianfredi et al., 2020). However, when discussing PA, it is also important to consider the role of sedentary behaviour (SB). Sedentary behaviour is any waking behaviour that is characterised by a sitting or reclining posture, expending $\leqslant$1.5 METs (Sedentary Behaviour Research Network, 2012). While there is a common misconception that SB is simply the lack of PA or being physically inactive, in reality, SB is more complex and a behaviour distinct from PA. In the past, those who did not meet PA guidelines were considered to be sedentary (Sedentary Behaviour Research Network, 2012), however, research now states that it is possible to be both physically active

and sedentary (Owen et al., 2010). A person can meet PA guidelines, while also spending a large percentage of their time in sedentary behaviours such as driving, working on the computer or watching television (Owen et al., 2010). Therefore, it would be interesting to explore PA and SB as separate behaviours in relation to stress and well-being.

Both PA and SB have been suggested as health behaviours associated with stress. Reviews have reported stress as a predictor of PA, but also PA as a predictor of stress (Mikkelsen et al., 2017; Stults-Kolehmainen & Sinha, 2014), potentially suggesting that the PA-stress association is bi-directional in nature. There is also evidence that SB is associated with stress, with reviews finding that more time spent in sedentary behaviours, such as screen time and sitting, predict increased risk of anxiety and depression (Allen et al., 2019; Wang et al., 2019). Also, SB is related to other indicators of negative mental health. For example, a systematic review into SB and mental health in adolescence has been found increased time spent in sedentary activities, particularly screen time, to be associated with higher depressive symptoms, higher psychological distress and lower self-esteem (Hoare, Milton, Foster, & Allender, 2016)

When examining SB in their systematic review Teychenne et al. (2019) find mixed results. The review examines a variety of different methodological approaches, namely cross-sectional, longitudinal, clinical trials, pilot interventions and direct observations. Across all of the study types 37% of studies found that increased SB was associated with increased stress, 10% found that increased SB was associated with decreased stress, and the remaining 53% found no association, leading Teychenne et al. (2019) to the conclusion that there is not sufficient evidence to come to a conclusion on the SB and stress relationship. The equivocal nature of the evidence relating to the relationship between SB and stress suggests that more detailed investigation into the relationship is warranted.

One possible reason for the equivocal results found for the PA/SB and stress relationship is the way that the studies are conducted. In the Stults-Kolehmainen and Sinha (2014) review approximately two thirds of the studies included examined a single time point. Of these papers examining stress and PA at a single time point, two thirds of papers found higher stress was associated with lower PA. However, within the same review, when examining if stress could predict PA from 2 weeks to multiple years in the future, Stults-Kolehmainen and Sinha (2014) found equivocal results. When examining SB, the Teychenne et al. (2019) review predominately examined single time point studies but in contrast to Stults-Kolehmainen and Sinha (2014) found equivocal results. Additionally, within the Stults-Kolehmainen and Sinha (2014) review, single time point studies and prospective studies returned different associations. As PA/SB and stress fluctuate between and within days (Shang et al., 2018; von der Embse & Mankin, 2021) this is perhaps to be expected, but is largely overlooked when studies ask participants to report their PA/SB and stress as general levels over several days or weeks. Therefore, it is important to use a methodology that allows for the examination of these relationships taken into consideration fluctuations within and between days, and not just at a single time point, to gain a more comprehensive overview of the existence and direction of a PA/SB-stress relationship.

One methodology that could be used to examine the PA/SB-stress relationship over time is Ecological Momentary Assessment (EMA). EMA is a method which uses repeated sampling of participant behaviour, feelings, and experiences in real time while participants go about their normal lives (Shiffman et al., 2008). Capturing data in participants' free-living environment over several days allows researchers to examine how fluctuations in PA/SB, both between and within days, are related to fluctuations in stress over the same time period (Dunton, 2017; Shiffman et al., 2008). Collecting data in this way allows for the

separation of between-person (deviation from average group level) and within-person (deviation from individuals own average) associations. In other words, it enables researchers to explore if the associations are mainly driven by variations in general levels of PA/SB/stress (i.e., deviation from average group level) or temporal variations in PA/SB/stress at an individual level (i.e., deviation from individual own average) (Curran & Bauer, 2011; Dunton, 2017). Using EMA also provides a good opportunity to assess both concurrent and prospective associations. Concurrent associations refer to relationships between PA/SB and stress occurring at the same time such as overall day levels. Prospective associations refer to how PA/SB at one time point is associated with stress at a subsequent time point. For example, prospective associations could explore the associations between PA in the morning with stress that afternoon. Being able to examine between and within-person associations between PA/SB and stress, as well as simultaneously examining the concurrent and prospective associations would allow for a more comprehensive examination of the existence and direction of potential PA/SB-stress relationships.

While EMA has previously been used to explore variations within and between days in stress, as well as objective and subjective PA/SB, the extent of this research is not known. Little is also known to what extent EMA has been used to examine the PA/SB and stress relationship when both variables have been measured using EMA assessments or continuous monitoring, or what the outcomes of this research are. A scoping review would be beneficial as it would allowed for the examination of what evidence is already available relating to the area of interest (PA/SB and stress relationships using the EMA methodology), as well as providing an overview of which research designs have been used to explore these associations, and how the relevant concepts (PA/SB and stress) have been examined. In addition a scoping review can be used to highlight any potential gaps in this area that need

to be investigated in order to progress the field (Munn et al., 2018; Peters et al., 2015). Given the increased availability of wearable technology to track behaviour in real-life setting, it is timely to provide an overview of the existing literature. For these reasons, a scoping review was chosen as an appropriate method to examine the literature investigating PA/SB and stress relationships using EMA methodology.

Aims and Research Questions

The current scoping review aimed to examine the research currently available that utilises EMA to investigate the relationships between PA/SB and stress. While stress can be conceptualised in different ways, in this review, psychological stress is conceptualised as reported perceptions, feelings and experiences of psychological stress. Key characteristics of EMA methodology are the ability to examine between and within-person association, as well as concurrent and prospective associations. Therefore, this scoping review aimed to identify studies that examine whether PA/SB is associated with stress using EMA methodology and address the following research questions: What are the concurrent associations between PA/SB and stress and vice versa in studies using EMA methodologies? What are the prospective associations between PA/SB and stress and vice versa in studies using EMA methodologies?

Methods

The review was guided by the PRISMA scoping review extension checklist (Tricco et al., 2018). This checklist, which specifies where/how the review complies with these guidelines is included as supplementary data. The scoping review framework presented by Peters et al. (2015) was also used to guide the entire review process, and this is reflected in the reporting of the results (e.g., flow chart, which data to report and how to report the data).

Eligibility Criteria

Papers were eligible for inclusion if they met the following criteria: used an ecological momentary assessment methodology of any length and contained a measure of stress. Papers also had to include a measure of PA OR SB. Study participants could be from any age group. Articles could be from any date up until the end of February 2022, published in English. Papers were excluded from the review based on the following exclusion criteria: the participants in the study were from a current clinical population as it was deemed that clinical factors may impact on PA levels, a relationship between PA/SB and stress was not examined, PA/SB and stress were only presented as a baseline value, conference abstract only available, or studies if they were presented without results (see Table 1 for further guidance on inclusion criteria).

Information Sources and Search Strategy

Searches were conducted using Medline, EMBASE, PsycInfo, PubMed and the Cochrane Library. Searches were run up until February 2022. The search terms used comprised three main groups: ecological momentary assessment terms, PA/SB terms and stress terms.

The search terms used were: "(ecological momentary assessment OR experience sampl* OR ambulatory assessment OR diary) AND (physical activity OR exercise OR walk* OR active OR movement OR sport OR sedentary* OR sitting OR television OR inactiv* OR physical inactivity) AND (stress OR psychological stress OR mental stress OR everyday stress OR distress)." Truncations were used to encompass multiple word endings (e.g., sampl* would capture sample, sampling etc.).

Study Screening, Paper Selection and Data Charting

Papers were downloaded into EndNote (X9.2) reference management software and duplicate articles removed. Titles and abstracts were then screened for eligibility using the screening guidance (Table 5.1) and any irrelevant papers excluded. All titles and abstracts were screened by author 1, with author 3 screening a randomly assigned sample (20% of papers). Any papers where disagreements about inclusion arose were screened in full. Full text articles were then read to establish final inclusion, using the same process. Any disagreements regarding inclusion were discussed by author 1 and author 3, referring back to the inclusion and exclusion criteria to reach consensus. The final total number of papers in the review was 33 and were agreed and read in full by authors 1 and 3 (see Figure 5.1 for process chart, used in accordance with Peters et al. (2015) framework).

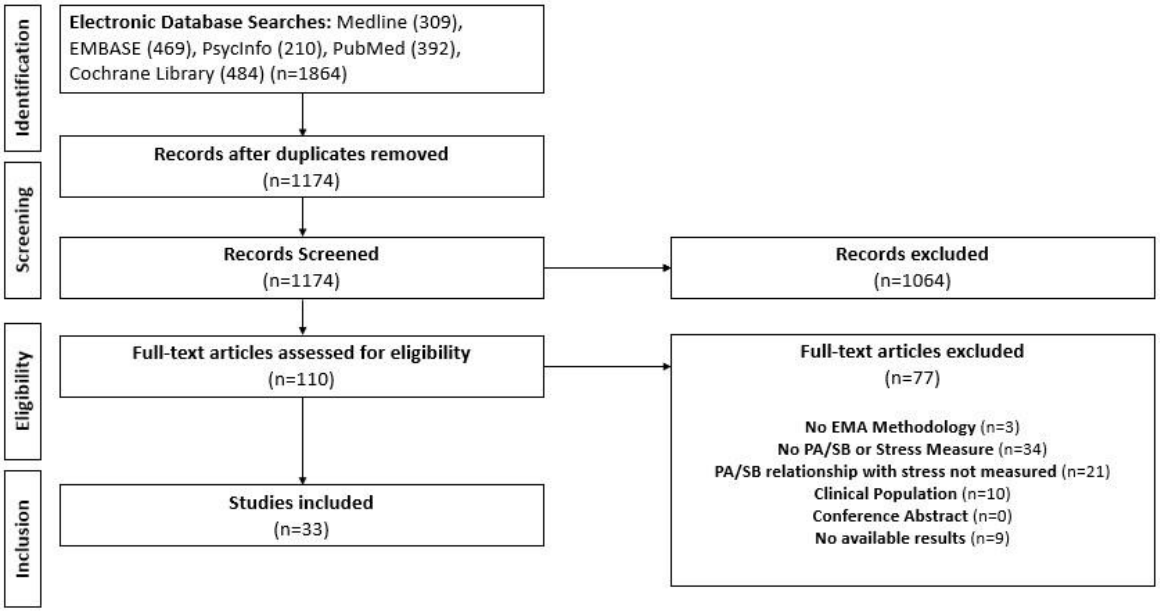

Figure 5.1: Paper screening process for inclusion

Table 5.1: Inclusion Criteria and Guidance Screening Chart

Criteria	Guidance
Ecological Momentary Assessment	Uses an ecological momentary assessment methodology of any length
Physical Activity OR Sedentary Behaviour Measure	Can be objective or subjective. Can be a continuous monitoring OR measured with EMA prompts. Must have at least one measurement (or have continuous measurement on each EMA day) Exclude if baseline measure only
Stress	Any measure of stress (e.g., perceived stress scale, daily hassles etc) Must be measured at least once per EMA day. Exclude if baseline measure only
Participants	Any age groups. Cannot be in a current clinical population (e.g., inpatient participants, current chemotherapy etc)
Physical Activity/Sedentary Behaviour and Stress Relationship	Must contain a measure of a relationship between PA/SB and stress (e.g., correlation, regression, multilevel modelling etc).
Full Paper Availability	Exclude if only conference abstract, no results available (e.g., feasibility studies)
English Language	Exclude if not available in English

Data was charted in table form in Microsoft Excel (version 2010), with separate Tables for concurrent relationships (Table 5.2) and prospective relationships (Table 5.3) using suggestions from the Peters et al. (2015) framework for guidance on data charting. Data charted included participant characteristics, EMA duration and assessment characteristics, PA/SB measure, stress measure, analysis used and whether relationships examined were within or between-person.

Categorising the Results

Results were presented in tabular and descriptive format as suggested in the scoping review framework proposed by Peters et al. (2015), with separate Tables for studies reporting on concurrent and prospective associations. Within these broader categories, papers were further split into those that use a within-person or between-person analysis and whether the paper examined the relationship between PA/SB and stress, or stress and PA/SB. Between-person analyses explore associations in general levels of PA/SB/stress based on an overall average of these outcomes per participant. Within-person analyses explore associations in temporal variations in PA/SB/stress at an individual level. A range of statistical analyses were used to explore between-person and within-person analyses. Correlations and regression analyses can be used to explore between-person associations. Multilevel analyses are more commonly used to explore both between- and within-person associations. To examine both research questions, studies were also categorised as either "concurrent" or "prospective". Concurrent associations were deemed to be any PA and stress measurements taken at the same time and relating to the same time period. For example, looking at associations between daily averages of PA and stress is concurrent. Prospective analyses involved the assessment of associations between an assessment of an outcome (PA/SB or stress) at a specified time and the assessment of the other outcome (stress or PA/SB) at a later time. For example, the association between PA measured on the hour, and stress measured as little as 15 minutes later, or longer periods such as stress measured in an evening and the associations with PA the following day. Studies using an 'N-of-1' design are reported separately. These studies assessed participants for up to 1 year and completed separate analyses per participant and then report the overall summary of these individual analyses.

Results

Overview

Tables 5.2 and 5.3 present the summaries of the studies reporting concurrent and prospective associations, respectively. Table 5.4 presents an overall summary of the associations. Most of the studies (n =28) investigated PA, two studies focussed on SB (Diaz et al., 2018; Pinto et al., 2020) and three studies investigated both PA and SB (Jones et al., 2017; Lin et al., 2021; Zenk et al., 2017). Different measures of stress were used. Stress was most commonly (n =17) measured relating to feelings of stress (e.g., how stressed do you feel?), but other studies (n =10) used occurrence of hassles and stressors to assess stress level. PA was measured in 15 studies objectively (mainly accelerometers), 13 studies used self-report measures and 3 studies included both an accelerometer and self-report measures. All studies investigating SB used accelerometers to measure SB, with 1 study also including a self-report SB measure (Pinto et al., 2020). Studies varied with regards to sample size (ranging from 14 to 605), EMA sampling rate (ranging from 1 assessment per day to 1 assessment every 45 minutes), and number of days of measurement (ranging from 1 day to 1 year). Studies tended to have a higher percentage of female participants than males. Please see Tables 2 and 3 for more detailed information about the individual studies.

Physical Activity

Concurrent Analysis – Between-Person

None of the studies included in the review explored concurrent between-person associations between stress and PA. None of the three studies which examined the concurrent between-person associations of PA predicting stress reported significant associations. A mix of accelerometer and self-report measures of PA were used alongside a range of stress measures (see Table 2). It is worth noting that Anderson and Fowers (2020)

found higher levels of PA were associated with lower levels of stress, but when correcting for smoking, social interaction, socioeconomic status, and alcohol intake (Table 3), this association was no longer significant.

Concurrent Analyses – Within-Person

Five studies examined concurrent within-person associations of stress predicting PA in adults (n =3) and students (n =2). A mix of self-report and accelerometer measures of PA were used, with most studies using hassles/stressors as the stress measure. Two studies reported that high stress (measured as hassles) was associated with more overall daily PA (Gloster et al., 2017; Zenk et al., 2017), and two studies reported no significant association between stress and PA (Lin et al., 2021; Määttänen et al., 2021). The only study that measured perceived stress, reported a negative association between stress and movement during the day (daSilva et al., 2021).

Six studies examined concurrent within-person associations of PA predicting stress in adults (n =5) or students (n =1), using self-report measures of PA and a range of stress measures, with the most common being feelings of stress (see Table 2). All studies reported no within-person associations between PA and stress (Anderson & Fowers, 2020; Dalton, 2020; Igic et al., 2013; Li et al., 2020; Strahler et al., 2020; Zawadzki et al., 2015).

Prospective Analyses – Between-Person

Six studies examined the prospective between-person associations of stress predicting subsequent PA in adults (n =3), students (n =1) or children (n =2), using accelerometers to measure PA and feelings of stress or job demands as the stress-related outcome (see Table 3). Five studies reported no significant associations between stress and subsequent PA (Almeida et al., 2020; daSilva et al., 2021; Do et al., 2021; Määttänen et al.,

2021; Naya et al., 2021). However, Almeida et al. (2020) (study 2) found higher stress was related to more PA up to 2 hours later.

Four studies examined the prospective between-person associations of PA predicting subsequent stress in adults (n =2), students (n =1), or adolescents (n =1), using objective measures of PA and mostly perceived stress (see Table 3). Whereas walking after work was associated with lower stress at bedtime (Hallman & Lyskov, 2012) and PA in the previous hour with less stress-relating eating (Smith et al., 2021), other studies reported no such associations (daSilva et al., 2021; Jones et al., 2017).

Prospective Analysis – Within-Person

Fourteen studies examined the prospective within-person associations of stress predicting subsequent PA in adults (n =9), students (n =3), or children (n =2). Studies used either accelerometer or self-report measures of PA, and a mix of stress measures, but most commonly studies measured feelings of stress (see Table 3). The findings are mixed. Seven studies reported no associations between stress and subsequent PA (Almeida et al., 2020; Anderson & Fowers, 2020; Calderwood et al., 2020; Lin et al., 2021; Nägel et al., 2015; Payne et al., 2010; Sala et al., 2017). Seven studies reported associations between stress and subsequent PA, but the direction of the associations varied. More specifically, five studies reported that higher stress was associated with less subsequent PA (Abdel Hadi et al., 2021; daSilva et al., 2021; Do et al., 2021; Naya et al., 2021; Schultchen et al., 2019) with timeframes ranging from 10 minutes to the next day. Other studies reported stress to be associated with more PA (Almeida et al., 2020) (study 2) Jones et al. (2017) also found that stress was associated with more PA, but this association was only evident for light PA, no association was reported between stress and moderate to vigorous physical activity (MVPA).

Nine studies examined the prospective within-person associations of PA predicting subsequent stress in adults (n =5), students (n =2) or adolescents (n =2). Studies used either accelerometer or self-report measures of PA and measures of stress were predominately focussed on feelings of stress (see Table 3). Four studies reported no within-person association between PA and subsequent stress levels (Kolar et al., 2020; Lee et al., 2021; Sala et al., 2017; Smith et al., 2021). Four studies reported that PA was negatively associated with subsequent stress up to one day later (Abdel Hadi et al., 2021; daSilva et al., 2021; Park. et al., 2022; Schultchen et al., 2019). The only study reporting a positive association between PA and stress found that light PA was associated with subsequent stress, whereas MVPA was not associated with subsequent stress (Jones et al., 2017).

When examining whether PA was associated with subsequent stress, there did not appear to be any consistent methodological differences that could account for significant or non-significant findings (see Table 3).

N-of-1 analyses – Concurrent

The only study to examine within-person concurrent N-of-1 associations of overall daily stress predicting self-reported PA, reported a median negative correlation at participant level but did not conduct formal statistical analyses (Comulada et al., 2018).

N-of-1 analyses – Prospective

Burg et al. (2017), Cheung et al. (2017) and Bos et al. (2018) used N-of 1 analyses to explore within-person associations of stress predicting PA. When looking at overall group associations, Cheung et al. (2017) reported that if stress is experienced, a person was less likely to exercise 2 days later, but stress was only a predictor for exercise in 5 out of 79 participants, suggesting no overall significant relationship. In line with this, Burg et al. (2017) found there was a great deal of inter-participant variation, with data from the majority of

participants not indicating a significant relationship between PA and stress (or vice versa). Similarly, Bos et al. (2018) reported that more stress was associated with lower PA.

Sedentary Behaviour

Concurrent Analysis – Between-Person

No studies explored between-person associations between stress and SB or SB and stress.

Concurrent Analysis – Within-Person

Four studies examined the concurrent within-person associations between stress and SB in adults (n =4), using objective measures of SB and a variety of stress measures (see Table 2). Diaz et al. (2018) found that although stress at the end of the day was not associated with overall sitting time, lower end of the day stress was associated with more bouts of SB with a duration of ≥ 90 minutes. Lin et al. (2021) and Liao et al. (2015) found that increased stress was associated with more SB, whereas Zenk et al. (2017) found that experiencing more hassles was related to lower SB.

Prospective Analysis – Within-Person

Three studies examined the prospective within-person associations between stress and subsequent SB in adults. Accelerometer measures of SB were used in all studies, with Pinto et al. (2020) also using a self-report measure, and measures of stress were feelings of stress(see Table 3). Two studies reported no associations between SB and subsequent stress (Lin et al., 2021; Pinto et al., 2020). Jones et al. (2017) found that higher levels of stress were associated with lower SB in the subsequent 15 minutes.

Of the two studies which examined the prospective within-person associations between accelerometer measured SB and subsequent stress (feelings of stress), one found that higher SB in the 15 minutes prior was associated with lower stress (Jones et al., 2017),

but the other study reported no association between SB in the previous 3 hrs and stress levels (Pinto et al., 2020).

2729 Table 5.2: Concurrent Associations between Physical activity/Sedentary Behaviour, and Stress

Author	Participants, EMA Duration and Assessments	PA/SB Measure	Stress Measure	Analysis	PA/SB-Stress associations from Between–Person analysis	PA/SB-Stress associations from Within–Person analysis
Stress associations with Physical Activity/Sedentary Behaviour						
daSilva et al (2021)	88 students (m=21yrs) 56% female EMA Characteristics: mean duration: 67 days, 1 per day (randomly between 9am and 8pm).	Passive Mobile Sensoring: Total distance travelled (km) (Daily)	How stressed are you? (daily)	Two step multilevel vector autoregressive model.	Not analysed.	↑ Stress associated with ↓ movement.
Diaz et al (2018)	79 adults (m=32yrs), 57% female EMA Characteristics: 1 year, 4x daily (includes an end of the day assessment)	Activity Monitor (Fitbit): SB: total number of minutes per day where 0 steps and intensity classification of 0 took place.	Overall, how stressful was your day? Have you experienced any of the following (list of stressors e.g., traffic, other) (both end of day assessment) How stressed did you feel (just before assessment)?	Random coefficients linear regression models	Not analysed.	End of day stress not associated with sitting time. ↓ end of day stress associated with ↑ bouts (≥90 min) of SB.

Lin et al (2021)	70 adults (m=42yrs) 100% female EMA Characteristics: 7 days, 5x daily (7am-10am, 10am-1pm, 1pm-4pm, 4pm-7pm, 7pm-10pm)	Accelerometer: Daily minutes of MVPA and SB	Daily work hassles (last prompt of the day)	Bivariate fixed effect regression Logistic fixed effects regression.	Not analysed.	↑ Work hassles associated with ↑SB. No association between work hassles and MVPA
Määttänen et al (2021)	44 adults (m=25yrs) 77% female EMA Characteristics: 2 days active measurement (take own physiological measures), 1-3 days passive measurement (no involvement needed from participant to take measures) every 45 minutes (for both active measurement and passive measurement days)	Accelerometer: Movement (measured acceleration)	Has something stressful happened since the last report (Y/N)? How stressful was it? Were you in control of the situation?	Linear mixed models	Not analysed.	No association between stress and movement.

Pinto et al (2020)	20 adults (m=52yrs) Breast cancer survivors EMA Characteristics: 12 months, assessments at 0, 3, 6, 9, 12 months 7 days EMA each time 4x daily (8-11am, 11am-2pm, 2-5pm, 5-8pm)	Accelerometer: Activity Counts (SB) Self-Report: What are you doing now? (includes leisure and non-leisure SB)	How stressed do you feel right now?	Longitudinal regression models	Not analysed.	↑ stress associated with ↑ SB in univariate analysis only. Stress no longer associated with SB in multivariate model (affective valence, sadness, anxiety, stress, worry, fatigue, treatment, BMI, and ethnicity covariates).
Zenk et al (2016)	97 adults (range - 25-65yrs) 100% female EMA Characteristics: 7 days, 5x daily (7-10am, 10am-1pm, 1pm-4pm, 4pm-7pm, 7pm-10pm)	Accelerometer: Daily minutes of MVPA Daily hours of SB	Daily hassles (evening assessment)	Mixed multivariable linear regression models	Not analysed.	↑ Daily hassles associated with ↑ MVPA and ↓ levels of SB.
Gloster et al (2017)	108 students (m=21yrs), 82% female EMA Characteristics:	Self-report: GLT – total daily activity score weighted by	Hassles (number in a 24-hour period)	Correlations for each participant using multilevel structural equation models	Not analysed.	↑ Stress associated with ↑ PA.

	First 61 days: 1 assessment every 6 days (reflecting on day of assessment) Final 33 days: 1 assessment per day	duration and intensity of activity.				
Physical Activity/Sedentary Behaviour associations with Stress						
Igic et al (2013)	39 adults (17+) (m=32yrs), 51% female EMA Characteristics: 14 days, 1 per day (before bed)	Accelerometer: Time spent in PA (hours)	Daily social stressors (whole day)	Correlations per participants	Not analysed.	PA not associated with social stress.
Lindberg et al (2018)	231 adults (m=44yrs), 50% female EMA Characteristics: 3 days (consecutive workdays) Hourly during work hours	Accelerometer: Overall intensity of movement (including sitting, standing, walking).	How tense do you feel? (at the time of assessment)	Structural Equational Modelling	Pathway between PA and stress at work found to be non-significant.	Not analysed.

Anderson & Fowers (2020)	76 adults (m=40yrs), 58% female EMA Characteristics: 14 days, 1 per day (released at 8pm	Self-report: GLT- total daily activity score weighted by duration and intensity of activity.	Kessler psychological distress scale (whole day)	Correlations and mixed multilevel modelling	↑ PA associated with ↓ psychological distress in correlation analyses. In multilevel model, not associated	No association between PA and distress in correlation analyses. No association in multilevel model.
Dalton (2020)	127 students (m=19yrs), 75% female EMA Characteristics: 14 days, 1 per day (before bed)	Self-report: Minutes of MVPA	Daily stressors (whole day)	Hierarchical linear modelling.	Not analysed.	No association between PA and stress.
Li et al (2019)	82 adults (m=35yrs), 63% female EMA Characteristics: 7 days, 1 per day (evening)	Self-report: GLT - total daily activity score weighted by duration and intensity of activity.	Short form (4 item) PSS (whole day)	Between and within-person correlations	No association between PA and stress.	No association between PA and stress.
Strahler et al (2020)	77 adults (m=24yrs), ~ 49% female EMA Characteristics: 4 days, 5x daily (30 mins after waking,	Self-report: Total time (mins): Walked, Cycled, worked out, active in household (all activities summed)	I feel stressed. (at time of assessment, daily average calculated)	Two level hierarchical linear regression	Not analysed.	No association between PA and stress.

	11am, 2pm, 6pm, 9pm)					
Zawadzki et al (2015)	115 adults (m=41yrs), 76% female EMA Characteristics: 3 days (Thursday-Saturday, 6x daily, randomly in 3hr intervals	Self-report: What were you doing at the time of the prompt? sports, exercise, or recreation (yes or no).	How stressed are you? PSS (4 item) (at the time of assessment)	Mixed multilevel models.	Not analysed.	No association between PA and stress.
N-of 1 associations between Stress and Physical Activity/Sedentary Behaviour						
Comulada et al (2018)	14 adults (m=31yrs) 100% female EMA Characteristics: 6 months, 4x daily (only end of day assessment used in analyses)	Self-report: How many minutes of activity did you do today? (Sum of light, moderate and vigorous PA reports)	How stressful was your day overall? (end of day assessment)	Correlation	Not analysed.	↑ In stress associated with ↓ PA. (correlation only, not indicated if significant).

Note: EMA = Ecological Momentary Assessment PA = Physical Activity, SB = Sedentary Behaviour, MVPA = Moderate to Vigorous Physical Activity, LTPA =Leisure Time Physical Activity, LPA= Light Physical Activity, PSS = perceived stress scale, GLT = Godin Leisure Time Exercise Questionnaire.

2734

2735 Table 5.3: Prospective associations between Physical Activity/Sedentary Behaviour and Stress

Author	Participants, EMA Duration and Assessments	PA/SB Measure	Stress Measure	Analysis	PA/SB-Stress associations from Between–Person analysis	PA/SB-Stress associations from Within–Person analysis
Associations between Stress and Physical Activity/Sedentary Behaviour						
Abdel Hadi et al (2021)	199 adults (m = 36yrs) 76% female EMA Characteristics: 14 days, 3x daily	Accelerometer: Leisure time MVPA after work (mins)	Job demands and control (whole day, completed after work)	Multilevel Structural Equation analysis	Not analysed.	↑Job demands associated with ↓ after work LTPA.
Almeida et al (2020) Study 1	Study 1: 115 adults, (m= 41yrs), 75% female EMA Characteristics: 3 days (Thursday-Saturday), 6x daily, random 2-hour intervals	Study 1: Accelerometer Activity counts/minute (10-, 60- and 120-minutes post assessment)	Study 1: How stressed were you feeling? (since last prompt)	Mixed multilevel models	No association between perceived stress and PA.	No association between perceived stress and PA.
Almeida et al (2020) Study 2	Study 2: 297 adults (m=42yrs), 50% female EMA Characteristics:	Study 2: Accelerometer Activity counts/minute	Study 2: How stressed have you been? (since last prompt)	Multilevel models	↑ Perceived stress associated with ↑ PA in the subsequent 10, 60, and 120 minutes.	↑ Perceived stress associated with ↑ PA in the subsequent 10, 60, and 120 minutes.

	2 days, every 45 minutes, fixed intervals	(10-, 60- and 120-minutes post assessment)				
Calderwood et al (2020)	71 adults (m =41yrs), 76% female EMA Characteristics: 5 days (Monday-Friday) 3x daily (6am-9am, 4pm-7pm, 9pm - 12am)	Accelerometer: Total number of steps taken at work	Daily challenge and hindrance stressors on predicting day (afternoon survey)	Correlations	Not analysed.	No association between stress and PA during subsequent working day.
daSilva et al (2021)	88 students (m=21yrs) 56% female EMA Characteristics: mean duration: 67 days, 1 per day (randomly between 9am and 8pm).	Passive Mobile Sensoring: Total distance travelled (km) (daily)	How stressed are you? (daily)	Two step multilevel vector autoregressive model.	No association between stress and subsequent movement.	↑ Stress predicted ↓ movement the subsequent day. Stress did not predict movement 2 days later.
Do et al (2021)	190 children (m=10yrs) 53% female EMA Characteristics: 6 bursts of 7 days across 3 years 3x daily weekdays	Accelerometer: MVPA 15, 30 and 60 minutes after each EMA prompt	Stress variable based on perceived stress, ability to manage things, and perceptions of things working out	Multilevel structural equation modelling	No association between stress and subsequent MVPA in subsequent 15, 30, and 60 minutes.	↑ Stress associated with ↓MVPA in subsequent 15, 30, and 60 minutes.

	(3pm-8pm) 7x daily weekends (7am-8pm)		as planned (right now)			
Jones et al (2017)	105 adults, (m=40yrs) 72% female EMA Characteristics: 4 days (Saturday-Tuesday), 8x daily	Accelerometer: Total minutes of light, moderate, vigorous PA, and SB.	How stressed were you? (right before the assessment)	Mixed multilevel models.	No associations between stress and subsequent SB, light PA, or MVPA.	↑ stress associated with ↓ SB in subsequent 15 minutes. ↑ Stress associated with ↑ light PA in the subsequent 15 minutes. No association between stress and subsequent MVPA.
Lin et al (2021)	70 adults (m=42yrs) 100% female EMA Characteristics: 7 days, 5x daily (7am-10am, 10am-1pm, 1pm-4pm, 4pm-7pm, 7pm-10pm)	Accelerometer: Daily minutes of MVPA and SB	Daily work hassles (last prompt of the day)	Bivariate fixed effect regression Logistic fixed effects regression.	Not analysed.	No association between work hassles and SB No association between work hassles and MVPA.
Naya et al (2020)	143 children (m=10yrs), 44% female EMA Characteristics: 4 waves of data collection (6 months	Accelerometer: Daily minutes of moderate to vigorous PA.	Stress variable based on perceived stress, ability to manage things, and perceptions of things working out	Mixed multilevel models.	No association between stress and MVPA.	↑ Stress in morning associated with ↓ MVPA during the day.

	apart). In each wave, 2 weekend days of EMA data collected in morning.		as planned (right now)			
Pinto et al (2020)	20 adults (m=52yrs) Breast cancer survivors EMA Characteristics: 12 months, assessments at 0, 3, 6, 9, 12 months 7 days EMA each time 4x daily (8-11am, 11am-2pm, 2-5pm, 5-8pm)	Accelerometer: Activity Counts (SB) Self-Report: What are you doing now? (includes leisure and non-leisure SB)	How stressed do you feel right now?	Longitudinal mixed effects model Cross-lagged models.	Not analysed.	Stress not associated with SB in subsequent 3 hrs
Schultchen et al (2019)	51 students (m=24yrs), 80% female EMA Characteristics: 7 days 6x daily (9am, 11:30, 2pm, 4:30pm, 7pm, 9:30pm)	Accelerometer: Time in minutes Self-Report: How many minutes have you been physically active since the last signal (sweated or out of breath)	Perceived stress (2 items PSS) "Do you feel that you can cope with things" "Do you feel you're on top of things", and do you feel nervous/stressed (at time of assessment)	Hierarchical linear models	Not analysed.	↑ Stress associated with ↓ PA in subsequent 2.5 hours.

Anderson & Fowers (2020)	76 adults (m=40yrs), 58% female EMA Characteristics: 14 days, 1 per day (released at 8pm)	Self-report: GLT- total daily activity score weighted by duration and intensity of activity.	Kessler psychological distress scale (whole day)	Correlations and mixed multilevel modelling	Not analysed.	No association between PA and distress the subsequent day.
Nagel et al (2015)	120 adults (m=39yrs), 51% female EMA Characteristics: 5 days (Monday-Friday) 2x daily (after work, before bed)	Self-report: How many minutes exercised after work?	Job stressors (whole day)	Multilevel modelling	Not analysed.	No association between job stressors and exercise
Payne et al (2010)	41 adults (no m age reported) 45% female EMA Characteristics: 14 days, 1 per day (~ 6pm)	Self-report: Sum (hours) of all exercise. For analysis, exercise dichotomised into exercise and non-exercise days.	Job demands (whole day)	Multilevel modelling	Not analysed.	No association between job demands and likelihood to exercise the subsequent day.

Sala et al (2017)	129 students (m=20yrs), 100% female EMA Characteristics: 7 days, 4x daily (1 per 3-hour block)	Self-report: How long did you exercise since your last check in?	DASS- stress subscale (at the time of assessment)	Generalised linear mixed model	Not analysed.	No association between stress and PA in subsequent 3 hours.
Associations between Physical Activity and Stress/Sedentary Behaviour						
Abdel Hadi et al (2021)	199 adults (m=36yrs) 76% female EMA Characteristics: 14 days, 3x daily	Accelerometer: Leisure time MVPA (mins)	How stressed do you feel at the moment? (completed at bedtime)	Multilevel structural equation analysis	Not analysed.	↑LTPA after work associated with ↓ evening stress.
daSilva et al (2021)	88 students (m=21yrs) 56% female EMA Characteristics: mean duration: 67 days, 1 per day (randomly between 9am and 8pm).	Passive Mobile Sensoring: Daily total distance travelled (km)	How stressed are you? (daily)	Two step multilevel vector autoregressive model.	No association between movement and stress the next day.	↑ movement associated with ↓ stress the next day.
Hallman & Lyskov (2012)	47 adults 23 Pain Group: (m=41yrs), 91% female 22 Healthy Control: (m=41yrs) 91% female EMA Characteristics:	Activity Monitor: Overall intensity values for 24 hour for sitting, walking, standing, lying. Also split into values for 6pm-	Stress energy questionnaire Stress subscale: low and high activation adjectives (past 10 minutes)	Correlations	↑ walking in the evening associated with ↓ stress at bedtime.	Not analysed.

	24 hours, 5x daily	10pm, first hour after waking, 9am-12pm and 12pm-4pm.				
Jones et al (2017)	105 adults, (m=40yrs) 72% female EMA Characteristics: 4 days (Saturday-Tuesday), 8x daily	Accelerometer: Total minutes of light, moderate, vigorous PA, and SB 15 minutes before or after EMA assessment	How stressed were you? (right before the assessment)	Mixed multilevel models.	No association between SB, light PA or MVPA and subsequent stress.	↑ SB 15 minutes prior to stress question associated with ↓ stress. ↑ Light PA 15 minutes prior to stress question associated with ↑ stress. No associations between MVPA and subsequent stress.
Kolar et al (2019)	62 adolescents Anorexia Nervosa: 32 (m=16yrs) Healthy Control: 30 (m=16yrs), 100% female EMA Characteristics: 1 day (hourly 7am-11pm)	Accelerometer: Minutes of PA (30 minutes prior to EMA assessments, all levels of PA based on activity counts).	At this time, how intense is your emotional tension?	Linear mixed model	Not analysed.	PA in previous 30 minutes not associated with aversive tension (in either group).

Pinto et al (2020)	20 adults (m=52yrs) Breast cancer survivors EMA Characteristics: 12 months, assessments at 0, 3, 6, 9, 12 months 7 days EMA each time 4x daily (8-11am, 11am-2pm, 2-5pm, 5-8pm)	Accelerometer: Activity Counts (SB) Self-Report: What are you doing now? (Includes leisure and non-leisure SB)	How stressed do you feel right now?	Longitudinal mixed effects model Cross-lagged models.	Not analysed.	SB in previous 3 hours not associated with stress
Schultchen et al (2019)	51 students (m=24yrs), 80% female EMA Characteristics: 7 days 6x daily (9am, 11:30, 2pm, 4:30pm, 7pm, 9:30pm)	Accelerometer: Time in minutes Self-Report: How many minutes have you been physically active since the last signal (sweated or out of breath)	Perceived stress (2 items PSS) "Do you feel that you can cope with things" "Do you feel you're on top of things", and do you feel nervous/stressed (at time of assessment)	Hierarchical linear models	Not analysed.	↑ PA associated with ↓ stress in the subsequent 2.5 hrs.
Smith et al (2021)	77 adolescents (m=15yrs), 42% female EMA Characteristics: 7 days, every 2 hours (3pm- 9pm	Accelerometer: Total activity counts and minutes of moderate to vigorous PA 60	Are you stressed? Yes/no Stress eating (is the answer yes to are you stressed, while	Generalised estimating equations	↑ MVPA in previous 60 minutes associated ↓ stress eating	MPVPA in previous 60 minutes not associated with stress eating

	weekdays, 10am-10pm weekends)	minutes prior to stress measure.	eating) (at the time of assessment)			
Lee et al (2021)	478 adults (m=50yrs) 51% female EMA Characteristics: 2 weeks, 3x daily (7am-11:59am, 12pm-4:59pm, 5pm-9:59pm)	Self-report: Did you exercise yesterday? (Y/N) (first prompt of the day)	To what extent do you feel stressed right now? (daily average calculated)	Fixed effect model	Not analysed.	No association between exercise on previous day and stress next day.
Park et al (2022)	605 adults (m=45yrs) 54% female EMA Characteristics: 8/9 days, 1 per day (7pm)	Self-Report: Did you do any sport, exercise, or leisure time physical activity today? (Y/N)	How stressed do you feel right now?	General estimating equations	Not analysed	LTPA during the day associated with ↓ stress in the evening.
Sala et al (2017)	129 students (m=20yrs), 100% female EMA Characteristics: 7 days, 4x daily (1 per 3-hour block)	Self-report: How long did you exercise since your last check in?	DASS- stress subscale (at the time of assessment)	Generalised linear mixed model	Not analysed.	No association between PA and stress in subsequent 3 hours.

N-of 1 associations between Physical Activity/Sedentary Behaviour and Stress					
Burg et al (2017)	69 adults (m=32yrs), 57% female EMA Characteristics: 12 months 5x daily 1 x morning, 1 x evening, 3 random prompts per day (between 7am and 10pm)	Activity monitor (Fitbit): PA day: a day with any 30-min period of MVPA Self-Report: How likely are you to exercise today? (AM assessment) Have you exercised for 30 minutes or more today? (Evening assessment)	how stressful do you expect today to be? (AM assessment) How stressful was your day? (evening assessment) How stressful do you think your day will be tomorrow? (evening) Key sources of stress (list of options) 4 item PSS (both at each assessment)	Random coefficient linear regression models	Due to high individual variation, overall no association between physical activity and stress or stress and physical activity.
Bos et al (2018)	40 adults 20 anhedonic (m=40yrs), 95% female 20 non-anhedonic (m=44yrs), 95% female (matched on depression) EMA Characteristics: 30 days, 3x daily	Self-report “I was physically active” (not at all-very much) (since the last measurement)	"I am upset"	Vector autoregression (VAR) model with cumulative impulse response function	Stress experience associated with ↓ PA at next measurement.

Cheung et al (2017)	79 healthy adults (m=32yrs) 57% female EMA Characteristics: 1 year, 5x daily	Activity monitor (Fitbit): PA day: a day with any 30-min period of MVPA Self-Report: How likely are you to exercise today for 30 minutes or more at MVPA? (AM assessment) Did you exercise today for 30 minutes or more at MVPA? (evening assessment)	How stressed did you feel? (just before assessment) How stressful do you expect today to be? (AM assessment) How stressful do you think tomorrow will be? (evening assessment)	Classification decision tree, applied random forest to yield ranking of variable importance, select variables that lead to standardised decrease in classification accuracy.	When stress was experienced, participants were less likely to be physically active 2 days later. No significant associations between PA and stress/stress and PA.

Note: EMA = Ecological Momentary Assessment PA = Physical Activity, SB = Sedentary Behaviour, MVPA = Moderate to Vigorous Physical Activity, LTPA =Leisure Time Physical Activity, LPA= Light Physical Activity PSS = perceived stress scale, GLT = Godin Leisure Time Exercise Questionnaire, DASS- Depression, Anxiety and Stress Scales.

2742 Table 5.4: Summary of the direction of findings for concurrent and prospective associations

	Concurrent analyses						Prospective analyses					
	Between-person associations			Within-person associations			Between-person associations			Within-person associations		
	Positive	Negative	Null	Positive	Negative	Null	Positive	Negative	Null	Positive	Negative	Null
Stress-PA	0	0	0	2	1	2	1	0	5	2	5	7
PA-Stress	0	0	3	0	0	6	0	2	2	1	4	4
Stress-SB	0	0	0	1	2	1	0	0	0	0	1	2
SB-Stress	0	0	0	0	0	0	0	0	0	0	1	1

2743 Note: total values may add up to more than total number of studies due to multiple findings. PA=physical activity, SB=sedentary behaviour.
2744

Discussion

The present review set out to investigate the concurrent and prospective associations between PA/SB and stress and vice versa in studies using EMA methodologies. For a summary of the direction of the findings for concurrent and prospective associations, please see Table 5.4. A clear strength of EMA studies is the ability to explore the associations between outcomes at a within-person level, and more specifically explore the impact of stress on subsequent PA/SB or the impact of PA/SB on subsequent levels of stress. It is therefore not surprising that within-person analyses, and in particular prospective within-person analyses have been most frequently reported in the studies reviewed focussing on stress and PA. The within-person associations between stress and subsequent PA, and PA and subsequent stress were mixed. Approximately half of the within-person studies reported no associations, while the other half reported that stress was negatively associated with subsequent PA and PA was negative associated with subsequent stress (see Table 4 for summary). Between-person associations between stress and subsequent PA and PA and subsequent stress were mostly non-significant. The majority of studies exploring concurrent associations reported no significant between- or within-person association between stress and PA. Considerably less studies examined the associations between stress and SB or SB and stress. The results of these studies, which only included within-person analyses, are mixed.

The findings from prospective within-person associations between stress and subsequent PA were equivocal. Those that report an association tended to show that stress is related to reduced PA with lag times ranging from 30 minutes to the next day (Abdel Hadi et al., 2021; daSilva et al., 2021; Do et al., 2021; Naya et al., 2020; Schultchen et al., 2019). Half of the studies reported no within-person association between stress and subsequent

PA. Measures of stress or PA, or different lag times cannot explain these different findings. However, closer inspection showed that while these non-significant findings applied to whole samples, personal characteristics of participants influenced the associations between stress and subsequent PA. More specifically, there were negative associations between stress and subsequent PA in people with low motives for exercise, whereas positive associations were evident between stress and subsequent PA in those with higher motivation for exercise (Nagel et al., 2015). Similarly, in participants with lower levels of eating disorder-related symptoms (i.e., drive for thinness, bulimic symptoms, and body dissatisfaction), stress was related to increased subsequent PA, but this relationship was not evident in those with moderate or high levels of symptoms associated with eating disorders (Sala et al., 2017). Additionally, even though not prospective analyses, concurrent associations between stress and PA were only shown in those who had strong beliefs of PA as a way to cope with stress (Dalton, 2020). Within-person associations between PA and subsequent stress reported an equal amount of non-significant associations as positive associations. Again, there are no apparent systematic differences in stress or PA measures, or lag times to explain these differences. Only one study examined interaction effects of individual characteristics on these associations and reported a significant impact of BMI on the association between PA and stress eating; for those with high BMI, PA was related to lower levels of stress, whereas the reverse was found for those with low BMI. Taken together, there is emerging evidence that individual characteristics can influence the association between stress and PA and PA and stress. This has been previously suggested in the review conducted by Stults-Kolehmainen and Sinha (2014), who mentioned that those who were regular exercisers may exercise more during times of stress. Therefore, to get a deeper understanding of the these within-person associations, it is important to take

personal characteristics into consideration beyond the commonly examined covariates (e.g., age, gender).

Several studies explored the bidirectional associations between stress and subsequent PA and PA and subsequent stress in the same participants (Abdel Hadi et al., 2021; daSilva et al., 2021; Jones et al., 2017; Sala et al., 2017; Schultchen et al., 2019). It was most commonly found that stress was related to lower PA, and PA was associated with lower stress (Abdel Hadi et al., 2021; daSilva et al., 2021; Schultchen et al., 2019). Moreover, PA was reported to mediate the association between job demands and perceived stress in the evening (Abdel Hadi et al., 2021). These different sequential associations emphasise the importance of using EMA methods to determine the associations between stress and PA, which are not captured when participants are asked to rate their stress and PA levels as an overall average of a period of several days or a week. Furthermore, these observed associations also suggest that PA should be recommended as a way to reduce perceived stress.

Two studies reported stress to be associated with increased subsequent PA (Almeida et al., 2020; Jones et al., 2017), and one study reported PA to be associated with increased subsequent stress (Jones et al., 2017). Closer inspection of these studies revealed a potential impact of the type of PA (Jones et al., 2017) or the way stress is assessed (Almeida et al., 2020). Higher levels of stress were associated with more light intensity PA but not MVPA in the subsequent 15 minutes. Similarly, light intensity PA, but not MVPA, was associated with more stress in the subsequent 15 minutes (Jones et al., 2017). Further exploration of the light physical activities showed that participants generally reported doing chores, such as getting ready for work or cooking. Therefore, the reason or purpose of this type of activity could potentially be perceived as stressful itself and could have contributed

to the higher stress level 15 minutes later. Unfortunately, no information was provided about the types of activities that were conducted during moderate to vigorous PA, therefore it is not possible to determine if the difference in associations between stress and light PA and stress and MVPA can be contributed to the intensity of the activity or the type of activity. In addition to the intensity or type of activity, the context in which PA is done has not been explored in detail. The health benefits of leisure time PA have been well documented, whereas occupational PA has been reported to be associated with negative health implications (Bonekamp et al., 2022). Some studies have specifically focussed on PA during work (Calderwood et al., 2020) and PA after work (e.g., Abdel Hadi et al. (2021), Nägel et al. (2015)), but without a direct comparison it is difficult to determine if there is a differential impact of leisure versus occupation PA on stress. Similarly, research has also suggested that being physically active outdoors has better mental health outcomes than being active indoors (Bowler et al., 2010; Dunton et al., 2015), so activity location could also be important to consider. In sum, in order to get a better understanding of the associations between stress and PA, future research is needed to explore the impact of PA intensity and context.

Different measures of stress were used when comparing the studies included in the review, which could potentially be a reason for some of the equivocal results. The importance of the way stress is measured is particularly evident from one of the studies conducted by Almeida et al. (2020). A positive association was reported between perceived stress and subsequent PA, but when stress was quantified as an accumulation of stressful events, it was negatively associated with subsequent PA. This suggests that the appraisal of a stressful event has a different association with PA compared to the association of the occurrence of a stressful event with PA. While being physically active does not remove the

stressor, being physically active could perhaps help a person cope better with the feelings of stress, which could in turn influence ratings of how stress is experienced. The findings mentioned earlier that in those who had stronger beliefs that PA could be a way to cope with stress, stress was negatively associated with PA provides some support for this suggestion (Dalton, 2020). Positive and negative affect are also likely to play a role in the associations between stress and PA. Previous research has suggested that negative affect is associated with lower levels of PA (Niermann et al., 2016), and PA is associated with increased positive affect (e.g., happiness and feeling energetic) (Liao et al., 2015). Positive affect has also been suggested to buffer against negative stress responses (van Steenbergen et al., 2021). Even though studies have often included both assessments of affect and stress, the interactions between stress, PA, and affect have not been explored in detail and warrants further investigation.

The results for the within-person associations between concurrent stress and PA were mixed. Only when a measure of perceived stress was used, was stress significantly associated with less PA (daSilva et al., 2021). When stress was quantified as daily work hassles or occurrence of stressful events, stress was either not associated (Lin et al., 2021; Määttänen et al., 2021) or more stress was associated with more PA (Gloster, 2017; Zenk et al., 2017). However, when exploring the concurrent associations between PA and stress, no significant associations were reported, regardless of measuring perceived stress (Anderson & Fowers, 2020; Li et al., 2019; Strahler et al., 2020; Zawadzki et al., 2015) or number of stressors (Dalton, 2020; Igic et al., 2013). In line with aforementioned comments made about the prospective analyses, it is possible that the concurrent associations are influenced by other factors that could contribute to the overall equivocal findings. However, only Määttänen et al. (2021) explored the influence of other factors on the concurrent

association between stress and PA. They found that social company (i.e., being with friends, with no one, or with other people) did not impact on the association between stress and PA. Therefore, more studies are needed to examine the impact personal and contextual factors have on the concurrent within-person associations between stress and PA.

As mentioned earlier, a limited number of studies explored the between-person associations between stress and PA. None of the three studies that explored concurrent associations between PA and stress found significant between-person associations (Anderson & Fowers, 2020; Li et al., 2020; Lindberg et al., 2018). This is in contrast with the previous review exploring stress and PA, where, even though not confirmed by all studies, there was stronger evidence for an association between stress and PA (Stults-Kolehmainen & Sinha, 2014). Methodological differences in data collection could be a reason for these differences. In the studies reported in this review, participants were asked to report on their levels of stress and PA at a regular basis (e.g., hourly, once per day). For the between-person analyses in the current review, measurements taken at all assessment points were averaged to provide an overall average value for each outcome per participant. The majority of the assessments in the previous review by Stults-Kolehmainen and Sinha (2014) included measures that represented the participant's reflection and memory of their overall perceived stress in the previous week. In contrast, deriving the average value based on data collected using EMA methods captures variations within and between days in the outcome measures, without relying on recall of the participant, and could arguably be a better reflection of their perceived levels of stress.

Looking at the prospective between-person analyses, stress was associated with subsequent PA in only one study (Almeida et al., 2020), and five studies reported no association (Almeida et al., 2020; daSilva et al., 2021; Do et al., 2021; Jones et al., 2017;

Naya et al., 2020). Interestingly, Almeida et al. (2020) reported two separate studies with similar designs, but only reported a significant positive association between stress and PA in one of the studies. The associations between PA and subsequent stress were more varied, with two studies reporting a negative association (Hallman & Lyskov., 2012; Smith et al., 2021) and two finding no association (daSilva et al., 2021; Jones et al., 2017). Again, study designs were similar in these studies.

So far, the discussion has focussed on the associations between stress and PA. The findings related to concurrent and prospective within-person associations between stress and SB are equivocal. No studies reported the between-person associations of stress and SB. Given the limited number of studies exploring stress and SB, there is not sufficient evidence for statements about whether or not associations exist. Similar to the discussion about the context of PA, the context of sitting is likely to influence the association between SB and stress. More broadly, there is increasing evidence for differential health benefits of different 'types' of sitting. For example, mentally active sedentary behaviour (e.g., office-based work) and mentally passive sedentary behaviour (e.g., watching tv) have differential relationships with psychological health (Hallgren et al., 2020). In addition, other behaviours done while sitting could influence the impact on overall well-being, such as poor diet or smoking. Only Pinto et al. (2020) included assessments of both objective and self-report (leisure, non-leisure) measures of sitting. However, they did not report the influence of the type of SB on perceived stress. Therefore, current data available from EMA studies is not sufficient enough to determine the associations between stress and SB, and further research is needed to explore the impact of different types of sitting on perceived stress.

Recommendations, Limitations and Future Research Implications

To the best of our knowledge, this is the first scoping review to investigate the relationship between PA and stress when using EMA, providing a valuable initial insight into the topic area. In contrast to the previous review by Stults-Kolehmainen and Sinha (2014), which examined a range of research designs, methodologies, and statistical approaches, and focused mainly on the effect of stress on PA, the current review focusses in on the specific methodology of EMA. The current review also explored the associations between stress and PA/SB as well as PA/SB and stress, and therefore provided additional information about the bidirectional nature of the PA/SB and stress relationship not included in the previous review. In addition, the current review comments on the potential influence of personal characteristics on the PA/SB and stress relationship and highlights the use of statistical analyses to further explore these additional characteristics. Consequently, the present review provides more insight into the stress and PA/SB relationship.

These deeper insights into the relationships between PA/SB and stress are a key contribution to the literature as they highlight the existing knowledge and identify key characteristics and commonly used techniques associated with the EMA methodology. The scoping review also highlights where there is missing information about the PA/SB and stress relationship. The findings highlight that when examining PA/stress the results are mixed and inconsistent, but there is some evidence for within-person associations between PA and subsequent lower stress, and higher stress and lower subsequent PA. While from the review, the mixed results do not appear to be the result of methodological differences, there is some evidence that individual characteristics could play a role. Therefore, future EMA research should examine not only the PA and stress relationship, but individual characteristics that could also drive this relationship (such as self-esteem or stress appraisals as discussed throughout this thesis). A further example of a gap in the literature the review

highlights is that only a small number of studies examined SB, and the results of these studies were inconsistent, making it not possible to conclude whether or not a SB/stress relationship exists or the direction of any relationship. As noted, this could be related to the context of SB, e.g., office based or leisure time SB, but the studies within this review do not provide the relevant data to conclusively make this connection. This highlights the need for more research into the SB/stress relationship, including the context of the SB to get a more comprehensive understanding.

The review however is not without its limitations. In many of the studies included, investigating the relationship between stress and PA was not the primary aim, meaning that the stress/PA relationship may not have been fully explored (e.g., only presenting a correlation for PA/stress when there are full lagged analyses for other variables), or the study may not have sufficient statistical power to explore these associations. This could mean that relationships are missed entirely or presented as non-significant, where more in depth analysis may have shown an association. Future directions for research should aim to address this limitation, with studies using EMA having a primary aim of looking at the associations between PA/SB and stress to allow for a more comprehensive view. Studies should take into consideration the number of assessments and the types of stress and PA/SB measures used, and which participant characteristics could influence the potential associations between PA/SB and stress.

Conclusion

In conclusion, there is a growing body of literature exploring the between and within-person associations between stress and PA/SB and PA/SB and stress using EMA methodologies. Overall findings appear to be mixed, however there appears to be some evidence for stress to be associated with subsequent lower levels of PA and PA to be

associated with lower levels of stress at a within-person level. Future research should investigate the impact of the way stress is quantified, different intensities of PA and the context of both PA and SB in order to get a better understanding of the associations between stress and PA/SB at both between and within-person levels. In addition, more detailed studies are needed to explore personal and contextual factors that could influence these associations is warranted.

Chapter 6

General Discussion

General Discussion

The main aim of this thesis was to conduct a novel/innovative examination of the relationship between PA, and stress and associations with mental health in adolescents and young people, by exploring factors underpinning the relationship and by using various analytical methodologies. The associations between PA and stress were examined across three empirical chapters and a scoping review using a range of methodologies and analytical techniques.

Summary of Results

For a brief summary of the thesis aims, chapter aims and key findings for each chapter, see Figure 6.1.

Chapter 2 examined self-esteem, perceived resources, challenge and threat appraisal tendencies, and distress tolerance as potential mechanism by which PA, stress, anxiety, and depressive symptoms are related. Using cross-sectional data, a model based on integrating Lubans et al. (2016) psychosocial hypothesis and Lazarus and Folkman (1984)'s transactional model of stress and coping was tested using path analysis. It was found that PA was associated with lower stress indirectly through higher self-esteem, greater perceived resources, a greater challenge appraisal tendency, and higher distress tolerance, as well as a lower threat appraisal tendency. Lower stress was in turn associated with lower anxiety and depressive symptoms.

Chapter 2 provided support for the theory that PA is associated with lower stress and better mental health (e.g., anxiety and depressive symptoms). **Chapter 3** took place during the start of the COVID-19 pandemic, and therefore aimed to examine how PA influenced the impact of an unexpected and unprecedented stressful situation (i.e.,

pandemic) on adolescent mental health. More specifically, the influence of PA on the association between fear of COVID-19 and adolescent mental health and wellbeing, in addition to the PA and stress relationship were explored. Hierarchical multiple linear regressions were used to examine the associations between fear of the COVID-19 pandemic, PA, stress and mental health and wellbeing indicators in this cross-sectional study. It was found that while COVID-19 fear was a negative predictor of increased stress, mental health, and wellbeing factors (such as increased depressive symptoms and reduced vitality). PA was found to be a stronger positive predictor of mental health and wellbeing outcomes. This suggests that PA could act as a protective factor against negative implications of COVID-19 fear on mental health and wellbeing. The findings of **Chapter 2** and **Chapter 3**, both highlighted that PA appears to be beneficial for both lower perceived stress and better mental health, however, both studies only examined these relationships using cross-sectional data to support these assertions. Additionally, PA was only measured as a single item in both of these studies which did not consider the intensity of the PA. Therefore, in order to examine if these associations were also evident over longer time periods, and to explore if different intensities of PA influenced the relationships between PA and stress, the study presented in Chapter 4 was conducted.

Chapter 4 aimed to examine longitudinal associations between PA intensities (vigorous, moderate, walking, and total PA) and stress. Additionally, similar factors underlying the PA and stress relationship first presented in **Chapter 2** (i.e., self-esteem, challenge appraisal, and threat appraisal) were re-examined. Proactive coping was also investigated as a potential factor, based on proactive coping aiding the development of personal resources (Aspinwall & Taylor, 1997), with resources being seen to be linked with self-esteem (self-esteem associated with increased resources), and challenge and threat

appraisals (resources associated with increased challenge and decreased threat appraisal) (in line with findings in Chapter 2). Measurements of PA, stress, self-esteem, stress appraisals and proactive coping were taken at three time points, approximately 4 weeks apart, during various stages of COVID-19 lockdown restrictions in university students. Multilevel analyses were conducted to examine these associations at between-person and within-person levels. Separate models were run for each PA intensity predicting stress. It was found that total PA, vigorous PA, and walking were independent predictors of stress at a between-person, but not at within-person level. This suggests that when participants were in general more physically active, they were also in general less likely to be stressed. However, being more physically active compared to their personal level of physical activity, was not associated with fluctuations in stress. Interestingly, when self-esteem, challenge appraisal, threat appraisal and proactive coping were added to each model, PA was no longer associated with stress at either at between-person or within-person level. The findings from Chapters 2, 3 and 4 suggest that the relationship between PA and stress differs depending on the time frame in which the relationship is measured. While Chapters 2 and 3 only capture PA and stress data at one time point, Chapter 4 captures data over the course of 4 months allowing for fluctuations over time to be explored. This suggested that study duration could influence the PA and stress relationship. However, all three chapters asked participants to reflect on their PA and stress during the previous week. As recall could potentially have altered the reported levels of PA and stress, investigating the more dynamic associations between PA and stress by taking more frequent assessments will reduce the risk of recall errors. This prompted the need for further investigation into PA and stress associations over differing time frames, for example reports across hours or between days, and methodologies that allow these associations to be examined.

Therefore, **Chapter 5** further explored the longitudinal associations between PA and stress through a scoping review, specifically focusing on studies utilising ecological momentary assessment (EMA) methodology. EMA is a methodology that allows for the capture of data in real time, within and across days and longer (Shiffman et al., 2008). The capture of real time data allows for the examination of the PA and stress relationship at much shorter time frames than any of the time frames examined throughout this thesis. The review aimed to examine the concurrent and prospective associations between PA and stress (and vice versa), both at a between- and within-person level. Chapter 5 also examined the concurrent and prospective associations between sedentary behaviour (SB) and stress. The findings of the review were inconclusive, with approximately half of all included studies not finding any associations between PA/SB and stress. However, there was some within-person evidence suggesting that PA is associated with lower subsequent stress (and that higher stress is associated with lower subsequent PA).

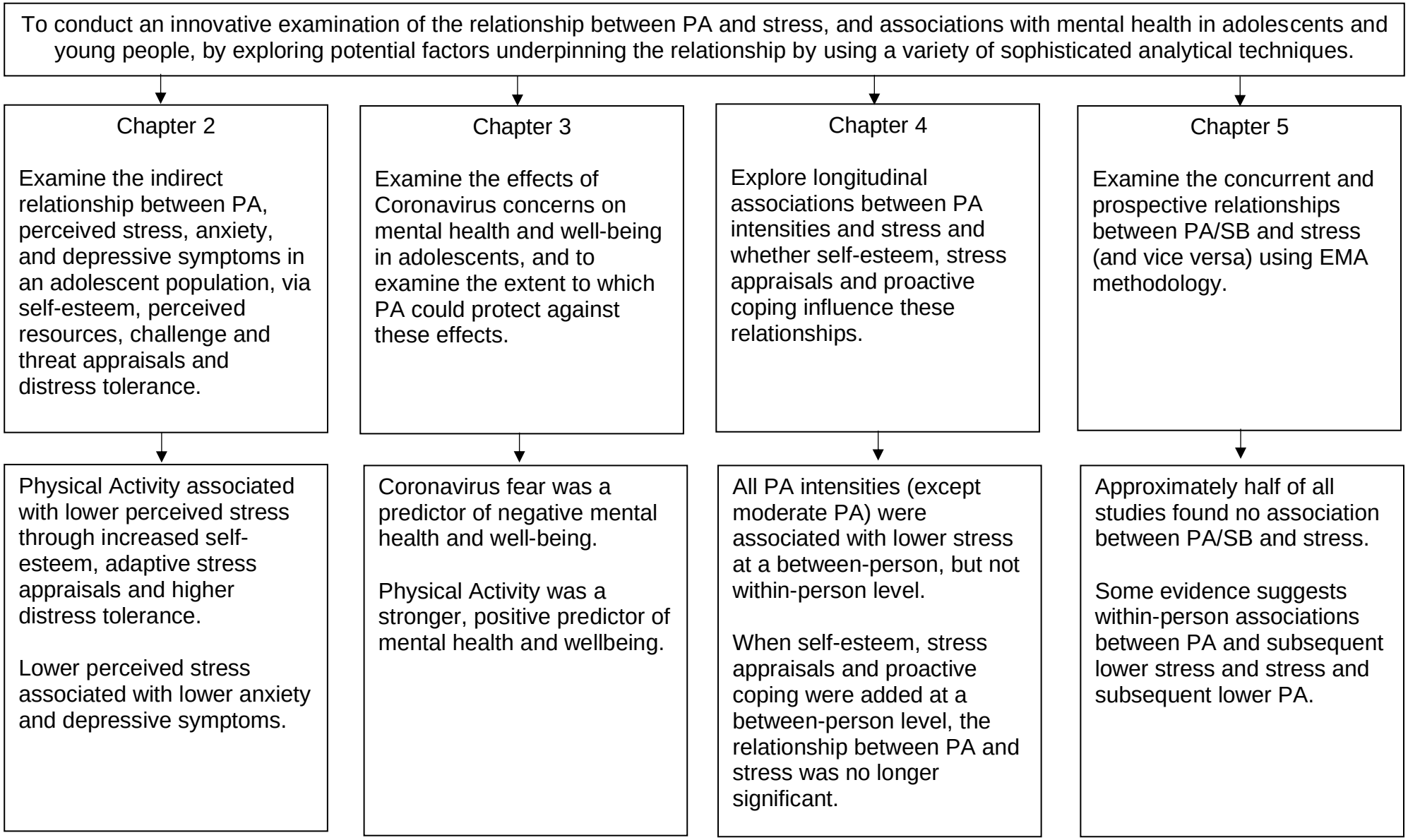

Figure 6.1: Summary of Thesis, from top to bottom, thesis main aim, chapter aims, chapter main findings.

Contributions to the Literature

Collectively, the thesis provides support for existing literature that PA is associated with lower stress and lower anxiety and depressive symptoms in adolescents and young people. The thesis extends the existing literature by examining a series of potential variables, namely self-esteem, stress appraisals, proactive coping and distress tolerance, and their contribution to the PA-stress relationship. By examining how these variables function in the PA-stress relationship, this thesis extends past the stance of "is there a relationship?" and begins to address the question of how the PA and stress relationship actually functions. The findings of this thesis provide evidence that the relationship between PA and stress is not just a direct one, and that it can in fact be underpinned by self-esteem and stress appraisals in particular. These findings provide a solid foundation for future research to more fully understand the PA and stress relationship in adolescents and young adults, where future research should aim to work to further confirm the role of self-esteem and stress appraisals.

The thesis as a whole utilises a range of progressive and complimentary analytical approaches and techniques in order to investigate more comprehensively the association between PA and stress (in addition to the SB stress relationship in Chapter 5). The use of path analysis in Chapter 2 allowed for the comprehensive analysis of a novel and integrated model, charting the indirect relationship between PA and stress, through variables including self-esteem, challenge and threat appraisals and distress tolerance. Establishing these relationships in this way allowed for the progression to multilevel modelling where the relationships between PA, stress, and other predictor variables (self-esteem, stress appraisals and proactive coping) were examined to see if the relationships established in Chapter 2 remained consistent with the added factor of time.

Within this thesis, Chapters 2, 3, 4, and 5 all find relationships between PA and stress; however, the specifics of the PA and stress relationship differs between chapters. Chapters 2 and 3 utilise cross-sectional methodologies and both find a relationship indicating higher PA is associated with lower stress. Chapters 4 and 5 however, examine the PA and stress relationship over differing time periods, Chapter 4 over a period of 4 months, and Chapter 5 includes a variety of timeframes. Chapters 2 and 4 examine largely similar variables; they explore the influence of self-esteem, challenge appraisal, threat appraisal and either distress tolerance (Chapter 2) or proactive coping (Chapter 4) on the associations between PA and stress. However, despite these similarities, Chapter 2 finds PA is associated with stress indirectly through the additional variables discussed, whereas Chapter 4 finds an association when only PA and stress are included in the model. This difference in findings between Chapter 2 and Chapter 4 could be due to the differences in timeframes of data collection.

The different populations used in the studies should also be acknowledged. Chapters 2 and 3 examine adolescents whereas Chapter 4 focuses on young adults. Young adults experience different stressors than adolescents, such as leaving home and gaining independence (van Sluijs et al., 2021), and potentially therefore a different stress experience. As discussed in the previous paragraph, the PA and stress relationship differs. Unlike Chapter 2, in Chapter 4, PA is not found to be associated with self-esteem or stress appraisals. In relation to stress appraisals, PA was associated with increased challenge and threat appraisals indirectly via self-esteem in Chapter 2. Given that PA was not associated with self-esteem in Chapter 4, it is perhaps not surprising that PA in Chapter 4 was also not associated with stress appraisals. In terms of self-esteem, it has been found that it naturally appears to decrease in adolescents and begin to pick up again around age 18 (Robins &

Trzesniewski, 2005), so it could be that PA is associated with the development of self-esteem in adolescents as self-esteem is naturally lower at this point than in young adults, whereas in young adults, there is no association between PA and self-esteem as self-esteem is already naturally rising. However, this theory would need more research to examine if this is the case.

Implications

While each chapter presented has its own individual implications, overall themes emerged from across the chapters, and are presented below. Collectively, all chapters provided at least some support for the presence of a relationship between PA and stress, with evidence also suggesting reductions in mental health problems. While this support for the suggestion that PA could be beneficial for stress and mental health problems is helpful for providing an option for mental health support, it is also important to highlight that PA is not the be all and end all when it comes to mental health care. While PA could be beneficial for some, individual needs must be taken into consideration when offering treatments/support. For example, the severity of individual symptoms or the clinical severity of certain mental health problems may be at a level where support such as talking therapies or medications may be needed either as well as, or instead of PA. Additionally, personal circumstances such as physical disabilities may limit the extent to which a person can participate in PA, or individuals just may not be interested in doing PA, so other options may be more beneficial for them.

Based on evidence from Chapter 2 suggesting that PA is beneficial for self-esteem, and previous research into self-esteem indicating that self-esteem decreases in adolescence (Robins & Trzesniewski, 2005), adolescence could potentially be a beneficial time to implement interventions targeted at increasing self-esteem. Lubans et al. (2016) systematic

review in children and adolescents, highlights the psychosocial hypothesis, which proposes ways that PA can influence self-esteem in adolescence. While Lubans et al. (2016) found a direct relationship between PA and self-esteem in some studies included in their review, PA was also found to be indirectly related to self-esteem through other mediating variables, such as perceived competence (Lubans et al., 2016) which should be taken into consideration. These associations between PA and self-esteem suggest that there could be potential to inform the basis of an intervention, with PA being used to help increase self-esteem in adolescents. However, before an intervention could be developed, additional research is needed to support the findings of Chapter 2. Initially, it would be beneficial to re-run the study using participants of a similar age, as well as expanding the sample into younger adolescents, as well as adolescents from a wide set of cultural and ethnic backgrounds to ensure the findings from Chapter 2 are replicable. Additionally, it would be beneficial to establish if the findings of Chapter 2 are consistent over time in order to ensure that introducing an intervention would have long term benefits.

Additionally, this thesis provides a novel insight into perceived stress of adolescent and young adults during the COVID-19 pandemic, with two of the empirical chapters (Chapters 3 and 4) presenting research from different stages of the pandemic. While the COVID-19 pandemic was novel in its nature and intensity, Marani et al. (2021) suggest that there is a 38% likelihood of another pandemic similar in severity and nature to COVID-19 occurring within our lifetimes. The knowledge gained from the research presented in Chapters 3 and 4, suggests PA can be beneficial for stress and mental health of adolescents and young adults under the conditions of the COVID-19 pandemic and the associated restrictions. Knowing this information is useful for preparing for and living through any subsequent pandemics. While this evidence is a starting point to suggest that should a

future pandemic arise, PA could be beneficial for adolescents and young adults to help reduce their stress and mental health problems, more research is needed to support this theory. It would be a prudent next step to conduct a systematic review and/or meta-analysis of existing literature from the COVID-19 pandemic, as well as other previous pandemics/epidemics, such as the SARS epidemic, into the role that PA could have in protecting the mental health of adolescents and young people. The findings of this review could then potentially be the starting point for informing any future policy, particularly policy with emphasis on adolescents and young adults. Additionally, research suggests that the COVID-19 pandemic was found to have a negative impact on adolescent mental health (Jones et al., 2021), therefore the findings of this thesis, could potentially be applied to other life events or stressful periods of time that invoke similar feelings of stress or negative mental health implications.

Strengths and Limitations

The individual strengths and limitations for each study have been discussed in the respective discussion sections of each empirical chapter, with the current section presenting overarching strengths and limitations of the thesis as a whole. To begin, a key strength of the current thesis is that a range of analyses are used to examine the mechanisms that contribute to the association between PA and stress, from simple correlations to path analysis and multilevel analyses. This unique and varied set of analyses allows for the relationships between PA and stress to be examined in different ways, highlighting the relationship and how it can differ depending on the method of analysis, adding novel findings to the existing PA and stress literature.

One overarching limitation of the thesis is the sole use of self-report measures of PA. Objective measures of PA, such as accelerometers, can reduce the limitations associated

with self-report measures, such as the risk of recall issues from participants, likely giving a more accurate representation of PA in comparison with self-report measures, particularly at lower intensities that are often forgotten about by participants (Fuezeki et al., 2017). However, due to the scale of the studies, including number of participants needed, as well as the timeframe available for conducting research, and the complications accessing and interacting with participants as a result of COVID-19 restrictions, it was not feasible to use accelerometers or other objective measures throughout the programme of research.

Another limitation is that the three empirical chapters utilised cross-sectional data, which does not allow for causation to be ascertained. However, the novelty of the combination of associations relating to PA and stress examined, specifically the influence of self-esteem and stress appraisals, provide the grounding for future, longitudinal and experimental research aiming to establish causality. This future research could then form the basis for development of interventions to improve adolescent and young adult mental health and wellbeing through reducing stress.

A further limitation of the thesis as a whole is the lack of diversity amongst participants. Within the studies included in this thesis, participants were predominantly white and lacked representation from other ethnic groups. This lack of representation could have implications for the generalisability of the work, as it does not take into account cultural differences. Future work should examine a more diverse sample in order to examine the relationships between PA and stress across a wider range of people, as well as examining any differences between communities.

Future Research Directions

While suggestions for future research are presented within each chapter, some of the broader themes and suggestions will now be discussed. Building on the cross-sectional

associations found in Chapters 2 and 3, as well as longitudinal associations from Chapter 4 and knowledge gained from the Chapter 5 review, it would be beneficial for future research to examine the association between PA and stress as well as the underlying factors, such as self-esteem and stress appraisals, using an EMA methodology. As highlighted in Chapter 5, EMA allows the examination of fluctuation in relationships across a variety of timeframes, including within and between days (Dunton, 2017; Shiffman et al., 2008), by collecting repeated data samples in real time as participants go about their daily lives (Shiffman et al., 2008). This would be particularly beneficial for measuring the PA and stress relationship, as both PA and stress have been seen to fluctuate across varying timeframes, including between and even within days (Dunton, 2017; Shang et al., 2018; von der Embse & Mankin, 2021). Future research would benefit from examining these fluctuations across time and how associations between PA and stress may differ, particularly when personal factors such as self-esteem and how stress is appraised are included in analyses.

Additionally, future research should look to use more objective measures of PA, such as accelerometers. Accelerometers allow for the more precise measurement of PA intensity, duration and frequency, while being minimally invasive to participants (often just being a wrist or hip worn monitor) (Ainsworth et al., 2015). Using accelerometer data in conjunction with EMA methodology could be particularly useful, as the repeated measurements taken would allow context to be added to the accelerometer data. For example, at a time of vigorous PA as measured by accelerometer, a participant could be asked about their current feelings of stress or about they activity they are taking part in.

Research in young adults suggests that participating in PA as part of a group, or participating in team sports is associated with lower depressive symptoms (Doré et al., 2018). The PA location may also have an impact, with one randomised control trial in

adolescents suggesting that PA indoors was associated with a decrease in stress, with indoor PA being favoured over PA in a park (Wade et al., 2020). Conversely, a study in adults suggested that being active in green spaces such as forests or by water was beneficial for stress reduction (Kajosaari & Pasanen, 2021). A similar result was found in a randomised control trial in college students in that outdoor PA was better for stress reduction than indoor PA (Bramwell et al., 2023). It would also be prudent to examine the dose-response associations between PA and stress, in order to get the optimal benefits. Department of Health and Social Care (2019) state that any activity is better than no activity, more activity is still better for mental health, but recommend 60 minutes of MVPA per day for adolescents and 150 minutes of MVPA across the week for young adults. While these recommendations are a good place to start, it is important to consider that individual differences must be taken into consideration, with some reaping the benefits at less than the recommended PA, whereas others will need to participate in more PA. Therefore, examining objective measures of PA, alongside self-report descriptions of the type of PA being examined would allow for a more comprehensive understanding of the PA and stress relationships.

As illustrated throughout this thesis, stress is complex. Stress does not happen in a vacuum with no other contributing elements. Stress can be as a result of context, e.g., work stressors or difficulties with home life. Stress as evidenced within this thesis is also influenced by how an individual appraises that stress, with a challenge appraisal being associated with lower stress. Examining how the context of stress interacts with perceptions of stress for example, gives a more in-depth picture of the stress experience than examining either alone. Therefore, in order to more comprehensively understand stress and its impact, instead of examining each of these elements individually, future research should consider

3269 factors such as whether stress is acute or chronic, the context, perceptions, and how stress
3270 is appraised as interconnected parts of a larger system.

3271 In addition, the COVID-19 pandemic provided a novel set of circumstances
3272 throughout the duration of this thesis, acting as a naturally occurring intervention, putting
3273 controls on participants natural behaviours as well as the opportunity for PA. It would be
3274 beneficial for future research to conduct controlled interventions in various stressful
3275 settings, such as during exam period or in clinical populations, where PA is manipulated by
3276 researchers to examine whether an increase or decrease in PA is beneficial/detrimental
3277 towards stress based on a pre-determined baseline level of PA.

3278 This thesis covers at least in part the age range of 13–25-year-olds, the majority of
3279 the participants studied were aged 15 and above. The World Health Organisation (2019)
3280 define adolescence as the period from age 10-19, however the current thesis does not
3281 examine the younger portion of this age group in any detail. This age group are also likely to
3282 experience different stressors to older adolescents, with there being less of a focus on
3283 exams for example. UNICEF (2021) suggest that up to 13.5% of 10–14-year-olds have a
3284 probable mental health disorder, with this increasing to up to 14.1% in 15–19-year-olds. By
3285 focusing future research on the 10-14 age group, findings could potentially not only help to
3286 decrease the level of probable mental health conditions in this age group but help to
3287 prevent mental health conditions in older adolescents.

3288 While the thesis provides some begins to provide information relating to SB, this is
3289 only covered by the scoping review presented in Chapter 5, and only in a limited way
3290 focussed on EMA methodology. Existing evidence as referenced in the introduction to
3291 Chapter 5 highlights that SB is a health behaviour separate to PA (Sedentary Behaviour
3292 Research Network, 2012) therefore should be investigated as such in relation to stress and

mental health. Current evidence from a meta-analysis of longitudinal studies in adolescents suggests that higher SB at baseline is associated with increased depression and anxiety at follow up (an average of 5 years later) (Zhang et al., 2022), suggesting that higher SB in adolescence could result in increased mental health issues in young adulthood. Additionally, context of SB may play a role in the relationships with stress and mental health. For example, one study found that SB in the form of television watching was associated with increased stress in adolescents (Silva et al., 2017), whereas another found that all screentime was associated with higher stress (Fang et al., 2014). In university students, it was found that SB for transport and occupation was not significantly associated with stress or anxiety, but screen-based SB was associated with higher stress and anxiety (Felez-Nobrega et al., 2020), highlighting the importance of considering the SB domain when examining the SB, stress and mental health relationships. It may also be beneficial to investigate the SB and stress relationship in a similar way presented for PA in this thesis. It could be that there could also be additional underpinning factors that influence the SB and stress relationship, but further research is needed to determine this.

Conclusions

This thesis comprises three empirical chapters and a scoping review examining the relationship between PA and stress by examining proposed factors underpinning this relationship in adolescent and young adult populations. It was demonstrated that in adolescence, PA was associated with stress through self-esteem, stress appraisals, and distress tolerance. In relation to the novel COVID-19 pandemic, PA was a protective factor against the fear of the COVID-19 virus in relation to negative mental health implications such as stress. When examining the PA and stress relationship longitudinally in young adults, overall levels of PA were associated with overall levels of stress, but fluctuations in PA were

not associated with fluctuations in stress at within-person level. When self-esteem, challenge appraisal, threat appraisal and proactive coping were included in the analysis the PA and stress relationship was non-significant. In contrast, evidence from the scoping review into the PA and stress relationship using EMA, provides some support that there are within-person associations between PA and stress across generally shorter timeframes than in Chapter 4, but these relationships need further exploration. The present thesis adds to the PA and stress literature, specifically by presenting psychological mechanisms explaining the PA and stress relationship and how these vary under differing analyses. However, the varied nature of the results highlights the need for further exploration of the PA and stress relationship, particularly in reference to within-person associations as well as the examination of relationships over time. Examining these factors would help to gain a more comprehensive understanding of the PA and stress relationship, and how PA could be best implemented as a method of stress reduction in order to improve overall mental health.

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Appendices

Appendix 1: Unstandardised Specific Indirect Effects between Model Variables

Specific Indirect Effect Pathway	Anxiety				Depressive Symptoms			
	Estimate	Lower (95%CI)	Upper (95%CI)	p	Estimate	Lower (95%CI)	Upper (95%CI)	p
PA-SE-PS	-.027	-.052	-.012	.007	-.027	-.052	-.012	.007
PA-SE-PS-IS	-.091	-.182	-.037	.008	-.067	-.133	-.023	.012
PA-SE-THR-PS	-.014	-.025	-.006	.008	-.014	-.025	-.006	.008
PA-SE-THR-PS-IS	-.045	-.086	-.018	.012	-.033	-.073	-.013	.007
PA-SE-THR-DT-PS	-.004	-.009	-.002	.004	-.004	-.009	-.002	.004
PA-SE-THR-DT-PS-IS	-.014	-.028	-.005	.005	-.01	-.023	-.004	.003
PA-SE-THR-CHAL-PS	-.002	-.005	-.001	.002	-.002	-.005	-.001	.002
PA-SE-THR-CHAL-PS-IS	-.006	-.018	-.003	.002	-.004	-.015	-.002	.001
PA-SE-THR-CHAL-DT-PS	0	-.001	0	.002	0	-.001	0	.002
PA-SE-THR-CHAL-DT-PS-IS	-.001	-.002	0	.002	-.001	-.002	0	.002
PA-SE-THR-DT-IS	-.042	-.09	-.021	.002	-.009	-.026	.015	.327
PA-SE-THR-CHAL-DT-IS	-.002	-.005	-.001	.003	-.001	-.002	0	.192
PA-SE-CHAL-PS	-.018	-.039	-.008	.004	-.018	-.039	-.008	.004
PA-SE-CHAL-PS-IS	-.06	-.119	-.026	.006	-.044	-.104	-.022	.003
PA-SE-CHAL-DT-PS	-.002	-.007	-.001	.003	-.002	-.007	-.001	.003
PA-SE-CHAL-DT-PS-IS	-.008	-.023	-.002	.004	-.006	-.017	-.002	.002
PA-SE-CHAL-THR-PS	-.002	-.005	-.001	.004	-.002	-.005	-.001	.004
PA-SE-CHAL-THR-PS-IS	-.008	-.02	-.004	.005	-.006	-.014	-.002	.004
PA-SE-CHAL-THR-DT-PS	-.001	-	0	.001	-.001	-	0	.001
PA-SE-CHAL-THR-DT-PS-IS	-.002	-	-.001	.001	-.002	-	-.001	.001
PA-SE-CHAL-DT-IS	-.024	-.052	-.006	.005	-.005	-.019	.005	.209
PA-SE-CHAL-THR-DT-IS	-.008	-.016	-.004	.001	-.002	-.006	.001	.208

PA-SE-RES-THR-PS	-.002	-.006	0	.013	-.002	-.006	0	.013
PA-SE-RES-THR-DT-PS	-.001	-.002	0	.006	-.001	-.002	0	.006
PA-SE-RES-THR-DT-IS	-.006	-.023	-.002	.01	-.005	-.016	-.001	.009
PA-SE-RES-THR-DT-PS-IS	-.002	-.007	0	.008	-.001	-.004	0	.008
PA-SE-RES-THR-CHAL-PS	0	-.001	0	.004	0	-.001	0	.004
PA-SE-RES-THR-CHAL-DT-PS-IS	-.001	-.002	0	.008	-.001	-.002	0	.006
PA-SE-RES-THR-CHAL-DT-PS	0	0	0	.004	0	0	0	.004
PA-SE-RES-THR-DT-IS	-.006	-.018	-.002	.009	-.001	-.006	.001	.192
PA-SE-RES-THR-CHAL-DT-IS	0	-.002	0	.004	0	0	0	.138
PA-SE-RES-CHAL-PS	-.004	-.008	-.002	.005	-.004	-.008	-.002	.005
PA-SE-RES-CHAL-DT-PS	-.001	-.002	0	.003	-.001	-.002	0	.003
PA-SE-RES-CHAL-PS-IS	-.014	-.027	-.007	.005	-.01	-.02	-.005	.003
PA-SE-RES-CHAL-DT-PS-IS	-.002	-.005	0	.004	-.001	-.005	0	.002
PA-SE-RES-CHAL-THR-PS	-.001	-.001	0	.004	-.001	-.001	0	.004
PA-SE-RES-CHAL-THR-PS-IS	-.002	-.005	-.001	.005	-.001	-.004	0	.005
PA-SE-RES-CHAL-THR-DT-PS	0	-	0	.001	0	-	0	.001
PA-SE-RES-CHAL-THR-DT-PS-IS	-.001	-	0	.001	0	-	0	.001
PA-SE-RES-CHAL-DT-IS	-.006	-.015	-.002	.003	-.001	-.005	.001	.183
PA-SE-RES-CHAL-THR-DT-IS	-.002	-	-.001	.001	0	-.002	0	.166
PA-SE-DT-PS	-.003	-	0	.029	-.003	-	0	.029
PA-SE-DY-PS-IS	-.009	-.028	-.001	.039	-.007	-	-.001	.023

Note: PA=Physical Activity, SE=Self-Esteem, PS=Perceived Stress, IS= Internalizing Symptom (Anxiety or Depressive Symptoms, see column header), THR= Threat Appraisal, CHAL= Challenge Appraisal, RES= resources, DT=Distress Tolerance

4464 Appendix 2: Coronavirus Inventory Factor Loadings for a Two-Factor Solution

4465

Item	Coronavirus Fear	Coronavirus prevalence
To what extent has the threat of the Coronavirus increased your stress levels?	.817	
To what extent are you concerned about the Coronavirus?	.690	
To what extent has the threat of the Coronavirus influenced your well-being?	.679	
If you did become infected with the Coronavirus, to what extent are you concerned that you will be severely ill?	.483	
How quickly do you believe the Coronavirus is spreading in the UK?		.634
To what extent do you believe that the Coronavirus is prevalent in the UK?		.601
How likely do you think it is that you could become infected with the Coronavirus?		.546
How likely is it that someone you know could become infected with the Coronavirus?		.495

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