ASSOCIATIONS BETWEEN PHYSICAL ACTIVITY AND FATIGUE IN STUDENTS DURING THE 2020-21 ACADEMIC YEAR

By

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ABSTRACT

Overview. Fatigue is a commonly reported health complaint and a key marker of wellbeing amongst university students. Physical Activity (PA) has been shown to be related to lower levels of fatigue, but less is known about the impact of the COVID-19 restrictions on students' PA behaviour and the associations between fluctuations in PA behaviour and levels of fatigue over time.

Objectives. This study aimed to 1) explore longitudinal changes in different modalities of fatigue, 2) explore longitudinal changes in different intensities of PA, and 3) explore the between- and within person associations between fluctuations in PA behaviours and fluctuations in fatigue and vitality over time. It was hypothesised that levels of PA and vitality would decrease whilst fatigue would increase during the study.

Method. 134 participants (*M*= 19.13 years, *SD* =1.10, 35% males) completed questionnaires assessing levels of PA (overall PA, vigorous PA, moderate PA, walking PA), fatigue (general fatigue, physical fatigue, mental fatigue, reduced motivation, reduced activity) and vitality. Data was collected at 3 timepoints at the start of (October 2020) and midway through an academic term (November 2020), and during an exam period (January 2021).

Results. Levels of fatigue increased, and levels of total PA and vigorous PA and vitality decreased from timepoint 1. Between- and within-person differences in total PA were the most consistent predictors of lower fatigue and higher vitality. The between- and within- person analyses revealed negative associations between vigorous PA and all fatigue outcomes except for mental fatigue and a positive association with vitality. Moderate PA was positively associated with vitality and negatively associated with all fatigue subscales at the within-person level but not the between-person level. Between- person walking PA was only negatively associated with fatigue subscale reduced activity.

Conclusions. Overall, within-person differences revealed more significant negative associations with fatigue and positive associations with vitality. These findings suggest that fluctuations in more intense forms of PA were more consistently associated with fluctuations in levels of fatigue amongst a highly active sample of students.

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The COVID-19 global pandemic resulted in several significant implications for students' physical and mental health. As of August 2022, the UK has recorded 23,634,821 cases (John Hopkins, 2022). In an effort to prevent the transmission of COVID-19 and curb hospital admissions, the UK Government adopted various different measures over the course of the pandemic, including 2m social-distancing, "Stay at Home" orders, a 4-tier regional restriction system in December 2020, and 3 nationwide lockdowns (UK Gov, 2022). Each lockdown period saw enforced closures of non-essential retail, hospitality, leisure facilities, and some educational settings, which helped lower the transmission of COVID-19 in the UK, which ultimately prevented higher rates of hospitalisations and mortality (WHO, 2020).

Though the restrictions slowed the rate of infection of coronavirus, these restrictions greatly affected students' physical behaviours and social activities. Previous research has shown that prolonged lockdown measures can adversely affect young people's daily lives, with serious implications for physical and mental health (Savage et al., 2020). For example, campus closures caused changes in teaching delivery, the online transitions of examinations, and other university resources, such as mental health services and academic guidance (UK GOV, 2022). Additionally, the lockdown limited individuals' opportunities to engage in physical exercise. During the first UK lockdown, outdoor physical activity (PA) was limited to 1-hour-per-day, in a socially distanced outdoor setting and not with anyone from another household. Similarly, the restrictions during the second and third lockdown limited PA to outdoor, socially distanced settings, but individuals could engage with outdoor PA for longer than 60 minutes each day and with one other member of a household. Organised sport, a sub-section of PA, was severely limited with closures to sport facilities, gyms, and cessation of competitions, leagues, and interrupted training regimes. These measures placed significant restrictions on students' exercise behaviours, training routines and sporting competitions, which forced students to alter their usual PA habits. In this sense, the series of UK lockdowns provided a unique opportunity to explore the effects of forced lifestyle changes on students' wellbeing, in this instance reduced opportunities for PA (Mutz, 2021).

Research prior to the pandemic has highlighted students are vulnerable to experiencing poorer mental wellbeing, with a prevalence as high as 50% in some studies (Uddin et al., 2019; Rogowska, 2020). Quarantine or lockdown restrictions have the potential to provoke increased fatigue, isolation, distress, anxiety, and boredom (Mutz, 2021), which may have aggravated previous existing mental health issues. An American study found 60% of a college student sample displayed depression or anxiety symptomology during the pandemic (Guintella et al., 2020), whereas a UK study found 52% of a student population reported moderate-severe symptoms of anxiety in 2020 (Dewa et al., 2021). Specifically, students reported negative disruptions to PA and mood, inconsistent sleeping patterns, increased levels of fatigue, and an overall decline in their mental wellbeing, all of which were associated with social isolation and depressive symptoms (Facer-Childs et al., 2021). Longitudinal data has also revealed that depressive symptoms have increased by approximately 25% in student samples since the WHO announced the coronavirus pandemic in 2020 (Guintella et al., 2020). Overall, the findings show evidence the pandemic worsened mental health in those who already experienced poor mental health as well as an increase in the prevalence of negative mental wellbeing throughout the student population (Evans et al., 2021). This is a cause for concern as 75% of psychological mental health illnesses first appear in early adulthood (Uddin et al., 2019). Many of the aforementioned studies, however, are based on cross-sectional findings. Furthermore, the limited longitudinal findings which examined the impact of the first lockdown on students' wellbeing, relied on historic data which could be liable to recall bias (Guintella et al., 2020). Unfortunately, the pandemic has lasted much longer than was initially anticipated, for example, lockdowns and restrictions are still implemented in other countries even two years after the start of the pandemic. Therefore, it is of interest to examine the impact of ongoing pandemic restrictions on students' mental health over a longer time period.

Physical Activity (PA) is a healthy behaviour that has been consistently associated with lower levels of stress in young adults (Haghighi & Gerber, 2018) and improved overall wellbeing (Maher et al., 2013). Physical Activity refers to any bodily movement which results in energy expenditure and is not limited to sport participation or physical exercise (Caspersen, Powell, & Christenson, 1985). The WHO recommends that adults should participate in 150-300 minutes of moderate activity or 75-100 minutes of vigorous activity per week (WHO, 2020). Specifically in student populations, PA was shown to be associated with positive mental wellbeing (Wunsch et al., 2017), and a longitudinal study found that insufficient PA was associated with higher psychological distress (Uddin et al., 2019). Moreover, higher levels of PA have been shown to benefit students' wellbeing during times of chronic high stress, i.e., examination periods, (Flueckiger et al., 2016) and prevent the onset of work-related fatigue (Gerber et al., 2015). Associations between positive mental wellbeing and a physically active lifestyle have also been confirmed during COVID-19 lockdowns. A systematic review found that during the initial stages of the pandemic, physically active adults reported lower feelings of distress and fewer symptoms of depression and anxiety including lower general fatigue (Pascoe et al., 2020).

It is plausible that PA may mitigate the negative effects of pandemic-related distress on students' mental wellbeing (Wright, Williams, & Veldhuijzen van Zanten, 2022). Overall, the existing literature suggests that PA is an important predictor of mental health in student populations (Guintella et al., 2020), and therefore could be a key contributor to students' wellbeing during the COVID-19 pandemic.

The COVID-19 restrictions significantly changed individual's exercise habits and therefore PA. Studies from the first UK lockdown, however, resulted in mixed findings (Bird, 2021): UK adults reported a 40% decrease in PA (Robinson et al., 2021), with students reporting the largest decrease in PA (Ingram, 2020). In contrast, Spence and colleagues (2020) found 57% of a UK adult sample either increased or maintained their PA levels. The discrepancies in the data could be explained by inconsistencies in data collection and PA measures. For instance, many of these studies relied on cross-sectional data collected with low validity, single-item PA questionnaires which asked participants to recall their pre-pandemic PA habits (Cross et al., 2021). As such, less is known about the longer-term consequences of COVID-19 on students' PA levels. Additionally, the single-item PA measures provided limited information concerning the type or context of changes in PA behaviours, with different implications to mental wellbeing. It is of note that many of these studies gathered data during the initial stages of the pandemic before the subsequent lockdowns, therefore, less is known about longitudinal impact of pandemic restrictions on students' PA.

As the COVID-19 pandemic progressed, researchers developed questionnaire-based studies providing more detailed information about PA during the pandemic. Interestingly, the Sport England Active Lives Survey found the lockdown restrictions more greatly impacted the type, but not necessarily the amount of PA in 2020 (Sport England, 2021). Student athletes, or physically active students, are one of the many subsamples who experienced elevated levels of poor mental health and reported significant reductions in wellbeing during the pandemic (Facer-Childs, 2021; Gubric et al., 2021). Consistent engagement with PA at university - such as leisure or recreational based exercise, regular gym sessions, organised training, or competitive sport - has been shown to be related to academic success, happiness, resilience, and protection against depression and/or anxiety symptoms (Munoz-Bullón et al., 2017). These same types of PA were particularly impacted by the COVID lockdowns. Therefore, disruptions to access to different types of PA caused by COVID-19 lockdown restrictions potentially caused several mental health issues on student athletes who relied on their sport routine and lifestyle for stress management (Toresdahl & Asif, 2020). Student athletes were forced to change their sporting behaviours and were unable to access social support structures from teammates or coaches, which left them more vulnerable to negative psychological consequences. A study prior to the pandemic reported inverse associations between students' PA, perceived levels of stress, and burnout, a marker of poor wellbeing which is often experienced prior to or concurrently with depression and/or anxiety (Gerber et al., 2018). Perhaps by monitoring how pandemic-related restrictions on students' PA behaviours provoked changes in mental wellbeing, it is possible to examine the relationship between PA and wellbeing in more detail to mitigate the acute and long-term psychological consequences of COVID-19 restrictions.

Chapter 2: Fatigue and Physical Activity

2.1. Fatigue

To date, much of the research concerning mental wellbeing status amongst students has focused broadly on symptoms of depression and/or anxiety without analysing how these symptoms may manifest in more detail (Field et al., 2021). Fatigue is an important indicator of negative wellbeing and known to be a key symptom of a variety of mental health concerns caused by excessive stress, including depression and anxiety (Williamson et al., 2005). Despite this, fatigue in non-clinical populations has received relatively little attention in literature both before (Engberg et al., 2017) and during the COVID-19 pandemic (Field et al., 2021). Fatigue is a subjective, multi-faceted concept with physical, cognitive, and emotional components (Puetz, 2006) and is a commonly reported health complaint in otherwise healthy young adults with a prevalence as high as 45%, as found in a Dutch study (Andrea et al., 2003). Fatigue differs from normal tiredness, commonly arising due to poor sleep or excessive activity and often resolved with rest. Fatigue, however, persists even with adequate rest (Harrington, 2012). Studies have shown that students are highly susceptible to developing severe fatigue during prolonged periods of stress (Koschel et al., 2017), which has negative implications for academic attainment and overall mental wellbeing (Smith, 2018). Given that stress related to the pandemic caused a marked decrease in students' mental health, it seems relevant to study fatigue in more detail during the COVID-19 pandemic to improve wellbeing.

The pandemic saw higher than normal levels of fatigue - for example, in a European adult sample, 64.1% reported feeling physical and/or mental exhaustion in the past year (Morgul et al., 2020). The COVID-19 pandemic changed perceptions surrounding fatigue; the emergence of the concept of "pandemic fatigue", defined as a reluctance to engage in physical, cognitive, or social activity due to pandemic-related stress or anxiety (Field et al., 2021). It is important to consider, however, the differences between "COVID-19 fatigue" - the direct effect of contracting COVID-19 on increased symptoms of acute and chronic fatigue (Gaber, 2021) - and "pandemic fatigue" - the indirect effects of pandemic lifestyle changes on individual's levels of fatigue (Field et al., 2021). Interestingly, during the first UK lockdown (March 2020-July 2020) younger adults reported the highest fatigue scores (Dewa et al., 2021; Field et al., 2021) and attributed their fatigue to demotivation (Moradian et al., 2021), shown to be a key indicator of affective-cognitive fatigue (Mills & Young, 2008). Previously, fatigue amongst university students was framed as exhaustion caused by external stressors e.g., examination periods (Baghurst & Kelley, 2014), and other lifestyle factors such as lack of PA (Xu et al., 2018), or poor sleep (Wunsch et al., 2017). However, less is known about how lockdown restrictions impacted levels of fatigue in students during an academic semester during the COVID-19 pandemic. Preliminary data suggests 51% of the variance in fatigue scores could be accounted by depression in an adult sample, though this was a cross-sectional study conducted in April 2020 which failed to measure lifestyle factors such as PA (Field et al., 2021). It is therefore of interest to investigate how stressors associated with COVID-19 restrictions impacted long-term fatigue scores in university students.

Despite the high prevalence of fatigue amongst students, very little is known about the subjective and heterogenous aspects of fatigue in non-clinical populations. Previous research relied upon uni-dimensional measures to assess physical or general fatigue as a symptom in clinical populations (Taylor, Jason & Torres, 2000). In the general population, fatigue is associated with both somatic and mental health problems, and it is important to study how the two interact to understand the negative implications of fatigue (Andrea et al., 2003). Recent research suggests that a multi-dimensional measure assessing behaviour, cognition, emotion, and motivation components is necessary to gain a valid assessment of fatigue in non-clinical populations (Puetz, 2006; ter Wolbeek et al., 2006). Additionally, a more comprehensive assessment of levels of fatigue is necessary to understand the relatively new concept of "pandemic fatigue" and the cognitive-affective dimensions of fatigue, in more detail. It is likely that the different domains of fatigue will interact and manifest differently in otherwise healthy students during periods of elevated stress, such as psychological distress caused by ongoing COVID-19 related restrictions (Morgul et al., 2020).

It seems relevant to re-evaluate how fatigue is measured in order to assess the impact of COVID-19 induced physical, emotional, and mental exhaustion as indicators of mental wellbeing. Assessments of fatigue levels often relied on a single continuum without considering the bi-polarity concept of fatigue and feelings of energy (Puetz, 2006; Deng et al., 2015). Vitality is defined as a positive, subjective perception of physical and psychological energy (Lavrusheva et al., 2020), and is directly associated with positive affect (Ryan & Frederick, 1997) as well as a positive predictor of wellbeing (Lavrusheva et al., 2020). Moreover, several studies observed positive longitudinal correlations between vitality and some lifestyle behaviours, such as greater PA (Lavrusheva et al., 2020). Vitality represents the positive aspects of feelings of energy or vigour, which could be of interest when exploring how the different modalities of fatigue manifest in a non-clinical sample of university students in times of prolonged stress caused by academic demand and lockdown restrictions. Specifically, during the beginning of the COVID-19 pandemic, a study identified negative associations between vitality and emotional and physical exhaustion (Martínez-González et al., 2021). Interestingly, increased sedentary behaviour but not decreased PA was associated with lower vitality in a sample of French and Swiss adults during the initial months of the first lockdown (Cheval et al., 2020). Vitality, as an outcome measure of positive wellbeing, is likely to reduce amongst university students as the pandemic continues. It could be of interest to investigate how longer term COVID-19 restrictions interact with fluctuations in fatigue and vitality scores amongst university students as markers of wellbeing.

2.2. Physical Activity and Fatigue

Previous research suggests PA can improve markers of fatigue. In an adult population, PA has shown to be an independent predictor of fatigue, with higher levels of PA associated with a 40% reduced risk of developing fatigue symptoms (Puetz et al., 2006). Additionally, intervention-based studies have shown that increasing PA reduced fatigue symptoms (O'Connor & Puetz, 2005; Puetz, Flowers, & O'Connor, 2008; Doerr et al., 2016) and improved cognitive functioning amongst female university students (de Vries et al., 2016). In addition, Strahler et al. (2016) suggested PA potentially prevents the onset of fatigue under low chronic stress in a group of students. Furthermore, longitudinal studies proved the long-term benefits of PA amongst adults with stress-related exhaustion (Lindegard et al., 2015). PA is also a positive predictor of vitality (Lavrusheva, 2020) as concluded in a review paper which revealed that physically active adults reported higher levels of vitality, resulting in a 41% lower risk of developing fatigue (Puetz, 2012).

It would be an oversight to suggest that simply engaging in more PA will reduce levels of fatigue; the type and the intensity of the PA individuals engage with is likely to impact the effects the PA has on fatigue and vitality. However, the most effect type of PA to reduce fatigue is far from conclusive. Previous research suggests a lower intensity of PA - i.e., moderate continuous training as opposed to HIIT - is more beneficial to reducing fatigue and improving wellbeing in a group of female university students (Paolucci et al., 2018). Whereas other research points to an inverse association between the time spent engaging with vigorous forms of PA and fewer symptoms of depression amongst undergraduate university students (Gerber et al., 2014). Similarly, only vigorous PA reduced burnout scores in a group of Swiss students (Elliot et al., 2015). Another intervention study concluded that PA modes reduced different types of fatigue and enhancing vitality in cancer patients with varying effects (Taaffe et al., 2017). Conversely, one experimental study found no significant differences between the moderate and vigorous PA conditions on feelings of fatigue and energy amongst fatigued university students (Puetz, Flowers, & O'Connor, 2008). It should be noted here that the associations between fatigue and different intensities of PA are complicated and relative to physical condition and exercise habits of the population in the sample (Bretland & Thorsteinsson, 2015). For example, healthy, active students are likely to have different PA behaviours - therefore varied physical capabilities - compared to a sample of inactive adults possibly explaining the variance in the studies. Despite the amount of research in this area, some knowledge gaps remain. Firstly, many of the aforementioned studies focused on small, convenience samples of participants with clinically diagnosed exhaustion or burnout, or fatigue as a secondary symptom of a clinical condition. Secondly, these studies pre-dated the pandemic, and some used inconsistent or limited measures of fatigue with a specifc focus on physical fatigue. It is likely that experiences of fatigue and vitality will differ in a healthy, student population subject to COVID-19 lockdown PA restrictions. Therefore, to explore whether the COVID-19 restrictions and academic semester impacted students' PA behaviours - and the subsequent associations between PA, vitality, and fatigue - a more comprehensive assessment incorporating the various exercise modalities and intensities is warranted.

As previously mentioned, the COVID-19 pandemic placed several restrictions on students' habitual PA and changed opportunities to engage in different types and intensities of PA. It is important, therefore, in the context of COVID-lockdown restrictions to distinguish between daily PA and organised sport and/or exercise. During the first lockdown, the early termination of sport seasons and group training sessions, and the closure of sports venues partially contributed to the reduction in students' PA (Ingram, 2020) with 78.9% of a sample of student athletes reporting that the pandemic contributed to PA disruptions (Facer-Childs et al., 2021). Specifically, student athletes experienced routine alterations, limited or reduced training, cancellation of competitions, and a lack of access to team support networks all of which have significant mental and physical health consequences (Gubric et al., 2021). Although some students maintained their PA levels by engaging with ways of being active (i.e., home workouts, running etc.), to others the lack of social support and motivation as well as physical barriers to participation potentially resulted in reduced PA (Stanton, 2020). Similarly, the 2nd and 3rd lockdown in the UK limited daily PA to socially distanced outdoor settings and with only one other member of another household. Lockdown forced sports facilities, venues, and gyms, group training sessions, exercise classes, and competitions to close. Overall, these changes to physical activity behaviours contributed to elevated negative mental wellbeing amongst students during the earlier months of 2020 (Stanton, 2020), and it is plausible that the subsequent two lockdowns had similar negative consequences. However, it is important to note the individual differences in the way the pandemic impacted PA in students; even though the average activity levels were above WHO guidelines during the first lockdown, 43% of the same student sample reported significant reductions in their habitual PA (Savage et al., 2020; Rogowska et al., 2020). Additionally, during 2020, young adults from France and Switzerland reported a large reduction in vigorous or moderate PA (Cheval et al., 2020). Seemingly, the large reduction in competitive sport, or group training, and modified or interrupted exercise routines caused a profound effect on students who are already sufficiently active. For example, student athletes reported the largest reduction in wellbeing in a sample of young adults (Mutz, 2021). Overall, the preliminary data suggests that students were consistently active during 2020, but they were unable to experience the welfare benefits of organised sport/exercise. It could be of interest to examine how the interruptions to sport caused by further lockdowns impacted students' mental wellbeing, especially after permitting sport at the beginning of the 2020-21 academic year.

The novelty of COVID-19 means little is known about the longer-term impact of lockdown restrictions on sporting exercise behaviours. Previous studies reported that student athletes attributed negative wellbeing to modified PA behaviours during early 2020 (Ingram et al., 2020; Grubic et al., 2021). There are some similarities with studies that used exercise withdrawal paradigms (Mutz, 2021) with a review paper concluding that reduced or altered PA habits due to external constraints, i.e., injury or enforced restrictions, invoked negative mood states, including fatigue, and depleted mental wellbeing (Weinstein, 2017). Interestingly, another review found consistent impact of a single bout of exercise on increasing feelings of energy, but the findings related to a single bout of exercise on feelings of fatigue were inconclusive (Loy et al., 2013). This further emphasises the importance of investigating the associations between PA and bipolarity of energy (e.g., vitality) and fatigue in more detail. Other experiments concluded that somatic markers and cognitive markers of poor wellbeing occurred 1- and 2-weeks post exercise withdrawal respectively (Berlin et al., 2006). Follow-up analyses, however, revealed that outcome wellbeing measures returned to baseline levels after 1-week of resuming normal exercise behaviours (Atunes et al., 2016). However, many of these studies used small convenience samples of university students and the exercise withdrawal intervention occurred over a short period of time (average 2 weeks). It was also impractical to ensure that all participants adhered to the exercise withdrawal condition (Blough & Loprinzi, 2018). Overall, the previous findings suggest reducing or changing PA behaviours involuntarily affects wellbeing detrimentally (Morgan et al., 2018) but few have investigated the impact of exercise withdrawal on fatigue and energy. It could be of interest to extend previous findings by investigating the effects of an enforced reduction of exercise behaviours in a real-life setting over the course of several months. It seems likely that extended COVID-19 restrictions on PA behaviours are likely to impact students' perceptions of fatigue and vitality, and therefore have important implications for their wellbeing.

Taken together, it is plausible a period of altered exercise behaviours caused by COVID-19 lockdown restrictions may affect students' PA behaviours and levels of fatigue and vitality. The fluctuations between exercise behaviours and fatigue scores over time may provide a deeper understanding of how these different outcome measures interact and thus potentially critically impact students' wellbeing during the COVID-19 pandemic. It is likely that the negative effects of enforced modified PA behaviours appear more pronounced in a population of highly active students participating in organised sport (Maugeri et al., 2020). Given the importance of improving mental wellbeing during the pandemic, it seems important to understand the role of different PA behaviours on markers of wellbeing - namely fatigue - to provide implications how universities could facilitate improvements in students' wellbeing.

2.3. Between- and within- person associations

Previous longitudinal studies examined the relationships between fatigue, energy, and PA using between-person analyses (Conn, 2010). More specifically, these studies explore to what extent individuals who engage in more PA differ in fatigue and energy levels than individuals who are less physically active. For example, a systematic review concluded individuals who habitually engage in more PA report lower levels of fatigue and higher vitality over time (Puetz, 2006). Although these findings shed light on the fatigue-PA relationship and the potential association with one another over time, previous studies are unable to analyse these relationships beyond the between-person effect level. Analysis at the within-person level, on the other hand, examines variations in the variables of interest from the individual's mean values over time (Hoffman & Stawski, 2009). For example, the within-person associations would reflect the extent the variations in an individual's mean PA levels are associated with variations from the individual's mean levels of fatigue and energy over time. Recently, researchers acknowledged the relevance of investigating within-person associations alongside between-person associations in the same set of longitudinal data (Curran and Bauer, 2011). In terms of research concerning PA and fatigue, however, little is known about within-person associations.

One of the reasons why there are few studies investigating the between- and within-person associations between PA-fatigue is due to the statistical complexity of distinguishing the two types of associations within the same set of longitudinal data (Hoffman, 2015). Multi-level modelling (MLM) is a tried and tested statistical method used to differentiate the between- and within-person associations within the same set of longitudinal data (Constantini, 2018). Bryk and Raudenbush (1992) MLM method first uses a "null" or "empty" model without entering predictor variables to calculate the total explained variance. The subsequent predictor models use the "empty" model but also include the person-centred mean (pcm) and sample-centred mean (or grand-centred mean, gcm) variables entered for the within-person and between-person values respectively. The pcm refers to variations in the dependent variable with reference to the individual's mean value, whereas the gcm refers to variations in the dependent variable with reference to the overall sample's mean value. By using this method, it is possible to investigate to what extent the between- or within-person differences in levels of PA can account for the variance or predict the fluctuations in levels of fatigue. However, in the PA-fatigue literature, there is a lack of studies examining these associations using MLM methodology in both clinical and non-clinical populations, resulting in a gap in knowledge how this statistical method is applicable to longitudinal research.

By using these statistical methods, there is potential to address researchers' comments that past PA-fatigue research overlooked the relative physical capabilities of levels of PA of the individual (within-person) and the population (between-person) in question (Bretland & Thorsteinsson, 2015; de Vries et al., 2016). Between-person differences can show how a sample's average PA may influence the average levels of fatigue, whereas exploring the within-person associations can provide more detail about the associations between PA and fatigue relative to the person's own mean values of these outcomes. Exploring within-person associations can provide a better understanding of the associations between PA and fatigue. For example, in a sample of people with rheumatoid arthritis or osteoarthritis, it was found that on days participants participated in more than their usual levels of PA, they reported less symptoms of fatigue and more energy (Hegarty et al., 2015). To my knowledge, less is known about these between and within-person associations within a non-clinical population and over a longer time period. As previously mentioned, it is likely that physical capabilities or usual exercise behaviours of the population will influence the PA-fatigue associations over time. This study aims to use a longitudinal study design and the MLM method, to firstly collect longitudinal data, and secondly differentiate the between and within PA-fatigue associations in a population of otherwise, healthy student

Chapter 3: The Present Study

3.1. The context of this study

To date, the basis of knowledge of the effect of COVID-19 lockdown restrictions on students' mental health and wellbeing is from the first lockdown (March 2020). Although similar trends are likely during the 2nd and 3rd lockdowns, suggestions of subtle differences in people's opinions and behaviours as lockdown restrictions continued are of note (Presti et al., 2021; Reicher & Drury, 2021). For example, a study found the majority of students returned home during the first lockdown (Van Zyl et al., 2021), whereas some students chose to remain at their term-time address during the second and third lockdowns as some universities opened libraries - though at a reduced capacity. Potentially changes in learning arrangements, campus closures, lifestyle behaviours and isolation from family during the first part of the 2020-21 academic year may contribute to a reduction in mental wellbeing, resulting in long-term mental health issues (Savage et al., 2020). Students' levels of fatigue tend to increase during an academic semester (Wunsch et al., 2017), however, the first part of the 2020-21 academic year saw students experiencing inconsistent pandemic-based restrictions and periods of lockdowns. Potentially, extra stress caused by the pandemic in conjunction with academic stress may have impacted students' levels of PA, fatigue, and vitality. Previous research suggested students do not have the required physical, emotional, or psychosocial support to avoid the negative psychological effects of COVID-19 (Van Zyl et al., 2021). It is therefore important to study how students' lifestyle behaviours, including PA, are associated with levels fatigue - a key marker of wellbeing - during the lockdowns.

Despite the amount of research investigating the increased prevalence of poor mental wellbeing amongst students and the associations between mental health and PA, less is known about the long-term fluctuations in different types of PA and the behavioural, cognitive, and affective dimensions of fatigue including vitality. It is also worth mentioning that much of the longitudinal data is from studies predating the pandemic, and therefore, less is known about the impact of COVID-19 restrictions and adaptions to daily lifestyles on students' mental wellbeing (Evans et al., 2021). As mentioned above, the current literature relies on findings that analysed between-person differences, whilst less is known about these associations over time at the within-person level. It is likely the fluctuations in the different intensity types of PA has varying effects on the different components of fatigue and vitality. Previous literature found that active students are more likely to engage in more intense forms of PA (Gerber et al., 2014; Eliot et al., 2015), shown to decrease due to university examinations (de Vries et al., 2016) and during the first UK lockdown in 2020 (Ingram, 2020; Sport England, 2021).

3.2. Aims and Hypothesis

In sum, this longitudinal study conducted during the first half of the 2020-21 academic semester and during the COVID-19 pandemic aims to 1) explore changes over time in different markers of fatigue and vitality (i.e., general, physical, and mental fatigue, reduced activity, reduced motivation, and vitality), 2) explore changes over time in different forms of PA (i.e., total, vigorous, moderate, and walking PA), and 3) explore the between- and within person associations between fluctuations in PA behaviours and fluctuations in fatigue and vitality over time. It was hypothesised that the students' levels of fatigue would increase, whereas levels of vitality and PA would decrease from baseline. As previous studies show that enforced changes to PA behaviours contribute to increased markers of depleted wellbeing, it was also hypothesised that the COVID-19 restrictions would significantly impact the students' exercise habits, which would explain for the between- and within- person differences in markers of fatigue and vitality.

3.3. Method

3.3.1. Participants A convenience sample of 297 healthy students aged 18-25-years-old were recruited from UK universities to participate in the study. Participants were contacted via email or social media and invited to participate in the study. The sample contained predominantly undergraduate students from the School of Sport, Exercise and Rehabilitation Sciences at the University of Birmingham. These students were predominantly recruited via the study information and invitation being shared via the virtual learning platform, with the incentive of being awarded research hours upon completion of the study. Exclusion criteria included: not being proficient in English; and a formal diagnosis of a mental health issue at the time of taking part in the study. All participants provided informed consent prior to beginning the study and the study obtained ethical approval from the University of Birmingham STEM Ethics Committee.

3.3.2. Outcome Measures

Fatigue. The 20-item Multi-dimensional Fatigue Inventory (MFI-20; Smets et al., 1995) assessed levels of fatigue. The MFI-20 measures 5 subscales: general fatigue (e.g., "I feel tired"); physical fatigue (e.g., "Physically I feel I am in bad condition"); mental fatigue (e.g., "I can concentrate well"); reduced activity (e.g., "I think I do very little in a day"); and reduced motivation (e.g., "I don't feel like doing anything") with 4 items for each respective subscale. Participants rated each item on a 5-point Likert scale ranging from 1 (“no, that is not true”) to 5 (“yes, that is true”) in relation to their perceptions of fatigue in the previous month. Some items were reversed scored, after which scores on each subscale were summed with higher scores reflecting higher levels of fatigue. The MFI-20 is a validated and highly reliable measure of fatigue used in various clinical and non-clinical populations, including university students (Schneider, 1998) and to identify indicators of poor mental wellbeing (Chung et al., 2014). In the present study the MFI-20 provided data that was internally reliable with Cronbach alpha coefficients all above .75 (see Table 1 for the values for each subscale across the 3 timepoints).

Vitality. The 5-item Subjective Vitality Scale (SVS; Ryan & Frederick, 1997) assessed perceptions of vitality, a measure of feelings of energy and indicator of positive mental wellbeing. The SVS is comprised of 5 items e.g., “I feel full of excitement” and “I feel like I have a lot of energy”. Participants rated each item on a 7-point Likert scale from 1 (not at all true) to 7 (very true) in relation to their perceptions of energy in the past month. Average scores were calculated, with a higher mean score reflecting higher subjective vitality. The SVS is a validated and reliable measure of subjective vitality (Bostic, Rubio, & Hood, 2000) that has been used in conjunction with the MFI-20 to accurately assess bi-polarity of feelings of fatigue and energy in UK adults (Ellingson et al., 2014). Recently, the SVS has been used to assess vitality during the COVID-19 pandemic in a sample of Spanish student athletes (Martínez-González, 2021). The Cronbach’s alphas reported in Table 1 indicate that the internal consistency for vitality in this sample across the 3 time points was excellent (>0.90).

Physical Activity. The short form of the International Physical Activity Questionnaire (IPAQ-SF; Craig et al., 2003) was used to assess self-reported PA. The IPAQ includes items regarding different intensities of PA, specifically vigorous, moderate, and walking activities. Data on light PA was also collected but not used as not part of formal IPAQ questionnaire. Examples of vigorous activities included heavy lifting, digging, aerobics, or fast cycling for at least 10 minutes at a time. Examples of moderate activities included carrying light loads, cycling at a regular pace, or doubles tennis for at least 10 minutes at a time. Examples of walking activities includes walking at work, home, walking as a mode of travel, and other recreational or leisure walking for at least 10 minutes at a time.

Participants were asked to first report how many times they had done each intensity of activity for at least 10 minutes at a time during the last 7 days. Then they indicated how much time (hours and minutes) they usually would usually spend on each intensity on one of those days. Scores were truncated to a maximum of 180 minutes per day for each activity, or a 3-hour bout of activity, in accordance with IPAQ guidelines (Craig et al., 2003).

To calculate weekly MET minutes, time spent in each activity was multiplied by the appropriate MET value, i.e., 8 for vigorous PA, 4 for moderate PA, and 3.3 for walking, by the minutes the activity was carried out and then by the number of the days that week the activity was performed. For example, if an individual reported vigorous activity for 30 minutes, 3 days a week, then the total MET minutes for vigorous activity is 8 x 30 x 3 = 720 METs.

Participants with a week total PA time of >1050 minutes were excluded from the final sample. This cut-off point took into consideration how much time per week a student could realistically spend in some form of physical activity, information each participant provided about the form of any PA extracurricular activities, and the amount of training sessions per week.

The short form IPAQ has been shown to be related to objective measures of PA in students (Nelson et al., 2019), and additionally to assess students' levels of PA during COVID-19 (Zhang et al., 2020). Regarding the internal consistency, the Cronbach's alphas show that internal consistency for vigorous PA in this sample is unacceptable (<0.7) at the 3 time points. The internal consistency for moderate and walking PA is acceptable (>0.7) to good (>0.75) at the 3 time points.

Table 1. *Cronbach's Alphas for Fatigue, Vitality and Physical Activity Subscales*

Subscale	Cronbach's α		
	T1	T2	T3
General Fatigue	.81	.82	.83
Physical Fatigue	.83	.85	.85
Mental Fatigue	.83	.85	.83
Reduced Activity	.79	.82	.83
Reduced Motivation	.78	.84	.83
Vitality	.90	.92	.91
Vigorous PA	.56	.62	.60
Moderate PA	.77	.79	.77
Walking PA	.73	.78	.76

3.3.3. Procedure In this longitudinal study, data was collected at 3 time points during three data collection windows between October 2020 – January 2021 during the 2020-21 academic year. The full breakdown of the dates for each data collection windows is displayed in Table 2 below.

This study took place during different phases of the COVID-19 pandemic and was subject to different UK restrictions. Details of the relevant restrictions at each time point are shown in Table 2.

The Oxford COVID-19 Stringency Index measures the severity of the pandemic in reference to several indicators of government responses, e.g., school/work closures, restrictions, travel bans, and financial measures. These values are rescaled from 0-100 (100 most severe) to provide a comparison tool. Due to the evolving situation with COVID-19 restrictions and lockdowns during the study, the 2-week time frame for the third data collection was postponed, meaning responses included the first 2-3 weeks of the January national lockdown (UK Gov, 2022) as well as the January examination period.

Table 2. *COVID-19 Restrictions for Data Collection Timepoints*

	T1 (October 2020)	T2 (November 2020)	T3 (January 2021)
UK Covid-19 cases per day (average)	6,914 (01/10/20)	22,124 (01/11/20)	68,053 (01/01/21)
Oxford COVID-19 Stringency Index Score (0-100)	67.59	64.81	87.96
Social distancing measures	Yes	Yes	Yes
UK lockdown dates	N/A	05/11/20 - 02/12/20	06/01/21 – 11/04/21
Restrictions on PA/sport	Social distancing restrictions	Gyms, sports facilities closures, no organised sport	Gyms, sports facilities closures, no organised sport
Restrictions on education	Social distancing restrictions	Educational settings open with social distancing	Educational settings closed

Note. *All statistics sourced from UK Government (UK Gov, 2022) calculated as an average over 7 days*

All data collection was completed via SmartSurvey. First, participants were provided with information about the study and told that they did not have to answer any question they did not want to. At the start of each data collection window participants were sent a link to the study which contained a brief overview and reminder of the study and the questionnaires to be completed. Those who agreed to participate in that particular phase completed the online consent form, followed by questionnaires that included questions about demographic characteristics (gender, age, etc.) and items that assessed levels of PA, fatigue, and vitality which took approximately 25 minutes to complete. At the next data collection point, only those who completed the previous data point were emailed the next questionnaire pack.

3.3.4. Data Reduction and Analyses The original sample consisted of 297 participants at T1, 221 participants at T2, and 196 participants at T3. The scores for each subscale were calculated. If an item was missing from a subscale of a questionnaire, the overall score for that subscale was excluded from the analysis involving that variable for that participant. Participants were included in the data analyses if they had provided full information regarding covariates (i.e., age, gender), and had completed the MFI-20, SVS, and IPAQ at baseline and either T2 or T3 or both. The majority of participants who were excluded from the final analyses had incomplete IPAQ data, specifically incomplete walking PA. The final sample used for analyses consisted of 134 participants. The majority of participants had full data for T1, T2, and T3 (n = 89), the remaining participants had data for T1 and T2 (n = 28) or T1 and T3 (n = 17). A one-way analysis of variance (ANOVA) revealed that out of all the variables of interest, only a significant difference was found for mental fatigue between participants that were included and participants that were excluded at baseline (see Table 3).

Table 3. *Mean (SD) Fatigue, Vitality and Physical Activity Values for Included and Excluded Participants in Data Analyses*

Variable	Included participants (*n=134*)		Excluded participants (*n=66*)		*F*
	M	*SD*	*M*	*SD*	
General Fatigue	10.51	2.70	10.15	2.88	0.77
Physical Fatigue	7.72	3.84	7.42	3.21	0.43
Mental Fatigue	12.20	3.55	10.86	3.05	6.68**
Reduced Activity	8.89	3.08	8.25	3.50	1.73
Reduced Motivation	9.30	3.04	8.77	2.43	1.50
Vitality	4.56	1.07	4.75	1.00	1.40
Total PA (METs)	3450	1925	3951	2266	0.98
Vigorous PA (METs)	1955	1499	2388	1867	1.19
Moderate PA (METs)	530	577	546	569	0.01
Walking PA (METs)	939	717	1017	900.08	0.17

Note. **p<.05, **p<.01*
Fatigue scores ranged from 4-20
Vitality scores ranged from 1-7
Total PA scores ranged from 0-13600, vigorous PA 0-8640, moderate 0-2880, walking 0-3564

Using the final sample, a one-way ANOVA was carried out investigating possible gender differences in the following dependent variables: general fatigue, physical fatigue, mental fatigue, reduced activity, reduced motivation, vitality, total PA, vigorous PA, moderate PA, and walking PA. This was done to explore if whether gender needed to be added as a covariate in subsequent analyses.

Secondly, a series of multilevel analyses were conducted to examine if there were any significant fluctuations in the fatigue subscales, vitality, and different PA types over time. These analyses used the overall sample mean at each timepoint to examine potential changes over the course of the study. Using the multi-level modelling method (MLM) outlined by Bryk and Raudenbush (1992), a second series of multilevel analyses were carried out to examine within- and between person associations between fluctuations in PA (total PA, vigorous PA, moderate PA, and walking) and the dependent variables (general fatigue, physical fatigue, mental fatigue, reduced activity, reduced motivation, and vitality) in separate analyses. The within-person (Level 1) predictors were centred person-means of the dependent variables of interest, therefore, the values represented variations in the variables relative to the person's mean value. The between-person (Level 2) predictors were grand-mean centred person-means of the dependent variables, and therefore, reflected variations in the mean values for each person relative to the overall sample mean. In these analyses, age and gender were included as covariates. The covariates were entered as the grand-mean centred age (average age of the overall sample) and a "dummy" value for sex (0 is male, 1 is female). Therefore, the grand-mean centred values are an estimate of the overall mean values for the dependent variables for a male participant of average age of the sample. For all analyses, significance was set to $p<.05$. All data analyses were carried out using SPSS Version 27.

Chapter 4: Results

4.1. Participant characteristics

Table 4 presents the characteristics the participants (*n*=134) included in the analyses. The majority of the participants were female (male *n* = 47; female *n* = 87; mean age *n* = 19.13; *SD* = 1.10 years), and in their first year of university (1st *n*=64, 48%, 2nd *n*=56, 42%, 3rd *n*=9, 6.7%, and 4th*n*=5, 3.7%). Separate ANOVAs revealed a significant gender difference in general fatigue and physical fatigue, with females reporting higher values for both variables (see Table 4). Therefore, gender was entered as a covariate in subsequent analyses. In general, the population reported moderate levels of fatigue, with the exception of mental fatigue which was relatively high (Smets et al., 1995).

Table 4. *Mean (SD) Fatigue, Vitality and Physical Activity Values at Timepoint 1.*

Variable (range of scores)	Males		Females		*F*
	M	*SD*	*M*	*SD*	
General Fatigue	9.51	2.83	11.10	2.48	10.75***
Physical Fatigue	7.04	2.74	8.08	2.84	4.18*
Mental Fatigue	12.34	3.95	12.11	3.34	0.12
Reduced Activity	8.98	3.21	8.84	3.03	0.06
Reduced Motivation	9.40	3.24	9.24	2.94	0.09
Vitality	4.76	1.05	4.46	1.07	2.44
Total PA (METs)	3718	2223	3303	1738	1.41
Vigorous PA (METs)	2186	1734	1830	1350	1.74
Moderate PA (METs)	545	620	522	555	0.05
Walking PA (METs)	987	798	914	672	0.32

Note. * $p<.05$, *** $p<.001$
Fatigue scores ranged from 4-20
Vitality scores ranged from 1-7
Total PA scores ranged from 0-13600, vigorous PA 0-8640, moderate 0-2880, walking 0-3564

4.2. Longitudinal Analyses

4.2.1. Longitudinal Changes in Fatigue, Vitality and Physical Activity Table 5 reports the mean values for each dependent variable for each time point, revealing significant fluctuations in general fatigue, physical fatigue, reduced activity, reduced motivation, vitality, total PA, and vigorous PA over time. The multi-level analyses revealed that general fatigue significantly increased from T1 to T2, then decreased significantly from T2 to T3. No significant differences were found between the mean values for general fatigue at T1 and T3. For the physical fatigue and reduced motivation subscales, the mean values increased significantly from T1 to T2 and did not change from T2 to T3 thus staying significantly higher at T3 compared to T1. The mean values for reduced activity subscale decreased significantly from T1 to T2, with a further decrease from T2 to T3. No significant differences were found for mental fatigue across the three time points. The group mean values for subjective vitality, on the other hand, decreased significantly from T1 to T2 and remained decreased at T3 compared to T1. The multi-level analyses also revealed that the mean levels of total PA decreased significantly from T1 to T2, and further decreased from T2 to T3. The group average level of vigorous PA decreased significantly from T1 to T2, however, there was no change from T2 to T3. No significant differences in the group mean levels at each timepoint were found for moderate or walking PA.

Table 5. *Estimated Mean Scores (SE) of Fatigue, Vitality and Physical Activity at Timepoints 1-3.*

Outcome measure	T1	T2	T3
General Fatigue	10.00 (0.41)	11.09 (0.22) ^{a}	10.34 (0.25) ^{b}
Physical Fatigue	7.48 (0.42)	8.67 (0.26) ^{a}	8.47 (0.28) ^{a}
Mental Fatigue	12.48 (0.49)	12.88 (0.23)	12.49 (0.24)
Reduced Motivation	9.35 (0.42)	10.87 (0.26) ^{a}	11.09 (0.25) ^{a}
Reduced Activity	9.41 (0.45)	10.78 (0.29) ^{a}	11.51 (0.31) $^{a\ b}$
Vitality	4.67 (0.15)	4.12 (0.09) ^{a}	4.18 (0.09) ^{a}
Total PA (METs)	3561 (234)	2993 (167) ^{a}	2544 (204) $^{a\ b}$
Vigorous PA (METs)	2080 (176)	1430 (125) ^{a}	1305 (145) ^{a}
Moderate PA (METs)	522 (65)	507 (60)	397 (65)
Walking PA (METs)	948 (86)	1058 (73)	863 (79)

***Note*.**
^{a} = sig difference from T1, $p<.05$; ^{b} = sig difference from T2, $p<.05$

4.2.2. Longitudinal Associations Between Physical Activity, Fatigue and Vitality A series of multilevel analyses using MLM were conducted to explore within- and between- person associations between fluctuations in fatigue and vitality and PA. Table 6 displays the multi-level analysis results for general fatigue. Exploration of the within-person associations (Level 1 analyses) revealed that total PA, vigorous PA and moderate PA were significantly and negatively associated with general fatigue. Therefore, when an individual engaged in less PA overall and less vigorous forms of PA than their usual levels, their levels of general fatigue were higher. The between-person (Level 2) associations showed that total PA and moderate PA were negatively associated with general fatigue meaning that when a person engaged in less overall PA, vigorous, and moderate forms of PA compared to the sample mean, their levels of general fatigue were likely to be higher.

Analyses for vitality are displayed in Table 7. Exploration of the within-person associations (Level 1) revealed that total PA, vigorous PA, and moderate PA were significantly and positively associated with vitality. This means that when an individual spent more time than usual engaging with PA overall, and vigorous or moderate forms of PA, they were more likely to have higher levels of vitality. Similarly, exploration of the between-person associations (Level 2) showed significant and positive associations between total, vigorous, and moderate PA and vitality, meaning that when a person engaged with more PA overall, vigorous PA, or moderate PA compared to the sample mean, their levels of vitality were more likely to be higher.

Table 8 shows the within- and between- person associations for physical fatigue. The within-person associations (Level 1) revealed that total PA, vigorous PA, and moderate PA were significantly and negatively associated with physical fatigue. Thus, when an individual engages in less PA overall and vigorous PA than usual, their levels of physical fatigue were higher. Likewise, an exploration of the between-person (Level 2) associations revealed that total PA and vigorous PA were significantly and negatively associated with physical fatigue. This means that when a person engages with more PA overall, or more forms of vigorous or moderate PA compared to the sample mean, it is likely that their levels of physical fatigue will be higher.

The analyses for mental fatigue are displayed in Table 9. Exploring the within-person (Level 1) associations revealed that total PA and moderate PA are significantly and negatively associated with mental fatigue, meaning that when an individual engages with less PA or moderate PA than usual, their levels of mental fatigue are likely to be higher. Exploring the between-person associations revealed a significant negative association between total PA and mental fatigue. Therefore, when a person spent less time engaging with PA compared to the sample's mean levels, their levels of mental fatigue were more likely to be higher.

Analyses for the reduced motivation subscale are shown in Table 10. The within-person associations (Level 1) revealed total PA, vigorous PA, and moderate PA are significantly and negatively associated with reduced motivation. Meaning that when an individual engages in less total PA or less vigorous or moderate PA than usual, their levels of reduced motivation are likely to be higher. Similarly, for the between-person (Level 2) associations, negative associations were revealed for total, vigorous, and moderate PA, and reduced motivation. Therefore, when a person spends less time engaging with total PA, forms of vigorous PA, or moderate PA compared to the sample's mean, they are more likely to have higher levels of reduced motivation.

The findings from the analyses for reduced activity are displayed in Table 11. The within-person analyses (Level 1) revealed that total PA, vigorous PA, and moderate PA are significantly and negatively associated with reduced activity. This means that when an individual spends less time than usual engaging with PA overall, vigorous PA, and moderate PA, they are likely to have higher reduced activity. Likewise, exploring the between-person associations (Level 2) revealed that total PA, vigorous PA, moderate PA, and walking PA are significantly and negatively associated with reduced activity. Therefore, when a person spends less time engaging with total PA, vigorous, moderate, and walking PA compared to the sample's mean, their levels of reduced activity are also likely to be higher.

Table 6. Multilevel Modelling Coefficients (SE) of Different Types of PA Predicting General Fatigue.

	B Coefficient (SE)			
Predictor	Total PA	Vigorous PA	Moderate PA	Walking PA
Fixed effects				
Intercept	10.51 (0.38)*	10.53 (0.38)*	10.43 (0.39)*	10.46 (0.39)*
Level 2 predictors				
Age	0.24 (0.21)	0.23 (0.21)	0.31 (0.21)	0.32 (0.21)
Gender	0.68 (0.47)	0.67 (0.47)	0.80 (0.48)	0.77 (0.48)
Between-person differences in the predictor	-0.05 (0.01)*	-0.07 (0.02)*	-0.10 (0.06)	-0.08 (0.04)
Level 1 predictor				
Within-person changes in the predictor	-0.03 (0.01)*	-0.04 (0.01)*	-0.06 (0.03)*	0.04 (0.02)
Random effects				
Intercept	4.94 (1.00)	5.12 (0.98)	5.47 (1.01)	5.48 (1.01)
Residual (AR1 diag)	3.62 (0.67)	3.50 (0.62)	3.57(0.62)	3.57 (0.60)
-2 restricted LL	1658	1663	1678	1681
AIC	1674	1679	1694	1697

Note. ** p<.05*

Table 7. Multilevel Modelling Coefficients (SE) of Different Types of PA Predicting Vitality.

	B Coefficient (SE)			
Predictor	Total PA	Vigorous PA	Moderate PA	Walking PA
Fixed effects				
Intercept	4.32 (0.14)*	4.32 (0.14)*	4.35 (0.14)*	4.34 (0.14)*
Level 2 predictors				
Age	-.05 (0.08)	-.05 (0.08)	-.07 (0.08)	-0.08 (0.08)
Gender	-.13 (0.17)	-.13 (0.17)	-.17 (0.18)	-.16 (0.18)
Between-person differences in the predictor	0.02 (0.01)*	0.01 (0.01)*	0.05 (0.02)*	0.03 (0.02)
Level 1 predictor				
Within-person changes in the predictor	0.02 (<0.01)*	0.02 (0.01)*	0.02 (0.01)*	0.01 (0.01)
Random effects				
Intercept	0.66 (0.13)	0.68 (0.14)	0.58 (0.08)	0.69 (0.15)
Residual (AR1 diag)	0.57 (0.09)	0.57 (0.09)	0.71 (0.13)	0.63 (0.10)
-2 restricted LL	994	1000	1020	1026
AIC	1010	1016	1036	1042

Note. ** p<.05*

Table 8. Multilevel Modelling Coefficients (SE) of Different Types of PA Predicting Physical Fatigue.

	B Coefficient (SE)			
Predictor	Total PA	Vigorous PA	Moderate PA	Walking PA
Fixed effects				
Intercept	8.24 (0.37)*	8.27 (0.36)*	8.14 (0.40)*	8.14 (0.40)*
Level 2 predictors				
Age	0.21 (0.20)	0.17 (0.02)	0.35 (0.22)	0.35 (0.22)
Gender	0.25 (0.46)	0.19 (0.45)	0.36 (0.49)	0.36 (0.50)
Between-person differences in the predictor	-0.08 (0.01)*	-0.11 (0.02)*	-0.09 (0.06)	-0.07 (0.04)
Level 1 predictor				
Within-person changes in the predictor	-0.06 (0.01)*	-0.08 (0.01)*	-0.10 (0.03)*	-0.05 (0.02)
Random effects				
Intercept	4.52 (1.00)	4.26 (1.01)	5.44 (1.12)	4.77 (1.39)
Residual (AR1 diag)	4.10 (0.70)	4.19 (0.74)	4.55 (0.73)	5.31 (1.13)
-2 restricted LL	1678	1684	1739	1745
AIC	1694	1700	1755	1761

Note. ** p<.05*

Table 9. Multilevel Modelling Coefficients (SE) of Different Types of PA Predicting Mental Fatigue.

	B Coefficient (SE)			
Predictor	Total PA	Vigorous PA	Moderate PA	Walking PA
Fixed effects				
Intercept	12.68 (0.46)*	12.66 (0.47)*	12.61 (0.47)*	12.64 (0.47)*
Level 2 predictors				
Age	0.27 (0.26)	0.29 (0.26)	0.34 (0.26)	0.35 (0.25)
Gender	-0.53 (0.58)	-0.51 (0.58)	-0.44 (0.58)	-.48 (0.58)
Between-person differences in the predictor	-0.04 (0.02)*	0.02 (0.02)	-0.14 (0.07)	-0.10 (0.05)
Level 1 predictor				
Within-person changes in the predictor	-0.02 (0.01)*	-0.02 (0.01)	-0.07 (0.02)*	0.01 (0.02)
Random effects				
Intercept	8.54 (1.28)	8.75 (1.30)	8.82 (1.28)	8.68 (1.29)
Residual (AR1 diag)	3.45 (0.51)	3.47 (0.50)	3.28 (0.45)	3.49 (0.50)
-2 restricted LL	1708	1718	1711	1720
AIC	1724	1734	1727	1736

Note. ** p<.05*

Table 10. Multilevel Modelling Coefficients (SE) of Different Types of PA Predicting Reduced Motivation.

	B Coefficient (SE)			
Predictor	Total PA	Vigorous PA	Moderate PA	Walking PA
Fixed effects				
Intercept	10.41 (0.40)*	10.40 (0.40)*	10.33 (0.40)*	10.36 (0.40)*
Level 2 predictors				
Age	0.13 (0.22)	0.14 (0.22)	0.17 (0.22)	0.19 (0.22)
Gender	-0.14 (0.49)	-0.15 (0.50)	-0.07 (0.49)	-0.10 (0.18)
Between-person differences in the predictor	-0.04 (0.02)*	-0.04 (0.02)	-0.14 (0.06)*	-0.06 (0.04)
Level 1 predictor				
Within-person changes in the predictor	-0.05 (0.01)*	-0.06 (0.01)*	-0.08 (0.03)*	-0.03 (0.02)
Random effects				
Intercept	5.29 (1.07)	5.56 (1.05)	5.21 (1.07)	5.28 (1.13)
Residual (AR1 diag)	4.73 (0.75)	4.61 (0.69)	5.01 (0.77)	5.22 (0.84)
-2 restricted LL	1744.10	1752.16	1763.85	1772.92
AIC	1760.10	1768.16	1779.85	1788.92

Note. ** p<.05*

Table 11. Multilevel Modelling Coefficients (SE) of Different Types of PA Predicting Reduced Activity.

	B Coefficient (SE)			
Predictor	Total PA	Vigorous PA	Moderate PA	Walking PA
Fixed effects				
Intercept	10.59 (0.39)*	10.60 (0.40)*	10.44 (0.41)*	10.49 (0.41)*
Level 2 predictors				
Age	0.16 (0.21)	0.16 (0.22)	0.26 (0.22)	0.29 (0.22)
Gender	-0.97 (0.48)*	-0.97 (0.50)	-0.80 (0.50)	-0.85 (0.51)
Between-person differences in the predictor	-0.08 (0.02)*	-0.09 (0.02)*	-0.02 (0.06)*	-0.13 (0.05)*
Level 1 predictor				
Within-person changes in the predictor	-0.07 (0.01)*	-0.08 (0.01)*	-0.13 (0.03)*	-0.05 (0.03)
Random effects				
Intercept	3.21 (1.83)	4.04 (1.63)	2.32 (2.74)	1.89 (3.06)
Residual (AR1 diag)	7.08 (1.77)	6.78 (1.50)	9.12 (2.77)	9.90 (3.13)
-2 restricted LL	1781.11	1802.70	1821.60	1835.31
AIC	1797.11	1818.70	1837.60	1851.31

Note. ** p<.05*

Chapter 5: Discussion

This current study observed significant longitudinal fluctuations in markers of fatigue, vitality, and PA levels in a non-clinical sample of UK university students during the 2020-21 academic semester and COVID-19 pandemic. Although there were some differences in the direction and magnitude of fluctuations in scores at timepoint 2 (November 2020) and timepoint 3 (January 2021), the overall trend in the data suggests that students' markers of fatigue increased, whereas vitality and PA decreased from timepoint 1 (i.e., start of academic term). Mental fatigue, which was scored the highest out of all fatigue scales, did not significantly change from timepoint 1. These findings generally confirmed the first hypothesis that fatigue scores would increase whilst vitality and PA would decrease during the first academic 2020-21 semester during the coronavirus pandemic.

Exploring the between- and within-person associations between different intensities of PA with different dimensions of fatigue and vitality partially supported the second hypothesis of this study. Analyses revealed that total PA was the most consistent within- and between-person predictor of fatigue and walking only presented a significant between-person association with reduced activity. Overall, the within-person analyses revealed more significant associations between PA and fatigue compared to the between-person analyses. In sum, firstly this study highlights how students' levels of fatigue, vitality and PA changed during the initial part of the 2020-21 academic year. Secondly, this study revealed the extent of which fluctuations in different forms of PA explained higher levels of fatigue and depleted vitality in a population of highly active students. Taken together, these findings suggest that it is important for students to maintain their usual PA behaviours to prevent higher levels of fatigue during the academic semester and the COVID-19 pandemic.

In relation to the first aim of this study, all of the fatigue subscales – with the exception of mental fatigue – significantly increased from the first timepoint. Our results add to similar longitudinal findings that students' levels of fatigue increased during an academic semester prior to the pandemic, although the previous study measured "personal burnout", a different component of fatigue (Baghurst & Kelley, 2014). Additionally, the students' levels of vitality decreased from the first time point, similar to a study conducted at the start of the pandemic amongst European students (Martínez-González et al., 2021). These findings are of relevance because elevated levels of fatigue or burnout combined with lower levels of vitality are key markers of depleted wellbeing in students (Williamson et al., 2005; Gerber et al., 2014; Gerber et al., 2018). To our knowledge, this is one of the first studies to observe multi-dimensional changes in fatigue amongst students over time. Firstly, this provides a more comprehensive understanding of how fatigue may manifest in a non-clinical population, and secondly, how students' fatigue fluctuated during one academic term during the pandemic.

This study extends upon existing knowledge by using the MFI-20 and SVS to gain a multi-dimensional assessment of the physical, psychological, and affective components of fatigue, and how markers of fatigue may manifest in a sample of otherwise healthy students (Mota, 2006; Karshikoff, Sundelin, & Lasselin, 2017). Vitality captured the concept of the bi-polarity of fatigue and feelings of energy (Lavrusheva, 2020), and moved away from previous research which has placed too much emphasis on physical fatigue (Puetz, 2006). It was important to assess other forms of fatigue as previously high levels of psychological and emotional markers of fatigue have been suggested to be pre-cursors to other issues relating to poor mental health, i.e., depression and/or anxiety (Andrea et al., 2002). The increase in fatigue – as observed in this study – suggests that the combined effect of the pandemic restrictions and academic demands contributed to a decline in the students' mental wellbeing during the 2020-21 academic year. This adds to the wealth of research acknowledging the increase in prevalence of elevated levels of fatigue amongst students since the start of the first UK lockdown in March 2020 (Dewa et al., 2021). Firstly, this highlights the importance of understanding factors that might influence students' levels of fatigue, and secondly, which aspects or types of fatigue impact students the most. Therefore, the assessment tools used in this study may provide relevant information concerning the implications of the COVID-19 and the academic year on students' levels of fatigue and vitality. This in turn, provides an insight into students' wellbeing.

Like other previous fatigue-based studies in students (Gerber et al., 2018), this study also found that mental fatigue was consistently the highest scoring fatigue subscale at each timepoint. Example items from the MFI-20 which assesses mental fatigue include: "I can concentrate well" and "it takes a lot of effort to concentrate on things". Therefore, high scores on this subscale indicate a reduced ability to cope with cognitive demands (Smets et al., 1995). Previous research showed that elevated levels of mental fatigue may have detrimental consequences for cognitive functioning (Boksem & Tops, 2009) and motivation (Marcora et al., 2009), which may further implicate mental wellbeing. High levels of mental fatigue have been shown to be associated with higher levels of mental distress (Gerber et al., 2015). Indeed, it is likely that the students did experience variations in stress, not just due to the academic term, but also the ongoing COVID-19 restrictions likely exacerbated usual academic stressors on university studies and added additional causes of stress. Notably, there was not a significant increase in mental fatigue at the third time point during the January exams, which is at odds with a previous study which saw a significant increase in students' mental fatigue and stress levels during a university examination period (de Vries et al., 2016). However, due to the restrictions, many of the university examinations took place online and students could sit them at home, potentially less stress-inducing than traditional in-person exams. It could be that the restrictions increased stress in other ways, or the mechanisms which may explain how the high levels of mental fatigue differ from previous pre-COVID studies. Although this is mere speculation, further research is needed to explore specific factors that can influence fatigue in this population.

In the context of the COVID-19 pandemic, the finding that there were increases in reduced activity and reduced motivation, and reductions in vitality from time 1 provides additional evidence to the idea that the pandemic possibly contributed to an increase in mental and emotional fatigue (Field et al., 2021). As previously mentioned, it is important to think of fatigue as more than just simply a physical symptom, but it is complicated to disentangle "physical" versus "mental" versus "emotional" fatigue, as often the components co-exist and interact with each other. For example, items from the MFI-20 which assess reduced motivation include "I don't feel like doing anything" and items such as "I think I do very little in a day" for reduced activity (Smets et al., 1995), and items from the SVS include "I look forward to each day", all of which allude to elements of physical and mental fatigue (Ryan & Frederick, 1997). "Pandemic fatigue" observed during the COVID-19 restrictions, characterised by emotional and mental burnout, potentially with attitudinal implications to overall frustration and motivation to be physically, mentally, and/or socially proactive (Michie, West, & Harvey, 2020). It is also important to highlight the differences between "COVID-19 fatigue", which relates to the symptoms of acute or chronic fatigue caused by contracting the virus, with "pandemic fatigue" that covers the onset of symptoms of fatigue caused by all the changes and restrictions as a result of the pandemic (Field et al., 2021). Despite the absence of research looking into which components of fatigue are most closely associated with "pandemic fatigue", the observed increase in these three subscales could be indicative of an increase in "pandemic fatigue", which appear to have consequences on daily physical, mental, and social behaviour. It is plausible that the pandemic has contributed to the consistent high levels of mental fatigue and emotional fatigue, which can lead to a decrease in motivation, the perception of having less energy, and the overall feeling of being less mentally or physically active than usual. This remains speculation as the novelty of the concept of "pandemic fatigue" means there are few studies which have investigated this concept in depth. It is likely that as time goes on, more studies will emerge examining these separate domains of fatigue in more depth, both in the context of a pandemic, and more generally the context of academic stress and fatigue.

It is highly relevant to understand how pandemic fatigue along with academic demands might impact students fatigue levels to mitigate any negative effects on students' wellbeing. It is likely that the factors that contributed to higher levels of fatigue during the first UK lockdown – e.g., changes to routines and social activities, as well as overall uncertainty of the future (Labrague, 2020) – may have persisted during the second and third lockdowns. Previous pandemic restrictions have been suggested to cause an increase in levels of mental fatigue (Meo et al., 2020), which may manifest as mental burnout, a key characteristic of pandemic fatigue (Michie, West, & Harvey, 2020). Interestingly, the present study findings show that there were no consistent changes in levels of fatigue during lockdown restrictions. For example, the highest average scores for general fatigue, physical fatigue, mental fatigue, and lowest average score for vitality were recorded at timepoint 2. It might be expected that levels of fatigue would be the highest at timepoint 3 due to the third UK lockdown and January examinations. However, the students' levels of general fatigue, physical fatigue, mental fatigue and vitality did not change from timepoint 2 to 3. The consistency in the scores may reflect changes in other contexts during the Christmas holidays – e.g., the students' living situation – which may have served as a break from academic stress and university life, which is likely to have affected students' social interactions. This is not to say that the contexts of the third timepoint were not also stressful, for instance, students were in the middle of the January examination period and the third UK lockdown. However, the fluctuations suggest students' fatigue and vitality levels are influenced by several factors. The combination, or perhaps interaction, of novel pandemic-based stressors with university stressors that students may usually experience, needs to be examined further to understand changes in students' levels of fatigue and vitality. The longitudinal observations, although relevant, cannot comment on the influence of different contextual factors, however, it is still important to keep in mind the combined effect of several sources of stress when analysing the impact of the pandemic on students' fatigue and overall wellbeing.

Further analysis of other fatigue subscales may help us to understand the combined impact of the pandemic and university life on students' fatigue levels. The present study's findings revealed that reduced activity – an affective component of fatigue which has been linked to psychological burnout and pandemic fatigue (Michie, West, & Harvey, 2020) – was the only subscale to significantly increase over the course of the study. Items in the MFI-20, which assessed reduced activity asked students about their perceptions regarding: "I feel very active", "I think I do a lot in a day", "I think I do very little in a day", and "I get little done" (Smets et al., 1995). In a sense, higher levels of reduced activity reflect the students' perceived belief that they are doing less activity, whether that be physical (e.g., PA), mental (e.g., academic work), or social (e.g., social behaviours), than usual. Possibly, the COVID-19 restrictions and academic pressures placed more, or even different, physical, cognitive, and emotional demands on the students. This, in turn, depleted their energy and decreased their perceived physical activity levels, or the sense of doing less.

Additionally, students' levels of reduced motivation also increased during the study, although this did not further increase from timepoint 2 to 3. Items that assessed the students' levels of reduced motivation included: "I dread having to do things", "I have a lot of plans", and "I don't feel like doing anything". Previously, researchers suggested a lack of motivation to do tasks, specifically self-initiated motivation, is related to higher levels of mental fatigue when the perceived effort outweighs the rewards (Boksem, Meijman & Lorist, 2006). For instance, the COVID-19 restrictions and academic stressors experienced by the students during the 2020-21 academic year may have led to the perception that more effort was needed to meet an increased amount of physical, cognitive, and emotional demands, which over time contributed to elevated levels of fatigue.

In sum, the participants in this study felt that they were doing less and lacked motivation to do more. Similarly, one of the key markers of pandemic-fatigue is reduced interest in previously enjoyed activities (Margaritis et al., 2020). It would be interesting to understand the direction of these relationships, e.g., are the students demotivated due to their perceived reduction in PA, or whether the lack of motivation has caused the perception that they are not meeting additional demands, therefore, doing less. These questions are beyond the scope of this study; however, further research should analyse the relationships between these areas of fatigue. Understanding how different types of fatigue increased amongst students in an academic term during the pandemic would allow researchers to recommend how students may mitigate the negative consequences of elevated levels of fatigue.

The second aim of this study was to explore PA over the course of an academic semester during the COVID pandemic. This showed a significant decline in overall PA, most likely influenced by the reduced opportunities for PA during the lockdowns. Interestingly, the findings from this study also acknowledged the students' fluctuations in different forms, or intensities, of PA during the pandemic. This is relevant as further analysis of longitudinal changes in different PA behaviours during the pandemic may extend previous cross-sectional work (Facer-Childs et al., 2021; Ingram et al., 2021) and studies that used a single-item PA questionnaire (Rogowska et al., 2020; Stanton et al., 2020). Specifically, this study found that the time spent engaging with vigorous forms of PA decreased from timepoint 1 to timepoint 2 and 3 but did not significantly change from timepoint 2 to timepoint 3.

The students’ levels of moderate PA and walking PA did not significantly fluctuate during the study. Previous research found similar patterns in the levels of vigorous PA in a sample of European adults (Cheval et al., 2020), however, to our knowledge, this is one of the few studies to observe longitudinal fluctuations in different intensities of PA amongst a sample of healthy students over the course of an academic term during a pandemic. It is likely that the surrounding context of the pandemic and academic semester influenced students’ PA behaviours, which needs to be examined further to understand the potential implications on students’ overall wellbeing.

This study extends upon previous research by using the IPAQ to provide more information concerning the potential impact of the COVID-19 restrictions on levels of different intensities of PA over time. Ordinarily, students’ levels of PA have been shown to decrease during a semester due to increased academic and social demands from university life (Wunsch et al., 2017). It is possible that the combination of COVID-19 restrictions and other university stressors affected students’ usual exercise habits, which resulted in a decrease in students’ overall and vigorous PA. The IPAQ is a well validated and reliable tool for assessing levels of PA amongst healthy students (Nelson et al., 2019), however, our findings for vigorous PA demonstrated low internal consistency. A previous study, which assessed PA levels and chronic fatigue scores, attributed low Cronbach’s alphas scores to how the IPAQ is more indicative of more intense forms of PA due to way it is calculated (Meeus et al., 2010). For example, the students in this study were highly active, and therefore it was not feasible to fit in all the vigorous PA with moderate and walking PA, thus affecting the reliability scores. Therefore, the internal consistency scores should not detract from the relevance of the findings. Overall, although more research is necessary, analysing students’ fluctuations in different forms PA levels provides an interesting insight into the consequences of the COVID-19 restrictions during an academic term, which may have had wider implications to other aspects of the students’ wellbeing.

It is important to mention that the sample of students used in this study were highly active. A large majority of the sample were recruited from the School of Sport, Exercise and Rehabilitation Sciences at the University of Birmingham, many of whom are student athletes. For instance, according to World Health Organisation (WHO) guidelines when calculated as a MET score, adults should aim to accumulate 750-1000 METs per week to be sufficiently active (WHO, 2020). In this study, the estimated average total METs score at timepoint 1 was 3561 and even at timepoint 3 the estimated average total METs score was 2544. Additionally, IPAQ guidelines state that a high score equates to approximately 1 hour of moderate activity per day, or 3 1-hour bouts of vigorous PA in a week, at a minimum of 1500 MET minutes per week (Craig et al., 2003). Therefore, although the findings reveal that there was a significant decline in PA from timepoint 1, the students were still meeting the WHO guidelines for PA at all time points. There is a substantial amount of evidence that shows that meeting PA guidelines is associated with positive physical and mental wellbeing both prior to (Marques et al., 2016) and during the pandemic (Faulkner et al., 2021). Therefore, it is interesting to see that fatigue is prevalent in this cohort of healthy people with high levels of PA and emphasises the need to enhance our understanding of factors that can contribute to fatigue.

The final aim of the study was to explore the between- and within-person associations between changes in PA and fatigue over the course of an academic term during a pandemic. Much of what we know concerning the relationship between PA and fatigue is based on between-person analyses, or to what extent individuals who engage in more than the sample's average levels of PA differ in levels of fatigue and vitality (Conn, 2010). Further analysis revealed that the between-person associations corroborate with other longitudinal studies which found that amongst students, lower activity levels were associated with higher levels of fatigue and depleted vitality (Puetz, 2006; Gerber et al., 2014; Elliot et al., 2015; Uddin et al., 2020). The within-person analyses, on the other hand, revealed that when individuals participated in less PA than usual, this was associated with higher levels of fatigue and lower levels of vitality than their personal average levels. Both the types of analyses revealed that total PA was most consistently associated with levels of fatigue and vitality. More specifically, both within- and between- person associations were reported for total PA with all fatigue subscales and vitality, with higher levels of PA related to lower fatigue and higher vitality. It is important to disentangle the two types of analyses as they differ conceptually (Haas et al., 2017). The between-person associations contribute to the suggestion that regular PA has the potential to prevent different types of fatigue (Puetz, 2006) and promote positive wellbeing (Gerber et al., 2014). The within-person analyses emphasise the importance of considering how fluctuations in an individual's PA may have implications for their levels of fatigue and vitality. Therefore, the finding that PA and fatigue, and PA and vitality are associated in the same direction for both types of analyses underline the importance of maintaining PA levels for reducing fatigue and improving levels of vitality amongst students during an academic semester during the pandemic.

The finding that there were significant between-person associations for vigorous PA and all the outcomes of interest - with the exception of mental fatigue - suggests that having overall lower levels of vigorous PA decreased is related to overall higher levels of fatigue and lower levels vitality. Previous research has found that meeting PA guidelines for vigorous PA may prevent the onset of fatigue symptoms during times of high academic stress, i.e., towards the end of a semester (de Vries et al., 2016). Interestingly the results revealed that despite the high levels of vigorous PA (WHO, 2020), the students' fatigue levels increased, and vitality decreased over the course of the term. This is at odds with previous cross-sectional research which found that consistently engaging with vigorous forms of PA is associated with lower levels of fatigue (Gerber et al., 2014). This is partly explained by the within-person analyses, which revealed that when a student engaged in less vigorous PA than their average level, they reported lower vitality, and increased levels of all types of fatigue except for mental fatigue. In this sense, our study is able to extend cross-sectional or between-person associations which is limited to compare group mean levels of vigorous PA and fatigue. Interestingly, the findings from this study are at odds with diary studies examining the acute effects of PA over the course of several days amongst a population of non-active adults, which found that more intense forms of PA predicted negative affect and lower energy (Liao et al., 2017; Paolucci et al., 2018). However, it should be noted that these studies used a different study design and a less active sample, which may explain the contrasting results. It is beyond the scope of our observational findings to comment on the mechanisms of the reduction in the students' personal levels of vigorous PA, but it is likely that the students' exercise behaviours were influenced by a combination of pandemic restrictions and academic stressors. This could be of interest to future research to understand further the importance of the within-person associations between vigorous forms of PA and fatigue for highly active students.

Interestingly, the findings of the between- and within person analyses were less consistent for moderate PA. This study revealed significant within-person inverse associations between moderate PA and all the fatigue subscales, and a positive within-person association with vitality. Our observational findings extend previous experimental work that found that amongst students, engaging moderate forms of PA, i.e., cycling at 75% $VO_{2max,}$ increased feelings of energy and decreased levels of fatigue (Puetz, Flowers, & O'Connor, 2008). The between-person analyses, conversely, revealed associations for only moderate PA and reduced motivation, reduced activity, and vitality. It is plausible that less significant between-person associations were found for moderate PA because the overall sample mean for levels of moderate PA did not significantly change during this study. This might be because moderate forms of PA were more accessible during the period of assessments in this study, e.g., the pandemic restrictions and academic stressors did not impact opportunities to participate in moderate forms of exercise as much as other types of PA, and in particular vigorous. Although the sample average levels of moderate PA remained consistent, negative fluctuations in a student's usual amount of moderate PA were associated with higher fatigue and lower vitality suggesting that it is important for researchers to examine changes in PA behaviours and their influence on fatigue at a within person level. Potentially, it was not the amount of time students spent doing moderate forms of PA, but instead the context that the moderate PA took place in. For example, it was possible to engage in similar types of moderate PA during all the timepoints, however, lockdown restrictions during the second and third timepoints changed the social setting, for example, the location due to facilities closing or the reduced social contact. Overall, it seems relevant to future research to investigate the reasons why students changed their individual PA behaviours and the potential influence of this on their levels of fatigue.

It is important to reiterate here that the analyses conducted in the present study enabled the examination of different forms of PA, and how the different intensities may influence students' fatigue and vitality levels. Studies that examined longitudinal fluctuations in PA during the pandemic largely relied on general PA using single-item assessment measures (Cross et al., 2021), which may have overlooked the importance of changes in different forms of PA to levels of fatigue and vitality. For instance, no significant within-person associations were found for walking PA and the fatigue types and vitality. Thus, although higher than the individual's average levels of total, vigorous, and moderate PA were related to lower fatigue and higher vitality – except for vigorous PA and mental fatigue – more time spent walking did not relate to changes in fatigue levels over the course of this study. Similarly, the only significant between-person association was between walking and reduced activity. Again, this might be explained by the lack of significant longitudinal fluctuations in students' levels of walking PA during the semester. In sum, although the students reported to spend a lot of time walking during the study, this was not associated with the personal and overall increase in markers of fatigue.

The analyses from the present study emphasise the importance of personal changes in vigorous and moderate forms of PA, specifically, vigorous PA was a more significant predictor of fatigue at both the between- and within-person level. This is at odds with an experimental study that found low-moderate intensity exercise types are more effective in reducing markers of fatigue compared to high-intensity forms of PA amongst inactive students (Wang & Boros, 2019). The differences in the results could be a reflection of the normal fitness levels or the physical capabilities of the participants in the different studies. For example, an intervention study found that less intense forms of PA reduced levels

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low-moderate intensity exercise types are more effective in reducing markers of fatigue compared to high-intensity forms of PA amongst inactive students (Wang & Boros, 2019). The differences in the results could be explained by an intervention study that found different types of exercise – e.g., cardiovascular-based and resistance-based exercise – improved levels of fatigue in different ways (Bretland & Thorsteinsson, 2015). This suggests that different factors may influence the impact of different types of PA on reducing fatigue, for example the participants' baseline PA levels. This is mere speculation, but it might explain why a decline in overall and personal levels of vigorous PA were associated with elevated levels of several types of fatigue and depleted vitality for a population of highly active students. This further highlights the relevance of examining the within-person effects to consider the physical capabilities (de Vries et al., 2016), and secondly the value, or even the perceived benefits, of that type of PA or exercise for the individuals in the sample. If this is the case, research could look to potential reasons why participating in more intense forms of PA is beneficial for active students over the course of an academic term during the pandemic.

A potential reason why the fluctuations in students' individual levels of PA had a more significant effect on fatigue and vitality could be a consequence of the combination of pandemic restrictions and students' academic demands during the semester. Many researchers investigated how enforced changes to exercise behaviours can have an adverse effect on fatigue and energy levels. For example, experimental studies found that a period of enforced exercise withdrawal contributed to elevated levels of fatigue 2 weeks post intervention (Berlin et al., 2006; Atunes et al., 2016). The COVID-19 restrictions constrained organised sport and sport facilities, likely limiting the students' opportunities to engage with more intense forms of PA, whereas the restrictions affected lower intensity forms of PA comparatively less. This could be an explanation for the longitudinal decline in student's vigorous PA, but constant levels of moderate and walking PA. This is further exemplified by previous studies that attributed lower levels of vigorous PA to pandemic-based restrictions during the first lockdown (Constandt et al., 2020), and academic demands at the end of an academic term (de Vries et al., 2016). It is plausible that the students involuntarily changed their personal activity levels in response to external pandemic and academic constraints, consequently causing levels of fatigue to increase and vitality to decrease, potentially negatively influenced their mental wellbeing. The surrounding context of the pandemic provided a new opportunity to examine the real-life consequences of external constraints on PA behaviours without the need for experimental or lab-based conditions. However, it is beyond the scope of this study to comment on the direct effects of enforcing exercise behaviour change on levels of fatigue. Therefore, it could be of interest to investigate the mechanisms behind enforced exercise behaviour change on markers of fatigue and vitality to better understand the implications on wellbeing.

In addition to the negative effects of enforced changes to exercise behaviours, another potential reason why more physically active individuals experienced elevated levels of fatigue during the pandemic could be due to the removal of competitive sport or a consistent training routine. It is important to note that the sample of participants consisted of highly active students who participated in regular exercise, and not solely student athletes per se. Previous researchers hypothesised about the restrictions on competitive sport and the potential negative mental health consequences for students who rely on their training routines or sport competitions, and the sociability of group sport for stress management (Grubic et al., 2021). Prior to the pandemic, several studies found that markers of poor wellbeing, such as higher fatigue or anxiety, were lower in a sample of student athletes compared to non-athlete students (Gerber, 2018; Egan, 2019). The observations from the present study extend previous work by showing how the interruption to the sport season during a university term may contribute to reduced levels of PA. To reiterate, the students remained active throughout the study – e.g., they relied upon moderate forms of PA or walking instead – but the reduction in their personal levels of more intense forms of PA were associated with the increase in fatigue and decrease in vitality. Overall, the impact of an altered exercise routine, or enforced changes to PA behaviours, may explain the within-person inverse associations between PA and fatigue despite the consistent high levels of PA in this sample.

Another factor which potentially affected the students' changes to their usual exercise behaviours is their athletic identity (Uroh & Adewunmi, 2021). Athletic identity is a construct which encompasses behavioural, psychological, and affective components of an individual's self-identity as an athlete (Hagiwara, 2021). As previously mentioned, the COVID-19 restrictions impacted the students' normal exercise routine, training schedules, and their social networks from participating in regular sport. All of which may have affected their athletic identity. Previous literature linked maintaining a strong athletic identity during the pandemic with mental wellbeing. For instance, one study found that athletes who maintained their athletic identity by adapting their PA behaviours or maintaining social links with other teammates on social media, were less likely to report poor mental wellbeing (Graupensperger et al., 2021). Another study found a link between loss in athletic identity and increased levels of burnout amongst a group of female university athletes (Russell, 2021). It is conceptually challenging to assess associations between athletic identity and fatigue because of they are both subjective, multi-faceted constructs (Kennedy, Tamminenand, & Holt, 2013). However, it is interesting that both are affected by a combination of behavioural, psychological, and affective factors. Perhaps in highly active populations, such as this study, an individual's athletic identity is a more relevant factor in the PA-fatigue associations, which could explain why students' personal levels of fatigue significantly increased during the first part of the 2021-22 academic year. As our findings are based on observations, more research is needed to further our understanding of the potential relationships between these factors and the overall implications for students' levels of fatigue.

Chapter 6: Strengths, Limitations and Conclusion

6.1 Strengths

Firstly, this study used valid and reliable questionnaires which assessed a) overall PA and 3 different intensity types of PA, and b) the multi-dimensional constructs of fatigue and vitality. Past studies have assessed single-item measures of PA and a tendency to only measure fatigue as a physical symptom in clinical settings (Puetz, 2006). Thus, they are unable to capture the different modalities of fatigue in its totality in a non-clinical population. Although self-reported measures of fatigue, vitality, and PA are liable to recall bias and inaccuracies (Dishman, Washburn, & Schoeller, 2006), the IPAQ been found to be a reliable measure of PA, with high agreement with accelerometer data, in university students (Murphy et al., 2017). Additionally, the MFI-20 has been shown to be a valid and reliable method of collecting mental wellbeing-related data in students (Sandvik, Deiner, & Seidlitz, 2009). Given that physical and social restrictions during the pandemic meant that the use of objective measures of PA was not feasible, the questionnaires used in this study still allowed for a valid and reliable assessment that captured the multi-dimensionality of fatigue, vitality and different intensities of PA.

A second strength of the present study is the longitudinal study design, which allowed for data analyses at between-person and within-person levels. Our study showed that between- and within- person analyses revealed more information about the associations between PA and fatigue and vitality amongst students than between-person associations alone. Previous work, however, rarely used a study design that could implement the statistical methods for within-person associations. Examining the within-person PA-fatigue association overcomes previous comments about the relevance of the physical capabilities of the population – such as clinical vs non-clinical populations – for the implications of changes in PA behaviours on levels of fatigue (Bretland & Thorsteinsson, 2015). Furthermore, the longitudinal within-person associations are relevant considering the different types of pandemic restrictions, academic demands, and social behaviour changes that would have occurred during the course of this study. Overall, this study highlights the importance of examining how fluctuations in a student's personal PA levels may explain some of the variation in fluctuations in levels of fatigue and vitality.

Thirdly, this study was able to capture long-term enforced adaptions of students' PA in a real-life setting. Many previous studies relied upon experimental conditions, consequently resulting in generalisability issues and relating to a real-life context (Weinstein et al., 2017). As noted by Berlin and colleagues (2006), participants in these type of study designs are predisposed to their experiment group, which may incur negative wellbeing states. The observational findings in this study differ from the previous experimental studies; all the students in our study were subject to the same COVID-19 restrictions on their exercise habits. In this sense, the pandemic presented a novel opportunity to observe the consequences of involuntarily adapting exercise habits on levels of fatigue in real time. This should not detract from experimental studies – which are able to control for different variables and the potential to comment on any mechanisms – though, the real-life setting of the present study makes the findings highly relevant.

6.2. Limitations

Firstly, the second and third UK COVID-19 lockdowns were unexpected. Though this is a common feature in many of the studies conducted during the pandemic (Cross et al., 2021). Consequently, some factors could not be controlled for, which could have impacted students' responses. For example, depleted wellbeing has been linked with changes to living situation, the UK tier system that occurred in between timepoint 2 and 3, and COVID-19 infection (Mutz, 2021). Furthermore, this study did not assess students' perceived stress levels which likely affected their levels of fatigue. For instance, higher levels of perceived stress are associated with elevated fatigue (Koschel et al., 2017), or even fatigue in otherwise healthy adults, could be a stress-related disorder (Kocalevent et al., 2011). Additionally, it is highly likely that the combination of the stress caused by the pandemic and university life affected the students, but it is unknown which parts were additive, or the extent of their interaction. Formerly, researchers hypothesised that potentially higher levels of PA mitigate increased chronic stress caused by university examinations, (de Vries et al., 2016) and reduce stress-related fatigue (Strahler et al., 2016). However, in this study, the students' inability to maintain their normal PA behaviour due to the restrictions imposed during the January examination period exposed them to increased stress from a) academia, and b) the COVID-19 lockdown itself.

Secondly, the observational nature of this study means it is beyond the scope of this study to comment on causation or mediating mechanisms, possibly influencing levels of fatigue. Our findings, albeit insightful, can only conclude that the surrounding context possibly influenced the students' exercise habits which are associated with between- and within-person fluctuations in fatigue and vitality. It is, therefore, of interest for future research to investigate potential explanations why enforced changes to PA behaviours relate to changes in markers of fatigue. For example, previous research focused on intra-individual differences in motivations to be active (Scholz et al., 2008) and the mediating role of athletic identity (Uroh & Adewunmi, 2021).

6.3. Conclusion

This study is an example of how longitudinal between- and within- person analyses can provide a more detailed examination of the associations between different intensities of PA and different modalities of fatigue in a non-clinical, highly active sample of students. The evidence that enforced changes in PA behaviours were associated with a longitudinal increase in markers of fatigue on the individual level further highlights the importance of examining associations between PA-fatigue with the activity levels of the population in mind. Even highly active, healthy students were significantly affected by the combination of academic and pandemic-based demands placed upon them during the 2020-21 academic year, which had negative implications for their levels of fatigue, a key marker of mental wellbeing. It is often thought that higher levels of PA may protect individuals from detrimental effects of the increased demands caused by university life and the pandemic, but this study further exemplifies that physically active students were highly vulnerable to depleted wellbeing. Therefore, it could be of interest to researchers to explore potential mechanisms of the associations between PA-fatigue to mitigate any negative consequences to students' mental wellbeing.

List of References

Andrea, H., Kant, I., Beurskens, A., Metsemakers, J., & Van Schayck, C. (2003). Associations between fatigue attributions and fatigue, health, and psychosocial work characteristics: a study among employees visiting a physician with fatigue. *Occupational and environmental medicine*, *60*(suppl 1), i99-i104.

Antunes, H. K. M., Leite, G. S. F., Lee, K. S., Barreto, A. T., Dos Santos, R. V. T., de Sá Souza, H., Tufik, S., & de Mello, M. T. (2016). Exercise deprivation increases negative mood in exercise-addicted subjects and modifies their biochemical markers. *Physiology & Behavior*, *156*, 182-190.

Baghurst, T., & Kelley, B. C. (2014). An examination of stress in college students over the course of a semester. *Health Promotion Practice*, *15*(3), 438-447.

Berlin, A. A., Kop, W. J., & Deuster, P. A. (2006). Depressive mood symptoms and fatigue after exercise withdrawal: the potential role of decreased fitness. *Psychosomatic Medicine*, *68*(2), 224-230.

Bird, J. M., Karageorghis, C. I., & Hamer, M. (2021). Relationships among behavioural regulations, physical activity, and mental health pre-and during COVID–19 UK lockdown. *Psychology of Sport and Exercise*, *55*, 101945.

Blough, J., & Loprinzi, P. D. (2018). Experimentally investigating the joint effects of physical activity and sedentary behavior on depression and anxiety: a randomized controlled trial. *Journal of Affective Disorders*, *239*, 258-268.

Boksem, M. A., Meijman, T. F., & Lorist, M. M. (2006). Mental fatigue, motivation and action monitoring. *Biological Psychology*, *72*(2), 123-132.

Boksem, M. A., & Tops, M. (2008). Mental fatigue: costs and benefits. *Brain Research Reviews*, *59*(1), 125-139.

Bostic, T. J., Rubio, D. M., & Hood, M. (2000). A validation of the subjective vitality scale using structural equation modeling. *Social Indicators Research*, *52*(3), 313-324.

Bretland, R. J., & Thorsteinsson, E. B. (2015). Reducing workplace burnout: The relative benefits of cardiovascular and resistance exercise. *PeerJ*, *3*, e891.

Bryk, A. S., & Raudenbush, S. W. (1992). *Hierarchical linear models: Applications and data analysis methods*. SAGE Publications, Sage CA: Los Angeles, CA.

Caspersen, C. J., Powell, K. E., & Christenson, G. M. (1985). Physical activity, exercise, and physical fitness: definitions and distinctions for health-related research. *Public Health Rep*, *100*(2), 126-131. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1424733/pdf/pubhealthrep00100-0016.pdf

Cheval, B., Sivaramakrishnan, H., Maltagliati, S., Fessler, L., Forestier, C., Sarrazin, P., Orsholits, D., Chalabaev, A., Sander, D., & Ntoumanis, N. (2021). Relationships between changes in self-reported physical activity, sedentary behaviour and health during the coronavirus (COVID-19) pandemic in France and Switzerland. *Journal of Sports Sciences*, *39*(6), 699-704.

Chung, K.-F., Yu, B. Y.-M., Yung, K.-P., Yeung, W.-F., Ng, T. H., & Ho, F. Y.-Y. (2014). Assessment of fatigue using the Multidimensional Fatigue Inventory in patients with major depressive disorder. *Comprehensive Psychiatry*, *55*(7), 1671-1678. https://www.sciencedirect.com/science/article/abs/pii/S0010440X14001564?via%3Dihub

Conn, V. S. (2010). Depressive symptom outcomes of physical activity interventions: meta-analysis findings. *Annals of Behavioral Medicine*, *39*(2), 128-138.

Constandt, B., Thibaut, E., De Bosscher, V., Scheerder, J., Ricour, M., & Willem, A. (2020). Exercising in Times of Lockdown: An Analysis of the Impact of COVID-19 on Levels and Patterns of Exercise among Adults in Belgium. *International Journal of Environmental Research and Public Health*, *17*(11), 4144. https://www.mdpi.com/1660-4601/17/11/4144

Costantini, E. (2018). *R-squared measures in Multilevel Modelling: The undesirable property of negative R-squared values* Manuscript submitted for publication

Craig, C. L., Marshall, A. L., Sjöström, M., Bauman, A. E., Booth, M. L., Ainsworth, B. E., Pratt, M., Ekelund, U., Yngve, A., & Sallis, J. F. (2003). International physical activity questionnaire: 12-country reliability and validity. *Medicine and Science in Sports and Exercise*, *35*(8), 1381-1395.

Cross, T. J., Isautier, J. M., Stamatakis, E., Morris, S. J., Johnson, B. D., Wheatley-Guy, C., & Taylor, B. J. (2021). Self-reported physical activity before a COVID-19 ‘lockdown’: is it just a matter of opinion? *BMJ Open Sport & Exercise Medicine*, *7*(2), e001088.

Curran, P. J., & Bauer, D. J. (2011). The disaggregation of within-person and between-person effects in longitudinal models of change. *Annual Review of Psychology*, *62*, 583.

de Vries, J. D., van Hooff, M. L., Geurts, S. A., & Kompier, M. A. (2016). Exercise as an intervention to reduce study-related fatigue among university students: A two-arm parallel randomized controlled trial. *PloS One*, *11*(3), e0152137. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4816334/pdf/pone.0152137.pdf

Deng, N., Guyer, R., & Ware, J. E. (2015). Energy, fatigue, or both? A bifactor modeling approach to the conceptualization and measurement of vitality. *Quality of Life Research*, *24*(1), 81-93. https://link.springer.com/article/10.1007/s11136-014-0839-9

Dewa, L. H., Crandell, C., Choong, E., Jaques, J., Bottle, A., Kilkenny, C., Lawrence-Jones, A., Di Simplicio, M., Nicholls, D., & Aylin, P. (2021). CCopeY: a mixed-methods coproduced study on the mental health status and coping strategies of young people during COVID-19 UK lockdown. *Journal of Adolescent Health*, *68*(4), 666-675.

Dishman, R. K., Washburn, R., & Schoeller, D. (2006). Measurement of physical activity. *Active Living, Cognitive Functioning, and Aging*, *1*, 91-112.

Doerr, J. M., Fischer, S., Nater, U. M., & Strahler, J. (2017). Influence of stress systems and physical activity on different dimensions of fatigue in female fibromyalgia patients. *Journal of*

Psychosomatic Research, *93*, 55-61. https://www.sciencedirect.com/science/article/abs/pii/S0022399916305748?via%3Dihub

Egan, K. P. (2019). Supporting mental health and well-being among student-athletes. *Clinics in Sports Medicine*, *38*(4), 537-544.

Ellingson, L. D., Kuffel, A. E., Vack, N. J., & Cook, D. B. (2014). Active and sedentary behaviors influence feelings of energy and fatigue in women. *Medicine and Science in Sports and Exercise*, *46*(1), 192-200.

Elliot, C., Lang, C., Brand, S., Holsboer-Trachsler, E., Pühse, U., & Gerber, M. (2015). The relationship between meeting vigorous physical activity recommendations and burnout symptoms among adolescents: an exploratory study with vocational students. *Journal of Sport and Exercise Psychology*, *37*(2), 180-192. https://journals.humankinetics.com/view/journals/jsep/37/2/article-p180.xml

Engberg, I., Segerstedt, J., Waller, G., Wennberg, P., & Eliasson, M. (2017). Fatigue in the general population-associations to age, sex, socioeconomic status, physical activity, sitting time and self-rated health: the northern Sweden MONICA study 2014. *BMC Public Health*, *17*(1), 654.

Evans, S., Alkan, E., Bhangoo, J. K., Tenenbaum, H., & Ng-Knight, T. (2021). Effects of the COVID-19 lockdown on mental health, wellbeing, sleep, and alcohol use in a UK student sample. *Psychiatry Research*, *298*, 113819.

Facer-Childs, E. R., Hoffman, D., Tran, J. N., Drummond, S. P., & Rajaratnam, S. M. (2021). Sleep and mental health in athletes during COVID-19 lockdown. *Sleep*, *44*(5), zsaa261.

Faulkner, G., Rhodes, R. E., Vanderloo, L. M., Chulak-Bozer, T., O'Reilly, N., Ferguson, L., & Spence, J. C. (2020). Physical activity as a coping strategy for mental health due to the COVID-19 virus: a potential disconnect among Canadian adults? *Frontiers in Communication*, *5*, 571833.

Field, T., Mines, S., Poling, S., Diego, M., Bendell, D., & Veazey, C. (2021). COVID-19 lockdown fatigue. *American Journal of Psychiatric Research and Reviews*, *4*(1), 27-27.

Flueckiger, L., Lieb, R., Meyer, A. H., Witthauer, C., & Mata, J. (2016). The importance of physical activity and sleep for affect on stressful days: Two intensive longitudinal studies. *Emotion*, *16*(4), 488.

Gaber, T. (2021). Assessment and management of post-COVID fatigue. *Progress in Neurology and Psychiatry*, *25*(1), 36-39.

Gerber, M., Best, S., Meerstetter, F., Walter, M., Ludyga, S., Brand, S., Bianchi, R., Madigan, D. J., Isoard-Gautheur, S., & Gustafsson, H. (2018). Effects of stress and mental toughness on burnout and depressive symptoms: A prospective study with young elite athletes. *Journal of Science and Medicine in Sport*, *21*(12), 1200-1205. https://www.jsams.org/article/S1440-2440(18)30170-1/fulltext

Gerber, M., Brand, S., Elliot, C., Holsboer-Trachsler, E., & Pühse, U. (2014). Aerobic exercise, ball sports, dancing, and weightlifting as moderators of the relationship between Stress and depressive symptoms: An exploratory Cross-sectional study with Swiss university students.

Perceptual and Motor Skills, *119*(3), 679-697. https://journals.sagepub.com/doi/10.2466/06.PMS.119c26z4?url_ver=Z39.88-2003&rfr_id=ori:rid:crossref.org&rfr_dat=cr_pub%3dpubmed

Gerber, M., Brand, S., Herrmann, C., Colledge, F., Holsboer-Trachsler, E., & Pühse, U. (2014). Increased objectively assessed vigorous-intensity exercise is associated with reduced stress, increased mental health and good objective and subjective sleep in young adults. *Physiology & Behavior*, *135*, 17-24.

Gerber, M., Lang, C., Feldmeth, A. K., Elliot, C., Brand, S., Holsboer-Trachsler, E., & Pühse, U. (2015). Burnout and mental health in Swiss vocational students: the moderating role of physical activity. *Journal of Research on Adolescence*, *25*(1), 63-74.

Giuntella, O., Hyde, K., Saccardo, S., & Sadoff, S. (2021). Lifestyle and mental health disruptions during COVID-19. *Proceedings of the National Academy of Sciences*, *118*(9).

Graupensperger, S., Jaffe, A. E., Fleming, C. N., Kilmer, J. R., Lee, C. M., & Larimer, M. E. (2021). Changes in college student alcohol use during the COVID-19 pandemic: Are perceived drinking norms still relevant? *Emerging Adulthood*, *9*(5), 531-540.

Grubic, N., Jain, S., Mihajlovic, V., Thornton, J. S., & Johri, A. M. (2021). Competing against COVID-19: have we forgotten about student-athletes' mental health? In: BMJ Publishing Group Ltd and British Association of Sport and Exercise Medicine.

Haas, P., Schmid, J., Stadler, G., Reuter, M., & Gawrilow, C. (2017). Zooming into daily life: Within-person associations between physical activity and affect in young adults. *Psychology & Health*, *32*(5), 588-604.

Haghighi, M., & Gerber, M. (2019). Does mental toughness buffer the relationship between perceived stress, depression, burnout, anxiety, and sleep? *International Journal of Stress Management*, *26*(3), 297.

Hagiwara, G., Tsunokawa, T., Iwatsuki, T., Shimozono, H., & Kawazura, T. (2021). Relationships among student-athletes' identity, mental health, and social support in Japanese student-athletes during the COVID-19 pandemic. *International Journal of Environmental Research and Public Health*, *18*(13), 7032.

Harrington, M. E. (2012). Neurobiological studies of fatigue. *Progress in Neurobiology*, *99*(2), 93-105. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3479364/pdf/nihms396650.pdf

Hegarty, R. S., Conner, T. S., Stebbings, S., & Treharne, G. J. (2015). Feel the fatigue and be active anyway: physical activity on high-fatigue days protects adults with arthritis from decrements in same-day positive mood. *Arthritis Care & Research*, *67*(9), 1230-1236.

Hoffman, L. (2015). *Longitudinal analysis: Modeling within-person fluctuation and change*. Routledge.

Hoffman, L., & Stawski, R. S. (2009). Persons as contexts: Evaluating between-person and within-person effects in longitudinal analysis. *Research in Human Development*, *6*(2-3), 97-120.

Ingram, J., Maciejewski, G., & Hand, C. J. (2020). Changes in diet, sleep, and physical activity are associated with differences in negative mood during COVID-19 lockdown. *Frontiers in Psychology*, *11*, 23-28.

John Hopkins Medicine. (2022). *Coronavirus UK Overview*. Retrieved 18/08/22 from https://coronavirus.jhu.edu/region/united-kingdom

Karshikoff, B., Sundelin, T., & Lasselin, J. (2017). Role of inflammation in human fatigue: relevance of multidimensional assessments and potential neuronal mechanisms. *Frontiers in Immunology*, *8*, 21. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5247454/pdf/fimmu-08-00021.pdf

Kennedy, M. D., Tamminen, K. A., & Holt, N. L. (2013). Factors that influence fatigue status in Canadian university swimmers. *Journal of Sports Sciences*, *31*(5), 554-564.

Kocalevent, R. D., Hinz, A., Brähler, E., & Klapp, B. F. (2011). Determinants of fatigue and stress. *BMC Research Notes*, *4*(1), 1-5.

Koschel, T. L., Young, J. C., & Navalta, J. W. (2017). Examining the impact of a university-driven exercise programming event on end-of-semester stress in students. *International Journal of Exercise Science*, *10*(5), 754. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5609663/pdf/ijes-10-05-754.pdf

Labrague, L. J., & De los Santos, J. A. A. (2020). COVID-19 anxiety among front-line nurses: Predictive role of organisational support, personal resilience and social support. *Journal of Nursing Management*, *28*(7), 1653-1661.

Lavrusheva, O. (2020). The concept of vitality. Review of the vitality-related research domain. *New Ideas in Psychology*, *56*, 100752.

Liao, Y., Chou, C.-P., Huh, J., Leventhal, A., & Dunton, G. (2017). Associations of affective responses during free-living physical activity and future physical activity levels: an ecological momentary assessment study. *International Journal of Behavioral Medicine*, *24*(4), 513-519.

Lindegård, A., Jonsdottir, I. H., Börjesson, M., Lindwall, M., & Gerber, M. (2015). Changes in mental health in compliers and non-compliers with physical activity recommendations in patients with stress-related exhaustion. *BMC Psychiatry*, *15*(1), 1-10.

Loy, B. D., O'Connor, P. J., & Dishman, R. K. (2013). The effect of a single bout of exercise on energy and fatigue states: a systematic review and meta-analysis. *Fatigue: Biomedicine, Health & Behavior*, *1*(4), 223-242.

Maher, J. P., Doerksen, S. E., Elavsky, S., Hyde, A. L., Pincus, A. L., Ram, N., & Conroy, D. E. (2013). A daily analysis of physical activity and satisfaction with life in emerging adults. *Health Psychology*, *32*(6), 647.

Marcora, S. M., Staiano, W., & Manning, V. (2009). Mental fatigue impairs physical performance in humans. *Journal of Applied Physiology*, *106*(3), 857-864. https://journals.physiology.org/doi/pdf/10.1152/japplphysiol.91324.2008

Margaritis, I., Houdart, S., El Ouadrhiri, Y., Bigard, X., Vuillemin, A., & Duché, P. (2020). How to deal with COVID-19 epidemic-related lockdown physical inactivity and sedentary increase in youth? Adaptation of Anses' benchmarks. *Archives of Public Health*, *78*(1), 1-6.

Marques, A., Peralta, M., Martins, J., Catunda, R., de Matos, M. G., & Nunes, L. S. (2016). Associations between physical activity and self-rated wellbeing in European adults: a population-based, cross-sectional study. *Preventive Medicine*, *91*, 18-23.

Martínez-González, N., Atienza, F. L., Tomás, I., Duda, J. L., & Balaguer, I. (2021). The Impact of Coronavirus Disease 2019 Lockdown on Athletes' Subjective Vitality: The Protective Role of Resilience and Autonomous Goal Motives. *Frontiers in Psychology*, *11*, 4061.

Maugeri, G., Castrogiovanni, P., Battaglia, G., Pippi, R., D'Agata, V., Palma, A., Di Rosa, M., & Musumeci, G. (2020). The impact of physical activity on psychological health during Covid-19 pandemic in Italy. *Heliyon*, *6*(6), e04315.

Meeus, M., Van Eupen, I., Willems, J., Kos, D., & Nijs, J. (2011). Is the International Physical Activity Questionnaire-short form (IPAQ-SF) valid for assessing physical activity in Chronic Fatigue Syndrome? *Disability and Rehabilitation*, *33*(1), 9-16.

Meo, S. A., Abukhalaf, A. A., Alomar, A. A., Sattar, K., & Klonoff, D. C. (2020). COVID-19 pandemic: impact of quarantine on medical students' mental wellbeing and learning behaviors. *Pakistan Journal of Medical Sciences*, *36*(COVID19-S4), S43.

Michie, S., West, R., & Harvey, N. (2020). The concept of "fatigue" in tackling covid-19. *BMJ*, *371*.

Mills, R., & Young, C. (2008). A medical definition of fatigue in multiple sclerosis. *QJM: An International Journal of Medicine*, *101*(1), 49-60.

Moradian, S., Bäuerle, A., Schweda, A., Musche, V., Kohler, H., Fink, M., Weismüller, B., Benecke, A.-V., Dörrie, N., & Skoda, E.-M. (2021). Differences and similarities between the impact of the first and the second COVID-19-lockdown on mental health and safety behaviour in Germany. *Journal of Public Health (Oxford, England)*.

Morgan, J. A., Olagunju, A. T., Corrigan, F., & Baune, B. T. (2018). Does ceasing exercise induce depressive symptoms? A systematic review of experimental trials including immunological and neurogenic markers. *Journal of Affective Disorders*, *234*, 180-192.

Morgul, E., Bener, A., Atak, M., Akyel, S., Aktaş, S., Bhugra, D., Ventriglio, A., & Jordan, T. R. (2020). COVID-19 pandemic and psychological fatigue in Turkey. *The International Journal of Social Psychiatry*.

Mota, D. D., & Pimenta, C. A. (2006). Self-report instruments for fatigue assessment: a systematic review. *Research and Theory for Nursing Practice*, *20*(1), 49-78. https://connect.springerpub.com/content/sgrrtnp/20/1/49

Muñoz-Bullón, F., Sanchez-Bueno, M. J., & Vos-Saz, A. (2017). The influence of sports participation on academic performance among students in higher education. *Sport Management Review*, *20*(4), 365-378.

Murphy, J. J., Murphy, M. H., MacDonncha, C., Murphy, N., Nevill, A. M., & Woods, C. B. (2017). Validity and reliability of three self-report instruments for assessing attainment of physical activity guidelines in university students. *Measurement in Physical Education and Exercise Science*, *21*(3), 134-141.

Mutz, M. (2021). Forced adaptations of sporting behaviours during the Covid-19 pandemic and their effects on subjective well-being. *European Societies*, *23*(sup1), S184-S198.

Nelson, M. C., Taylor, K., & Vella, C. A. (2019). Comparison of self-reported and objectively measured sedentary behavior and physical activity in undergraduate students. *Measurement in Physical Education and Exercise Science*.

O'Connor, P. J., & Puetz, T. W. (2005). Chronic physical activity and feelings of energy and fatigue. *Medicine and Science in Sports and Exercise*, *37*(2), 299-305.

Paolucci, E. M., Loukov, D., Bowdish, D. M., & Heisz, J. J. (2018). Exercise reduces depression and inflammation but intensity matters. *Biological Psychology*, *133*, 79-84.

Pascoe, M., Bailey, A. P., Craike, M., Carter, T., Patten, R., Stepto, N., & Parker, A. (2020). Physical activity and exercise in youth mental health promotion: A scoping review. *BMJ Open Sport & Exercise Medicine*, *6*(1), e000677.

Presti, S. L., Mattavelli, G., Canessa, N., & Gianelli, C. (2021). Psychological precursors of individual differences in COVID-19 lockdown adherence: Moderated-moderation by personality and moral cognition measures. *Personality and Individual Differences*, *182*, 111090.

Puetz, T. W. (2006). Physical activity and feelings of energy and fatigue. *Sports Medicine*, *36*(9), 767-780. https://link.springer.com/article/10.2165%2F00007256-200636090-00004

Puetz, T. W. (2012). The Differential Effects of Exercise on Cancer-Related Fatigue in Cancer Patients During and Following Treatment: A Systematic Review and Meta-Analysis of Randomized Controlled Trials.

Puetz, T. W., Flowers, S. S., & O’Connor, P. J. (2008). A randomized controlled trial of the effect of aerobic exercise training on feelings of energy and fatigue in sedentary young adults with persistent fatigue. *Psychotherapy and Psychosomatics*, *77*(3), 167-174.

Puetz, T. W., O'Connor, P. J., & Dishman, R. K. (2006). Effects of chronic exercise on feelings of energy and fatigue: a quantitative synthesis. *Psychological Bulletin*, *132*(6), 866.

Raudenbush, S. W., & Bryk, A. S. (2002). *Hierarchical linear models: Applications and Data Analysis Methods* (Vol. 1). Sage. SAGE Publications Sage CA: Los Angeles, CA.

Reicher, S., & Drury, J. (2021). Pandemic fatigue? How adherence to covid-19 regulations has been misrepresented and why it matters. *BMJ*, *372*.

Robinson, E., Boyland, E., Chisholm, A., Harrold, J., Maloney, N. G., Marty, L., Mead, B. R., Noonan, R., & Hardman, C. A. (2021). Obesity, eating behavior and physical activity during COVID-19 lockdown: A study of UK adults. *Appetite*, *156*, 104853.

Rogowska, A. M., Pavlova, I., Kuśnierz, C., Ochnik, D., Bodnar, I., & Petrytsa, P. (2020). Does physical activity matter for the mental health of university students during the COVID-19 pandemic? *Journal of Clinical Medicine*, *9*(11), 3494.

Russell, W. D. (2021). The Role of Athletic Identity and Perceived Social Support on College Female Athletes' Burnout. *Journal of Sport Behavior*, *44*(1).

Ryan, R. M., & Frederick, C. (1997). On energy, personality, and health: Subjective vitality as a dynamic reflection of well-being. *Journal of Personality*, *65*(3), 529-565. https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1467-6494.1997.tb00326.x?sid=nlm%3Apubmed

Sandvik, E., Diener, E., & Seidlitz, L. (2009). Subjective Well-Being: The Convergence and Stability of Self-Report and Non-Self-Report Measures. In E. Diener (Ed.), *Assessing Well-Being: The Collected Works of Ed Diener* (pp. 119-138). Springer Netherlands. https://doi.org/10.1007/978-90-481-2354-4_6

Savage, M. J., James, R., Magistro, D., Donaldson, J., Healy, L. C., Nevill, M., & Hennis, P. J. (2020). Mental health and movement behaviour during the COVID-19 pandemic in UK university students: Prospective cohort study. *Mental Health and Physical Activity*, *19*, 100357.

Schneider, R. A. (1998). Concurrent validity of the Beck depression inventory and the multidimensional fatigue inventory–20 in assessing fatigue among cancer patients. *Psychological Reports*, *82*(3), 883-886.

Scholz, U., Nagy, G., Schüz, B., & Ziegelmann, J. P. (2008). The role of motivational and volitional factors for self-regulated running training: Associations on the between-and within-person level. *British Journal of Social Psychology*, *47*(3), 421-439.

Smets, E., Garssen, B., Bonke, B. d., & De Haes, J. (1995). The Multidimensional Fatigue Inventory (MFI) psychometric qualities of an instrument to assess fatigue. *Journal of Psychosomatic Research*, *39*(3), 315-325. https://www.sciencedirect.com/science/article/abs/pii/002239999400125O?via%3Dihub

Smith, A. P. (2018). Cognitive fatigue and the well-being and academic attainment of university students. *Journal of Education, Society and Behavioral Science.*

Snijders, T. A., & Bosker, R. J. (1994). Modeled variance in two-level models. *Sociological Methods & Research*, *22*(3), 342-363.

Spence, J. C., Rhodes, R. E., McCurdy, A., Mangan, A., Hopkins, D., & Mummery, W. K. (2021). Determinants of physical activity among adults in the United Kingdom during the COVID-19 pandemic: The DUK-COVID study. *British Journal of Health Psychology*, *26*(2), 588-605.

Stanton, R., To, Q. G., Khalesi, S., Williams, S. L., Alley, S. J., Thwaite, T. L., Fenning, A. S., & Vandelanotte, C. (2020). Depression, anxiety and stress during COVID-19: associations with changes in physical activity, sleep, tobacco and alcohol use in Australian adults. *International Journal of Environmental Research and Public Health*, *17*(11), 4065.

Strahler, J., Doerr, J. M., Ditzen, B., Linnemann, A., Skoluda, N., & Nater, U. M. (2016). Physical activity buffers fatigue only under low chronic stress. *Stress*, *19*(5), 535-541. https://www.tandfonline.com/doi/full/10.1080/10253890.2016.1192121

Taaffe, D. R., Newton, R. U., Spry, N., Joseph, D., Chambers, S. K., Gardiner, R. A., Wall, B. A., Cormie, P., Bolam, K. A., & Galvao, D. A. (2017). Effects of different exercise modalities on fatigue in prostate cancer patients undergoing androgen deprivation therapy: a year-long randomised controlled trial. *European Urology*, *72*(2), 293-299. https://api.research-repository.uwa.edu.au/files/31507804/Taaffe_et_al._2017_Effects_on_different.pdf

Taylor, R., Jason, L. A., & Torres, A. (2000). Fatigue rating scales: an empirical comparison. *Psychological Medicine*, *30*(4), 849-856.

Ter Wolbeek, M., Van Doornen, L. J., Kavelaars, A., & Heijnen, C. J. (2006). Severe fatigue in adolescents: a common phenomenon? *Pediatrics*, *117*(6), e1078-e1086. https://pediatrics.aappublications.org/content/117/6/e1078.long

Toresdahl, B. G., & Asif, I. M. (2020). Coronavirus disease 2019 (COVID-19): considerations for the competitive athlete. In: SAGE Publications Sage CA: Los Angeles, CA.

UK Government. (2022). *Coronavirus (COVID-19) in the UK*. Retrieved from https://coronavirus.data.gov.uk/

Uddin, R., Burton, N. W., & Khan, A. (2020). Combined effects of physical inactivity and sedentary behaviour on psychological distress among university-based young adults: a one-year prospective study. *Psychiatric Quarterly*, *91*(1), 191-202.

Uroh, C. C., & Adewunmi, C. M. (2021). Psychological Impact of the COVID-19 Pandemic on Athletes [Original Research]. *Frontiers in Sports and Active Living*, *3*(78). https://doi.org/10.3389/fspor.2021.603415

van Zyl, L. E., Rothmann, S., & Zondervan-Zwijnenburg, M. A. (2021). Longitudinal trajectories of study characteristics and mental health before and during the COVID-19 lockdown. *Frontiers in Psychology*, *12*, 349.

Wang, F., & Boros, S. (2019). The relationship between physical activity, stress, life satisfaction and sleep quality. *Journal of Physical Education and Sport*, *19*, 227-234.

Weinstein, A. A., Koehmstedt, C., & Kop, W. J. (2017). Mental health consequences of exercise withdrawal: A systematic review. *General Hospital Psychiatry*, *49*, 11-18.

World Health Organisation. (2020). Guidelines on physical activity and sedentary behaviour. Geneva, Switzerland: WHO.

Williamson, R. J., Purcell, S., Sterne, A., Wessely, S., Hotopf, M., Farmer, A., & Sham, P. C. (2005). The relationship of fatigue to mental and physical health in a community sample. *Social Psychiatry and Psychiatric Epidemiology*, *40*(2), 126-132.

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.

Wunsch, K., Kasten, N., & Fuchs, R. (2017). The effect of physical activity on sleep quality, well-being, and affect in academic stress periods. *Nature and Science of Sleep*, *9*, 117. https://www.dovepress.com/front_end/cr_data/cache/pdf/download_1610548785_5fff06310f6f8/NSS-132078-feel-good--sleep-good------examining-the-effect-of-physical-_042617.pdf

Xu, F., Liu, W., Rose Chepyator-Thomson, J., & Schmidlein, R. (2018). Relations of physical activity and stress vulnerability in university students. *College Student Journal*, *52*(1), 65-73.

Zhang, X., Zhu, W., Kang, S., Qiu, L., Lu, Z., & Sun, Y. (2020). Association between physical activity and mood states of children and adolescents in social isolation during the COVID-19 epidemic. *International Journal of Environmental Research and Public Health*, *17*(20), 7666.

Appendix 1: Participant Consent Form

Consent Form *

Statement	Select to consent
I confirm that I have read and understand the information sheet I was provided and have had the opportunity to ask questions.	☐
All questions have been answered to my satisfaction.	☐
I understand that my participation is voluntary and that I am free to withdraw at any time up to two weeks after completing the questionnaire pack without giving any reason or my rights being affected.	☐
I consent to participating in the study.	☐
I give consent for the data that I provide to be used for research purposes.	☐
I am happy to receive information about the opportunity for further participation listed in the information sheet.	☐

2. I confirm that I agree to take part in the study (please type first name in the box below) *

Appendix 2: Questionnaires

Demographics

. What is your gender? *

☐ Male

☐ Female

☐ Other

☐ Prefer not to say

7. If other, please specify:

How old are you(years)? *

What year of study are you in? *

MFI-20

We would like to get an idea of how you have been feeling in the last month. Please read each statement and then use the rating scale to indicate how true each statement is. *

	No, that is not true				Yes, that is true	Prefer not to answer
I feel fit	☐	☐	☐	☐	☐	☐
Physically I feel only able to do a little	☐	☐	☐	☐	☐	☐
I feel very active	☐	☐	☐	☐	☐	☐
I feel like doing all sorts of nice things	☐	☐	☐	☐	☐	☐

	No, that is not true				Yes, that is true	Prefer not to answer
I feel tired	☐	☐	☐	☐	☐	☐
I think I do a lot in a day	☐	☐	☐	☐	☐	☐
When I am doing something, I can keep my thoughts on it	☐	☐	☐	☐	☐	☐
Physically I can take on a lot of things	☐	☐	☐	☐	☐	☐
I dread having to do things	☐	☐	☐	☐	☐	☐
I think I do very little in a day	☐	☐	☐	☐	☐	☐
I can concentrate well	☐	☐	☐	☐	☐	☐
I am rested	☐	☐	☐	☐	☐	☐
It takes a lot of effort to concentrate on things	☐	☐	☐	☐	☐	☐
Physically I feel I am in bad condition	☐	☐	☐	☐	☐	☐
I have a lot of plans	☐	☐	☐	☐	☐	☐
I tire easily	☐	☐	☐	☐	☐	☐
I get little done	☐	☐	☐	☐	☐	☐
I don’t feel like doing anything	☐	☐	☐	☐	☐	☐
My thoughts easily wander	☐	☐	☐	☐	☐	☐
Physically I feel I am in excellent condition	☐	☐	☐	☐	☐	☐

SVS

Please respond to each of the following statements by indicating the degree to which the statement is true for you in the last month. *

	Not at all true			Somewhat true			Very true	Prefer not to answer
I feel full of excitement	☐	☐	☐	☐	☐	☐	☐	☐
I have high spirits	☐	☐	☐	☐	☐	☐	☐	☐
I look forward to each day	☐	☐	☐	☐	☐	☐	☐	☐
I nearly always feel alert and awake	☐	☐	☐	☐	☐	☐	☐	☐
I feel I have a lot of energy	☐	☐	☐	☐	☐	☐	☐	☐

IPAQ

During the last 7 days, on how many days did you do vigorous physical activities like heavy lifting, digging, aerobics, or fast bicycling for at least 10 minutes at a time? *

☐ 0

☐ 1

☐ 2

☐ 3

☐ 4

☐ 5

☐ 6

☐ 7

☐ Prefer not to answer

How much time in total did you usually spend on one of those days doing vigorous physical activities?

Hours ☐

Minutes ☐

During the last 7 days, on how many days did you do moderate physical activities like carrying light loads, bicycling at a regular pace, or doubles tennis for at least 10 minutes at a time? Do not include walking. *

- ☐ 0
- ☐ 1
- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5
- ☐ 6
- ☐ 7
- ☐ Prefer not to answer

How much time in total did you usually spend on one of those days doing moderate physical activities? Do not include walking.

Hours ☐

Minutes ☐

During the last 7 days, on how many days did you do light physical activities like archery or hanging out the washing for at least 10 minutes at a time? Do not include walking. *

- [ ] 0
- [ ] 1
- [ ] 2
- [ ] 3
- [ ] 4
- [ ] 5
- [ ] 6
- [ ] 7
- [ ] Prefer not to answer

How much time in total did you usually spend on one of those days doing light physical activities? Do not include walking

Hours ____________

Minutes ____________

During the last 7 days, on how many days did you walk for at least 10 minutes at a time? This includes walking at work and at home, walking to travel from place to place, and any other walking that you did solely for recreation, sport, exercise or leisure. *

- [ ] 0
- [ ] 1
- [ ] 2
- [ ] 3
- [ ] 4
- [ ] 5

- [ ] 6
- [ ] 7
- [ ] Prefer not to answer

How much time in total did you usually spend walking on one of those days?

Hours [ ]

Minutes [ ]