Development and Evaluation of the PEAK Program: a Health Behaviour Change Intervention to Support University Students' Mental and Cognitive Health through Physical Exercise

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This thesis is submitted in partial fulfilment of the requirements for the degree of

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LIST OF ABBREVIATIONS

AI	Artificial Intelligence
APEASE	Affordability, Practicability, Effectiveness/cost-effectiveness, Acceptability, Side-effects/safety, Equity
BCT	Behaviour Change Technique
BCTTv1	Behaviour Change Technique Taxonomy Version 1
BCW	Behaviour Change Wheel
BDNF	Brain-derived Neurotrophic Factor
CELMT	Campaign to End Loneliness Measurement Tool
COM-B	Capability, Opportunity, Model-Behaviour
IGF-1	Insulin-like Growth Factor 1
IPAQ	International Physical Activity Questionnaire
K10	Kessler Psychological Distress Scale
MRC	Medical Research Council
NICE	National Institute for Health and Care Excellence
PA	Physical Activity
PEAK	PEAK Mood, Mind, and Marks Program
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PROSPERO	International Prospective Register of Systematic Reviews
PSS-4	Perceived Stress Scale 4
SPSS	Statistical Package for Social Sciences
SWEMWBS	Short Warwick-Edinburgh Mental Wellbeing Scale
TDF	Theoretical Domains Framework
TIDieR	Template for Intervention Description and Replication
VAS	Visual Analogue Scales

ABSTRACT

The high prevalence of mental and cognitive health challenges among university students has adverse impacts on their quality of life. Engaging in regular physical exercise has demonstrable mental and cognitive health benefits, yet most students are not participating in the level of exercise required to obtain these benefits. Understanding students' barriers and facilitators to exercise in the context of behaviour change theory is valuable to inform the development of effective evidence-based interventions. The Behaviour Change Wheel (BCW) provides a framework for understanding the factors that influence students' engagement in exercise to develop an intervention informed by theory, evidence, and stakeholder perspectives. The primary aims of this PhD were to identify the determinants of students' engagement in exercise and use the BCW to develop and pilot the PEAK Mood, Mind and Marks program (i.e., PEAK), an intervention designed to engage students in three or more exercise sessions per week for the benefit of their mental and cognitive health.

A systematic literature review was conducted to identify the barriers and facilitators to university students' participation in physical activity, including exercise. Focus groups with university students (n = 25) and semi-structured interviews with university staff (n = 10) were then conducted and the BCW process was applied to identify the most appropriate intervention types and behaviour change techniques (BCTs) to increase students' engagement in exercise. This process led to the development of PEAK, a multicomponent intervention delivered across digital channels and in-person activities targeting students' capability (e.g., increasing knowledge about the mental and cognitive health benefits of exercise), opportunity (e.g., providing a flexible range of accessible exercise options and social support), and motivation (e.g., increasing the perceived importance of exercise) to exercise. A mixed-methods quasi-experimental pilot study was subsequently conducted to assess the impact of PEAK. Quantitative methods were used to assess students' (n = 115) exercise activity (i.e.,

weekly exercise frequency and duration, engagement in moderate to vigorous exercise, and sedentary behaviour at baseline and end-point), perceived mental and cognitive health, and engagement in PEAK. Qualitative interviews were conducted with 15 students to assess factors that influenced students' engagement in PEAK, the acceptability and appropriateness of the program, and mechanisms of behaviour change.

Findings from this thesis identified 31 barriers and facilitators to students' participation in exercise, and seven intervention types (Education; Modelling; Persuasion; Environmental Restructuring; Incentivisation; Training; and Enablement) and 26 BCTs to increase students' engagement in exercise. Students and staff felt PEAK provided a proactive, strengths-based approach to authentically support students' mental and cognitive health. On average, 48.4% of students engaged in the recommended frequency of three or more exercise sessions per week. This proportion decreased towards the end of PEAK. Mental and cognitive outcomes significantly improved. Students identified numerous areas PEAK's content and implementation can be optimised (e.g., use of a single digital delivery platform, more opportunities to connect with peers, and expanding the culturally inclusive program content).

This thesis provides a novel understanding of the key factors influencing students' engagement in exercise and identifies how to address these using best practice approaches to behavioural intervention development. The findings lay the groundwork to inform further research and program development to optimise an effective, engaging, scalable, and sustainable exercise intervention to enhance the mental and cognitive health of university students globally by enabling their lifelong healthy exercise habits.

SUMMARY OF RESEARCH OUTPUTS AND COMMUNICATIONS

Publications arising from this PhD research

1. **Brown, CEB.**, Richardson, K., Halil-Pizzirani, B., Atkins, L., Yücel, M., & Segrave, R. Key Influences on University Students' Physical Activity: a Systematic Review Using the Theoretical Domains Framework and the COM-B Model of Human Behaviour (2024). BMC Public Health. (in press)
2. **Brown, CEB.**, Richardson, K., Halil-Pizzirani, B., Hughes, S., Perowne, R., Pitt, J., Atkins, L., Yücel, M., & Segrave, R. (2024). PEAK Mood, Mind and Marks: Development of an Intervention to Support University Students' Mental and Cognitive Health through Physical Exercise. BMC Public Health. (in review)
3. **Brown, CEB.**, Richardson, K., Halil-Pizzirani, B., Hughes, S., Atkins, L., Pitt, J., Yücel, M., & Segrave, R. (2024). PEAK Mood, Mind and Marks: a Pilot Study of an Intervention to Support University Students' Mental and Cognitive Health through Physical Exercise. Frontiers in Psychiatry. (in review)

Conference presentations arising from this PhD research

1. **Brown, CEB.**, Richardson, K., Halil-Pizzirani, B., Hughes, S., Perowne, R., Pitt, J., Atkins, L., Yücel, M., & Segrave, R. PEAK Mood, Mind and Marks: Development of an Intervention to Support University Students' Mental and Cognitive Health through Physical Exercise. Poster Presentation at the European Health Psychology Society, Bremen, Germany. September 2023.
2. **Brown, CEB.**, Richardson, K., Halil-Pizzirani, B., Hughes, S., Atkins, L., Pitt, J., Yücel, M., & Segrave, R. PEAK Mood, Mind and Marks: a Pilot Study of an Intervention to Support University Students' Mental and Cognitive Health through

Physical Exercise. Poster Presentation at the European Health Psychology Society, Bremen, Germany. September 2023.

Other published works arising during this PhD candidature

1. Chung, O., Dowling, N., **Brown, CEB.**, Robinson, T., Johnson, A., Ng, C., Yücel, M., & Segrave, R. (2023). Using the Theoretical Domains Framework to Inform the Implementation of Therapeutic Virtual Reality into Mental Healthcare. Administration and Policy in Mental Health and Mental Health Services Research, 50(2), 237–268. https://doi.org/10.1007/s10488-022-01235-w

Scientific communications during this PhD candidature

1. **Brown, CEB.**, Richardson, K., Hughes, S., & Segrave, R. Linking Exercise and Academic Success. Monash Sport Seminar Series, Monash University, Melbourne, Victoria, Australia. February 2021.

GENERAL DECLARATION

I hereby declare that this thesis contains no material which has been accepted for the award of any other degree or diploma at any university or equivalent institution and that, to the best of my knowledge and belief, this thesis contains no material previously published or written by another person, except where due reference is made in the text of the thesis.

This thesis includes one original paper published in a peer reviewed journal and two submitted publications. The core theme of the thesis is the development and evaluation of an exercise-based intervention to support university students' mental and cognitive health. The ideas, development and writing up of all the papers in the thesis were the principal responsibility of myself, the student, working within the School of Psychological Science, Monash University, under the supervision of Dr. Rebecca Anne Segrave, Dr. Karyn Richardson, and Dr. Bengianni Halil-Pizzirani.

The inclusion of co-authors reflects the fact that the work came from active collaboration between researchers and acknowledges input into team-based research.

In the case of Chapter Four to Six, my contribution to the work involved the following:

Thesis Chapter	**Publication Title**	**Status** *(published, in press, accepted or returned for revision, submitted)*	**Nature and % of student contribution**	**Co-author name(s) Nature and % of Co-author's contribution***	**Co-author(s), Monash student Y/N***
Four	Key Influences on University Students'	In press at BMC Public Health	Catherine Brown; Conceptualisation of the review,	1) Rebecca Segrave: Conceptualisation, funding acquisition, data analysis,	No

	Physical Activity: a Systematic Review Using the Theoretical Domains Framework and the COM-B Model of Human Behaviour		development of the search strategy, article search and extraction, data analysis, and preparation of manuscript, 80%	reviewing and editing manuscript, 6% 2) Karyn Richardson: Conceptualisation, data analysis, reviewing and editing manuscript, 5% 3) Bengianni Halil-Pizzirani: Conceptualisation, article extraction, data analysis, reviewing and editing manuscript, 5% 4) Lou Atkins: Data analysis, reviewing and editing manuscript, 2% 5) Murat Yucel: Funding acquisition, reviewing and editing manuscript, 2%	
Five	PEAK Mood, Mind and Marks: Development of an Intervention to Support University Students' Mental and Cognitive Health through Physical Exercise	In review at BMC Public Health	Catherine Brown; Conceptualisation of study, development, data collection protocol, participant recruitment, execution of experiments, analysis of data, and preparation of manuscript, 80%	1) Rebecca Segrave: Conceptualisation, funding acquisition, protocol development, data collection, reviewing and editing manuscript, 6% 2) Karyn Richardson: Conceptualisation, protocol development, data collection, reviewing and editing manuscript, 5% 3) Bengianni Halil-Pizzirani: Conceptualisation, data collection and analysis, reviewing and editing manuscript, 4%	No

				4) Sam Hughes: 1% 5) Lou Atkins: Reviewing and editing manuscript, 1% 6) Rachel Perowne: Data analysis, reviewing and editing manuscript 7) Joseph Pitt: 1% 8) Murat Yucel: Funding acquisition, reviewing and editing manuscript, 2%	
Six	PEAK Mood, Mind and Marks: a Pilot Study of an Intervention to Support University Students' Mental and Cognitive Health through Physical Exercise	In review at Frontiers in Psychiatry	Catherine Brown; Conceptualisation of study, development, data collection protocol, participant recruitment, execution of experiments, analysis of data, and preparation of manuscript, 80%	1) Rebecca Segrave: Conceptualisation, funding acquisition, protocol development, data collection and analysis, reviewing and editing manuscript, 6% 2) Karyn Richardson: Conceptualisation, protocol development, data collection and analysis, reviewing and editing manuscript, 5% 3) Bengianni Halil-Pizzirani: Conceptualisation, reviewing and editing manuscript, participant recruitment, 3% 4) Sam Hughes: 2% 5) Joseph Pitt: 1% 6) Lou Atkins: Reviewing and editing manuscript, 1% 7) Murat Yucel: Funding acquisition, reviewing and	No

				editing manuscript, 2%	

I have not renumbered sections of submitted or published papers in order to generate a consistent presentation within the thesis.

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I hereby certify that the above declaration correctly reflects the nature and extent of the student's and co-authors' contributions to this work. In instances where I am not the responsible author I have consulted with the responsible author to agree on the respective contributions of the authors.

Main supervisor name: Dr Karyn Elizabeth Richardson

Main supervisor signature: **Date:** 31/01/2024

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To Bec, you have been my main mentor and source of academic wisdom ever since I completed my Honours research seven years ago under your supervision. Our meetings often left me feeling empowered and assured that, under your guidance, no challenge was insurmountable! Thank you for teaching me to think deeply, enabling me to build on my strengths and, above all else, believing in my abilities. To Karyn, thank you for intuitively anticipating when I would need support, often even before I knew I would. Your ability to balance roles as a mother, mentor, academic, and project coordinator, all while extending yourself to help those around you, is nothing short of inspiring. Your emotional attunement, deep compassion, and nurturance has both held our lab together, and inspired my own compassion as a clinician. To Bengianni, your ability to stay anchored to the bigger picture has kept me focused on what matters most and cognisant of the real-world impact of our research. I am particularly grateful for all the phone calls and coffee catch ups we've shared, which have broadened my perspective and encouraged me to continue to make a meaningful contribution to health behaviour change beyond this PhD.

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DOCTORAL PROGRAM OVERVIEW

This thesis forms the major research component of the Doctor of Philosophy (Clinical Psychology) at Monash University, Melbourne, Australia. This is a combined clinical training and research program, which I undertook continuously across February 2020 to January 2024. Therefore, in addition to the research contained within this thesis, I also completed coursework and three clinical placements.

This 'thesis by publication' has been prepared in keeping with Monash University guidelines. As such, sections of this thesis are manuscripts that have been published in or submitted to peer-reviewed journals, thereby differing from more traditional thesis formats. Due to this formatting, there are some instances of repetition of information across chapters.

INTRODUCTION AND THESIS OVERVIEW

The mental and cognitive health of university students plays a pivotal role in their academic success and post-university career prospects. However, a large proportion of students experience difficulties with these aspects of their health. Promoting regular physical exercise has the potential to be an effective and empowering approach to address these concerns. A robust body of evidence demonstrates that engaging in exercise has substantial positive impacts on mental and cognitive health, especially when exercise activities are performed regularly, at moderate to high intensities and incorporate aerobic and resistance exercises. However, despite significant efforts to increase students' physical activity, most are not engaging in the frequency or types of exercise required to achieve these benefits.

Initiating and/or maintaining health behaviours like exercise is challenging. In response to the need to better understand what it takes to change health behaviours, the field of behavioural science continues to rapidly grow. This growth has led to the establishment of best practice principles to inform the development, implementation, and evaluation of successful interventions to change behaviour. These principles include taking a theory-driven, evidence-based approach that incorporates stakeholder perspectives at all stages of the intervention development process. The explicit use of theory allows intervention designers to identify influences on behaviour change (i.e., barriers and facilitators to the behaviour) and to deliver interventions with fidelity. Involving key stakeholders in intervention development is equally important to maximise the acceptability, appropriateness, adoption, and scalability of an intervention.

The Behaviour Change Wheel (BCW) is a gold-standard, theoretically derived framework built on best practice principles for developing behaviour change interventions. The BCW provides a systematic process for intervention development across three stages: 1)

understanding the barriers to and facilitators of the target behaviour in the context of theoretical frameworks of behaviour change (i.e., the COM-B model and/or the Theoretical Domains Framework (TDF), 2) identifying intervention types, and 3) identifying intervention content and delivery mode. Once a behaviour change intervention has been designed it is valuable to conduct small-scale piloting and evaluation of the intervention's behavioural and health impacts and implementation to inform iteration and optimisation. Currently, the BCW has not yet been applied to design a behaviour change intervention to increase students' engagement in regular exercise. Developing and piloting an intervention of this nature presents an opportunity to support university students' mental and cognitive health.

Research Aims

The overarching aims of this thesis were to understand the barriers and facilitators to university students' physical activity, including exercise, and apply the BCW to co-design and pilot the PEAK Mood, Mind and Marks program (i.e., PEAK), a theoretically robust, scalable, exercise-based intervention to support university students' mental and cognitive health. These aims were achieved through three comprehensive, theory-driven research studies:

1. A systematic review of peer-reviewed research was undertaken to identify university students' barriers and facilitators to physical activity, map these factors to the TDF and COM-B model, and rank the TDF domains in order of relative importance.

2. An empirical qualitative co-design study was conducted with key stakeholders (i.e., university students, staff, and senior leadership at Monash University) to understand the most context-specific determinants of university students' engagement in exercise, and to identify program messaging, content, and delivery methods to support the acceptability, appropriateness, adoption, and scalability of PEAK.

3. A quasi-experimental single arm pilot study was conducted to evaluate the impact of PEAK on students' engagement in exercise, perceived mental and cognitive health, and implementation outcomes.

Overview of Thesis

This thesis by publication is comprised of three introductory chapters, the three empirical papers described above, and a general discussion of the overall findings. **Chapter One** provides an overview of the prevalence and consequences of poor mental and cognitive health among university students, their health-seeking behaviour, and a critical review of the limitations with current options to support their mental and cognitive health. **Chapter Two** demonstrates the evidence for the physical, mental, and cognitive health benefits of physical activity, including exercise. Subsequently, the key neurobiological and psychosocial mechanisms hypothesised to underlie the mental and cognitive health benefits of physical activity are explored. **Chapter Three** highlights the benefits and challenges in supporting health behaviour change, outlines best practice principles for developing, describing, and evaluating behaviour change interventions and describes the role of behavioural science and behaviour change frameworks in developing behavioural interventions. A brief summary of the literature review and gaps in the literature is then provided, including an outline of the advantages of adopting a exercise-based approach to support university students' mental and cognitive health, followed by a statement of the aims of this thesis and the studies conducted to achieve these aims.

Subsequently, three empirical studies are presented in **Chapters Four** to **Six**. Study One has been accepted for publication in a peer-reviewed journal (in press) during the doctoral candidature. Study Two and Three are submitted and yet to be accepted for publication. All three studies are presented in submitted format. Due to the thesis by

publication style, there is some inevitable repetition of material that is included in the literature review and introduction section of each empirical chapter. Explanatory notes precede each of the three studies to provide any necessary clarifications and to link each of the studies. Finally, the thesis concludes with a general discussion presented in **Chapter Seven**, which explores the implications of the studies conducted, grounded into a broader context, offers suggested directions for future research, and discusses the methodological strengths and limitations of the thesis.

CHAPTER ONE: University Students' Mental and Cognitive Health

1.1 University Students' Mental Health

The global prevalence and impact of mental illness are significant and far-reaching, affecting nearly 1 billion people worldwide across a multitude of conditions, from depression to schizophrenia (Rehm & Shield, 2019). This high prevalence of mental illness is associated with profound health and socio-economic burdens. In 2019 alone, it was estimated that 418 million disability-adjusted life years were attributable to mental disorders globally (Arias et al., 2022). Poor health and lost productivity as a result of mental illness were also estimated to cost the global economy US$5 trillion in 2019, a figure projected to rise to $6 trillion by 2030 (Arias et al., 2022; Bloom et al., 2012). Three-quarters of lifetime cases for common mental illnesses occur by the age of 24 (Fusar-Poli, 2019; Kessler et al., 2005, 2007). This is also the age at which more than 42% of young adults are enrolled in tertiary or higher education across Organisation for Economic Co-operation and Development countries (OECD, 2021). Within this context, university students are disproportionately affected by mental illness, with global estimates indicating that 31% meet the criteria for at least one mood or substance use disorder in a given 12-month period (Auerbach et al., 2018). The extent of students' mental health concerns extends beyond those meeting diagnostic criteria for a mental illness, with a high proportion of students reporting moderate to severe psychological distress (44%), loneliness (67%), and insomnia (85%), and at risk suicidal ideation (37%) (Akram et al., 2023; Chang et al., 2022). University students are even more vulnerable to mental illness and poor mental health than the general young adult population, in part due to increased financial and academic stress and reduced parental support (Holdaway et al., 2018). For example, a recent longitudinal study of over 4,000 young people in England found students who attended higher education had more symptoms of common

mental illnesses than their non-studying peers (McCloud et al., 2023). Similarly, an Australian study involving 955 university students revealed that 48% were psychologically distressed compared to 11% of age-matched population controls (Leahy et al., 2010). Furthermore, almost 11% had been treated for mental illness. University students' heightened susceptibility to poor mental health has prompted much research to understand the factors that contribute to this vulnerability to inform appropriate interventions (LaMontagne et al., 2023).

The high prevalence of mental health concerns among university students has been attributed to a confluence of factors, from developmental and environmental challenges to lifestyle-related and social risks (Limone & Toto, 2022). Navigating the transition from adolescence to emerging adulthood is often marked by significant changes in identity, autonomy, and responsibility (Wood et al., 2018), at a time that students are also adapting to new study demands and the novel university environment (Gonta & Bulgac, 2019). Academic pressures, such as maintaining grades, managing rigorous coursework, and preparing for a competitive job market are frequently described by students as substantial sources of stress (Cho & Hayter, 2020; Universities Australia, 2020). Alongside these stressors, students are frequently exposed to lifestyle and social risk factors that can adversely affect health. These include increased substance use such as binge drinking and illicit drug use and unhealthy lifestyle habits, including insufficient sleep and physical activity, poor diet, and social isolation (Barbayannis et al., 2022; Mofatteh, 2021; Ramón-Arbués et al., 2021; Vieira et al., 2021). Exposure to any of these risk factors, especially in combination, increases the risk of mental illness and a multitude of mental health difficulties, including depression, anxiety, heightened psychological distress, loneliness, and insomnia (Chang et al., 2022; Gardani et al., 2022; Jiang et al., 2022; Khader et al., 2020; Walters et al., 2018). In addition to these risk factors, international students (i.e., students enrolled in tertiary education outside their

country of origin) confront additional challenges that increases their susceptibility to mental health difficulties. Adapting to a new country, navigating language barriers, and experiencing social and cultural isolation and racism can all exacerbate international students' poor mental health (Browne, 2017; Cvetkovski et al., 2012; Huang et al., 2020; Wu et al., 2015).

Students' pre-existing mental health difficulties were exacerbated by the onset of the global COVID-19 pandemic and the public health measures enforced to curb the spread of the virus. One of the largest longitudinal studies evaluating changes in students' mental health during the pandemic found 70.8% reported worse mental health and rates of depression and anxiety increased by 15% compared to pre-pandemic times (Russell et al., 2023). Further, many students felt less connected with others during the pandemic, including their university peers and friends (Sun et al., 2020; Werner et al., 2021), which is known to play an important role in supporting mental health (Harandi et al., 2017). As in the pre-pandemic period, international students faced additional stressors during the COVID-19 pandemic compared to domestically enrolled university students, including lower levels of social support and race-based discrimination (Russell et al., 2023). International students were 1.5 times more likely to experience major depression and reported substantially higher levels of anxiety about the future (Dodd et al., 2021; Russell et al., 2023). The escalating mental health challenges faced by university students, both predating and following the COVID-19 pandemic, have become a significant global concern, particularly considering these difficulties can hinder students from achieving their goals.

Mental health impacts many aspirations that are important to students, including performing well at university, actively engaging in the university experience, and obtaining a degree to establish a future career. According to the American College Health Association (American College Health Association, 2023) report, a notable proportion of over 78,000 students reported their academic performance was negatively affected by stress (35.8%),

anxiety (30.5%), and depression (20.4%) over 12 months. These findings align with prospective evidence demonstrating that poor mental health, including symptoms of depression and anxiety, significantly predicts poor academic performance (Awadalla et al., 2020; Chu et al., 2023), and lower grades at university (Duffy et al., 2020). Beyond the academic ramifications of poor mental health, students experiencing these difficulties are often less engaged with university activities, including attending lectures, participating in class discussions, and being involved in academic and extracurricular activities at university (Lynch et al., 2013). This disengagement further adversely affects students' sense of belonging to the university (Gulliver et al., 2022; Knifsend, 2020), both of which contribute to higher levels of loneliness (Knifsend, 2020) and a greater likelihood of attrition (Pedler et al., 2022; Tight, 2020). Indeed, students facing mental health challenges are 4.3 times more likely to discontinue their higher education (Zając et al., 2023), thereby impeding their goals to graduate and career objectives. The impact of mental health challenges on students' goals is significant and intersects with another key aspect of student success – cognitive health.

1.2 University Students' Cognitive Health

Cognition, more colloquially known as one's 'thinking skills', refers to the mental processes performed by the brain to acquire knowledge, understand, and interact with the world (National Institute on Aging, 2020). Cognition encompasses an ability to concentrate, remember, problem-solve, plan, and quickly understand and respond to new information. Beyond the essential roles these skills play in daily life, cognitive health is especially critical in a range of education settings. Indeed, cognitive ability is consistently the most powerful predictor of academic achievement in primary, secondary and tertiary education contexts (Busato et al., 2000; Chamorro-Premuzic & Furnham, 2005; Colom & Flores-Mendoza, 2007; Deary et al., 2007; Kriegbaum et al., 2018; Kuncel et al., 2004; Kyttälä & Lehto, 2008). In a tertiary setting, students with stronger cognitive abilities are better able to

concentrate for longer periods of time (i.e., throughout lectures), attend to and encode key information more quickly and accurately in memory (i.e., lecture content), thus enabling them to better understand and recall this information (i.e., to complete assessments and examinations), resulting in better academic achievement (Berkowitz & Stern, 2018). Conversely, at lower levels of cognitive ability, knowledge is more easily missed in the learning process, which further reduces effective information output and leads to poorer academic performance (Vock et al., 2011).

Beyond the immediate benefits of supporting students' cognition for their performance at university, strengthening students' cognitive abilities can lay the building blocks for successful future career prospects. Indeed, there is an increasing expectation and demand for universities to hone students' readiness for the workforce throughout the time spent at university before they graduate (Alhelalat, 2015; Moore & Morton, 2017; Sushil Chakravarthy. A, 2020). Universities are therefore challenged to help students develop competencies that are desirable for future employees. While there are contextual variations between different countries and industries, globally there are similar expectations of and demands for the competencies that will boost graduates' employability (Andrews & Higson, 2008; Campbell & Kresyman, 2015; Deaconu et al., 2014; Pang et al., 2019). For example, critical thinking and adaptability are consistently identified by employers as desirable competencies in new graduates (Pang et al., 2019; Tudy, 2017; Weligamage, 2009), both of which are supported by cognitive health. For example, critical thinking draws on cognitive resources, such as executive functioning skills, to question, analyse, interpret, evaluate and make judgements about information (Li et al., 2021). Adaptability is similarly supported by cognitive skills, such as cognitive flexibility, to appropriately adjust one's thinking and behaviour to a changing environment (Laureiro-Martínez & Brusoni, 2018; Waldeck et al., 2021).

Cognitive concerns are salient among university students for several reasons. Firstly, high rates of mental illness and poor mental health increases students' risk of experiencing cognitive difficulties commonly concomitant with these challenges (Indahwati et al., 2023). Many mental illnesses are characterised by, or often associated with, cognitive difficulties in areas such as attention, executive functioning, and memory (Morozova et al., 2022). For example, 'diminished ability to think or concentrate' and 'difficulty concentrating or mind going blank' are diagnostic criteria for Major Depressive Disorder and Generalised Anxiety Disorder, respectively (American Psychiatric Association, 2013). Beyond diagnosis, symptoms of poor mental health such as psychological distress, anxiety, and low mood are known to have a deleterious impact on cognition (Freire et al., 2017; Kuvaas & Kaufmann, 2004; Robinson et al., 2013; Shermohammed et al., 2017). Secondly, students are frequently exposed to chronic and acute stressors, often academic-related, which can have a negative impact on cognition. While mild stress can facilitate an improvement in cognitive functioning, if the intensity of stress passes beyond one's perceived ability to cope, it causes cognitive difficulties (Sandi, 2013). The breadth of research conducted in the context of the pandemic has illuminated the extent to which external stressors can exacerbate students' cognitive concerns.

The pandemic was a significantly stressful event for many globally, and especially for university students. Therefore, it is unsurprising that many students experienced cognitive difficulties during this period. Three large-scale studies have explored the cognitive consequences of the pandemic on university students, all reporting high levels of subjective difficulties in concentration, memory and learning abilities (Bird et al., 2023; Giusti et al., 2021; Pisano et al., 2021). One of the largest of these studies found that, among 901 Australian students, over 60% were concerned about their cognition, including their concentration, memory recall, clarity of thought, and confidence in learning (Bird et al.,

2023). These cognitive concerns persisted after controlling for symptoms of depression and anxiety, indicating that students were experiencing distinct difficulties in their cognitive functions, independent of poor mental health. Beyond the context of the pandemic, these findings demonstrate the need to support students' cognitive health during other stressful contexts, such as examination periods (Koudela-Hamila et al., 2022).

1.3 Help-seeking and Support for Mental and Cognitive Health

The prevalence, experiences, and impact of mental and cognitive health challenges among university students call for effective solutions to support these areas of their health. Despite this need, not enough students receive sufficient mental and cognitive health support. This is starkly illustrated by the proportion who do not access treatment. For example, an international cross-sectional study of 13,984 first-year university students found only 25-30% of those with a mental illness seek any treatment in a given year (Bruffaerts et al., 2019). University students often delay or fail to seek help until their mental health challenges are severe or impacting their studies (Broglia et al., 2017), in part due to self-stigma associated with mental health-seeking behaviour and engaging with approaches designed to treat 'mental illness' (DeBate et al., 2018; Martin, 2010). These concerns are especially pronounced amongst men and international students (LaMontagne et al., 2023; Seehuus et al., 2021). The extent to which students seek support for their cognitive health is similarly low, with 23% reporting they had spoken to someone about their cognition concerns during the pandemic (Bird et al., 2023). Students' low rates of help-seeking emphasise a need for increasing support and proactive strategies to help them prevent and manage mental and cognitive health difficulties when they arise. Despite this need, traditional mental health treatment options are limited, and cognitive health support is lacking.

Pharmacological, psychotherapy and combined pharmacotherapy treatment are the first-line treatment approaches for mental illness (Nathan & Gorman, 2015; NICE

Guidelines, 2011). These treatments are widely adopted across the university sector through the provision of on-campus medical centres and student counselling services. While psychotherapy and pharmacotherapy can be effective in treating mental illness, many students report they have difficulty accessing them due to financial and cultural logistical barriers, and/or they do not find these approaches appealing (Bantjes et al., 2023; Han & Pong, 2015; Osborn et al., 2022). Low acceptability, in part, can be related to these treatment paradigms often focussing on a "deficit" model of care. This perspective focuses on the reactive treatment of mental illness after it has manifested, as opposed to proactively building resilience against the onset or relapse of mental health concerns. Limitations associated with pharmacological treatments include risk of side effects (Aaltonen et al., 2010), typically lower acceptability than non-pharmacological treatments (both among the general population and university students) (Richardson et al., 2024; Hanna et al., 2018), and not being appropriate for treating mild or subclinical symptoms of mental illness (Baumeister, 2012). Several limitations also apply to delivery of psychotherapy for supporting students' mental health. Accessing treatment can be difficult due to its high financial cost, the time commitment required to engage in therapy, and long wait times (Ebert et al., 2019; B. Hwang et al., 2014; Svetlak et al., 2021). International students face additional barriers to accessing therapy, including language difficulties, cultural differences in how mental illness is conceptualised and approached, and a lack of culturally appropriate services (Bista, 2018; Forbes-Mewett & Sawyer, 2019, 2011; Gan & Forbes-Mewett, 2018).

While supporting students' mental health has become a focus for the university sector, supports for cognitive health are uncommon. These are more commonly found outside the education sector and focus exclusively on populations experiencing neurological illnesses like dementia, mild cognitive impairment, or brain injury –conditions associated with established neuronal decline, dysfunction, or damage (Jean et al., 2010; Sanjuán et al., 2020;

Young et al., 2016). However, within the last decade, there has been a fourfold increase in the number of research studies investigating the optimisation of cognition across the lifespan, especially earlier in life and amongst people with no obvious signs of cognitive impairment (i.e., a cognitive enhancement as opposed to cognitive remediation approach) (Lövdén et al., 2020; Walhovd et al., 2023). As emerging evidence continues to demonstrate the positive impacts of supporting cognitive health at all ages and stages (Krivanek et al., 2021), a small, yet growing, number of programs have been established to invest in cognitive health early in life (e.g., the BrainHealth Project, (Centre for BrainHealth, 2024). However, programs to support young adults' cognitive health remains scarce in most sectors, including the university sector (Hosking et al., 2015). Developing and implementing programs targeting students cognitive wellbeing presents an opportunity to respond to students need for cognitive health support and contribute to a growing investment in prioritising young adults cognitive health more broadly.

1.4 Summary

The high prevalence of mental and cognitive health difficulties among university students around the globe has adverse impacts on their overall wellbeing and quality of life and hinders their goals to perform well at university and engage in university life. These challenges are further complicated by barriers to accessing appropriate mental health and cognitive support. As such, there is a need and opportunity to develop and implement effective, empowering, and strength-based approaches to support students' mental and cognitive health. Promoting student's engagement in physical exercise has substantial potential to address this need.

CHAPTER TWO: The Impact of Physical Activity on Physical, Mental and Cognitive Health

2.1 Benefits of Physical Activity

2.1.1 Physical Health

"Eating alone will not keep a (wo)man well; (s)he must also take exercise" (Hippocrates; 460-377 BC). While this statement was made over two thousand years ago, these words continue to be corroborated today by modern science. There is abundant literature on the pervasive physical health benefits of physical activity. Physical activity is defined as any voluntary bodily movement produced by skeletal muscles that requires energy expenditure, encompassing all activities including exercise. Exercise is defined as "planned, structured, and repetitive bodily movement done to improve or maintain one or more components of physical fitness" (Caspersen et al., 1985). Several meta-analyses provide a high level of evidence regarding the impact of habitual physical activity on reducing the risk of overall premature mortality (Kelly et al., 2014; Löllgen et al., 2009), including mortality related to cardiovascular disease (Je et al., 2013) and cancer (Hardefeldt et al., 2018). Higher levels of physical activity are also associated with a marked reduction in the risk of more than 25 chronic medical conditions including cardiovascular disease, type 2 diabetes mellitus, and stroke (Anderson & Durstine, 2019; Bassuk & Manson, 2005; Kruk, 2007; Warburton et al., 2006).

To achieve these health benefits, current physical activity guidelines recommend adults participate in at least 150-300 minutes of moderate to vigorous intensity, or 75-150 minutes of vigorous intensity physical activity per week alongside muscle-strengthening activities on at least two days a week (Bull et al., 2020). However, the evidence-base informing these recommendations has been questioned by research demonstrating lower levels of physical activity also deliver significant health benefits (Weed, 2016). Several studies evaluating data collected from the United Kingdom Biobank demonstrate that bouts

of moderate to vigorous physical activity as short as one to five minutes are associated with improved cardiovascular outcomes (Ahmadi et al., 2023). Moreover, two to three minutes of cumulative daily vigorous physical activity is associated with a lower risk of all-cause cardiovascular disease and cancer mortality, compared to no daily vigorous physical activity (Ahmadi et al., 2022; Stamatakis et al., 2022). The evidence demonstrating that even low levels of physical activity render substantial physical health benefits is especially relevant for people who face barriers to engaging in the level of activity recommended by most international guidelines.

2.1.2 Mental Health

A robust body of evidence demonstrates physical activity can improve mental health and treat and prevent symptoms of mental illness. For example, a cross-sectional study involving 1.2 million adults (Chekroud et al., 2018) demonstrated that people who were physically active during the preceding month had 43% fewer days of poor mental health compared to those who were inactive. The benefit of exercise exceeded that of other modifiable factors, such as having a college education versus high school alone, or an annual household income above US$50,000 versus a minimum wage of $15,000. Interestingly the benefits of exercise were not linear, with greatest benefits seen among people who exercised for 30 - 60 minutes, three to five times per week. These findings are consistent with a large body of research demonstrating that engaging in exercise regularly confers many mental health benefits. Specifically, engaging in regular exercise can enhance psychological wellbeing (Gondoh et al., 2009), reduce stress (Wunsch et al., 2017) and psychological distress (Sfendla et al., 2018) and, when performed with other people, can reduce social isolation and loneliness (Brady et al., 2020; McAuley et al., 2000). Moderate intensity exercise interventions lasting at least six weeks have also been linked to improvements in feelings of fatigue, energy, and vitality (Wender et al., 2022).

Regular exercise can maximise mental health benefits in the long term, however, even acute exercise (i.e., a single bout of exercise) can positively impact mental health (Basso & Suzuki, 2017). Acute exercise can both reduce negative affect and improve positive mood states, with effects demonstrated immediately and lasting up to 24 hours after exercise (Ekkekakis et al., 2020; Fleming et al., 2020; Reed & Ones, 2006; Suwabe et al., 2021). Beyond mood enhancement, acute exercise can reduce stress immediately following a stress-inducing event (Caplin et al., 2021; Gerber et al., 2020; Mariano et al., 2023). For instance, it has been demonstrated that acute exercise can lower psychological and physiological indicators of stress triggered by laboratory-induced stressors such as mental arithmetic, public speaking, and cognitive tasks (Basso & Suzuki, 2017; Caplin et al., 2021; Gerber et al., 2020). This stress-mitigating effect is believed to be influenced by the impact exercise has on suppressing the sympathetic nervous system's response to stress (Daniela et al., 2022). As such, exercise can effectively promote mental health both in the long and short term.

In addition to improving mental health, exercise plays a role in treating and preventing mental illness. The largest body of research evaluating the therapeutic potential of exercise for mental illness has been conducted on depressive symptoms (Bellon et al., 2021; Hwang et al., 2023). Large-scale, randomised controlled trials and meta-analyses substantiate that incorporating exercise into treatment for those with depression (i.e., those with subclinical symptoms or with a diagnosis of Major Depressive Disorder) results in significant and clinically meaningful reductions in depressive symptoms (Ashdown-Franks et al., 2020; Catalan-Matamoros et al., 2016; Chung et al., 2017; Haller et al., 2018; Schuch et al., 2016). In fact, an umbrella review of 97 meta-analyses demonstrates these treatment benefits can be comparable to those achieved through psychotherapy and pharmacotherapy (Singh et al., 2023). Various types of exercise, including aerobic, resistance, and mixed-modalities training, at any level of intensity, reduced depressive symptoms. However, antidepressant effects were

greatest when activities are performed at moderate to high intensities and incorporate resistance exercises (Singh et al., 2023).

Although research evaluating the mental health benefits of exercise has primarily focused on depression, evidence concurrently shows exercise can reduce the symptoms of other mental health conditions, such as anxiety, schizophrenia, and substance use disorders. Exercise can reduce anxiety among people with anxiety disorders (Ramos-Sanchez et al., 2021; Stubbs et al., 2017), as well as otherwise healthy populations (Carter et al., 2021; Singh et al., 2023). The treatment potential of exercise has also been demonstrated in schizophrenia and substance use disorders. For example, exercise can improve symptoms of schizophrenia (Acil et al., 2008; Beebe et al., 2005; Pajonk et al., 2010; Scheewe et al., 2013), and increase the abstinence rate, ease withdrawal symptoms, and reduce cravings among those with substance use disorders (Wang et al., 2014). Importantly, physical activity also plays a key role in preventing the onset of mental ill-health. Meta-analyses exploring the prospective relationship between physical activity and mental health have demonstrated that higher levels of physical activity can offer protection against the onset of depression (Schuch et al., 2018), and anxiety (Schuch et al., 2019).

2.1.3 Cognitive Health

A growing body of evidence also demonstrates exercise has a potent impact on cognitive health. Cross-sectional, epidemiological, and longitudinal studies all demonstrate that engaging in exercise has acute and long-term impacts on cognitive functions in young and older adults (Fernandes et al., 2017; Lista & Sorrentino, 2010). While exercise has been shown to improve many domains of cognition, including memory, attentional processes, and executive function (Chieffi et al., 2017; Grego et al., 2004; Pereira et al., 2007; Winter et al., 2007); the intensity and type of exercise influence the impact exercise has on cognition. While early evidence regarding the acute effects of exercise on cognition were mixed

(Lambourne et al., 2010; Petruzzello et al., 1997; Sibley & Etnier, 2003), more recent investigations have discovered that acute effects are dependent on exercise intensity. For example, research shows that as little as 5-20 minutes of moderate intensity exercise can have an immediate positive impact on sustained attention and elements of executive function (Fernandes et al., 2017), with effects lasting up to two hours following exercise (Basso et al., 2015; Basso & Suzuki, 2017). In contrast to moderate intensity exercise, there is some evidence that acute high intensity exercise can impair cognitive performance when the cognitive demands of a task are high and assessed during exercise (Sudo et al., 2022). While the mechanisms underpinning this finding are not well understood, a complex interaction between shifts in cerebral blood flow, neurotransmitters, and a variety of psychological factors (i.e., attention, motivation, perception of effort) during high intensity exercise have been proposed to acutely impair cognitive performance (Jung et al., 2023; Sudo et al., 2022). In the long term, however, systematic reviews and meta-analyses have provided high-level evidence demonstrating the benefits of regular high intensity aerobic exercise on improving executive functions, such as inhibitory control and working memory, and memory performance, and reducing cognitive impairment (Angevaren et al., 2008; Hsieh et al., 2021; Reyes-Amigo et al., 2022; Smith et al., 2010; Zhang et al., 2023; Zhang et al., 2022). Evidence indicates that regularly engaging in resistance exercise also has substantial benefits for executive functions such as inhibitory and reaction times control (Landrigan et al., 2020; Liu-Ambrose et al., 2012; Soga et al., 2018).

Engaging in physical activity earlier in life has consistently been identified as a modifiable risk factor for reducing the risk of dementia and attenuating cognitive decline associated with aging. For example, a review of 45 prospective studies revealed that engaging in moderate to high levels of physical activity reduces the risk of developing dementia by 21-24% and cognitive decline by 26-33% compared to engaging in no or low levels of activity.

Further supporting this link, a study involving adults aged 28–84 demonstrated that those with higher baseline physical activity levels reported less decline in episodic memory over a subsequent 10-year period (Guure et al., 2017). Additionally, a study tracking 5,200 adults aged 18 for up to 42 years found that lower physical fitness in early adulthood (a proxy indicator of lower physical activity) was associated with a 2.5 times higher risk of developing dementia (Kraal et al., 2021). This evidence highlights the substantial, long term cognitive benefits of engaging in physical activity earlier in life, emphasising its importance as a preventive measure against cognitive decline and dementia.

2.2 The Mechanisms Underlying the Benefits of Physical Activity

Understanding the mechanisms through which physical activity impacts mental and cognitive health has been of substantial and growing interest to researchers and clinicians. There is a breadth of evidence that suggests a range of different biological (e.g., neurobiological, neuroendocrine, inflammatory, metabolic) and psychosocial (e.g., self-esteem, social support, self-efficacy) mechanisms may underlie the mental and cognitive health benefits of physical activity (Kandola et al., 2019; Lubans et al., 2016; Mandolesi et al., 2018). In this section, particular attention is given to the neurobiological changes that relate to the mental and cognitive health benefits of regular exercise. In the context of this thesis, this evidence may be especially relevant for supporting university students' mental and cognitive health (see *Section 3.5* for an elaboration of this point).

2.2.1 Neurobiological Mechanisms

A key biological mechanism by which engaging in regular exercise is hypothesised to promote mental and cognitive health is through its impacts on neuroplasticity (Hotting & Roder, 2013; Kandola et al., 2019). Evidence demonstrating the neuroplastic brain benefits of exercise has been gathered from both animal and human studies (de Sousa et al., 2019; El-Sayes et al., 2019; Voss et al., 2013). The majority of animal studies have evaluated the

neuroplastic changes induced by aerobic exercise (i.e., by means of a running wheel or treadmill) in rodents. While studies in humans provide a more balanced evaluation of the effect of aerobic versus resistance exercise, aerobic exercise is still the most common (Herold et al., 2019). This section describes the evidence from animal and human studies demonstrating the impact regular aerobic and resistance exercise has on the structure, connectivity, and functioning of the brain. However, given many of these studies have small sample sizes, often infrequently considered replicability and poor generalisability, the evidence presented should be considered in light of these limitations.

2.2.1.1 Animal Studies

Initial and early evidence demonstrating exercise-induced neuroplastic changes have come from animal studies. *Structurally*, this body of evidence demonstrates exercise induced brain changes at the cellular and molecular level (Mandolesi et al., 2018). At the cellular level exercise increases rates of neurogenesis (i.e., the birth of new neurons), synaptogenesis (i.e., the formation of synapses between neurons), and gliogenesis (i.e., the generation of glial cells) in the hippocampus and neocortex, especially when performed at high intensities (Ehninger & Kempermann, 2003; Hirase & Shinohara, 2014; van Praag et al., 2005). Angiogenesis (i.e., the growth of new blood vessels) has also been documented in the hippocampus, neocortex, and cerebellum (Gelfo et al., 2018; Kleim et al., 2002; Song et al., 2020; Swain et al., 2003; Yoon et al., 2023). At the molecular level, exercise modulates neurotransmission systems (i.e., the transfer of information between neurons) by changing levels of serotonin, noradrenalin, and acetylcholine (Lista & Sorrentino, 2010; Shamsipour et al., 2021; Smriga et al., 2006); and increases neurotrophic factors (i.e., a family of biomolecules that support the growth, survival, and differentiation of neurons), including brain-derived neurotrophic factor (BDNF) (Lafenetre et al., 2011; Vaynman et al., 2004) and insulin-like growth factor-1 (IGF-1) (van Praag, 2009). Alterations in *connectivity* within and

between several brain regions including the dorsal hippocampus (Zhou et al., 2021), prefrontal cortex and basal ganglia (Wang et al., 2023) have also been observed. *Functionally,* many of these exercise-induced brain changes have been linked to improvements in behavioural indicators of mental health and cognitive performance. For instance, improvements have been demonstrated in anxiety-like behaviour (Fan et al., 2022), stress-coping strategies (Lalanza et al., 2015), exploratory behaviour (Alvarez-Monell et al., 2022), executive functions (Langdon & Corbett, 2012), spatial learning (Snigdha et al., 2014; van Praag et al., 2005; Zhou et al., 2021) and memory (Grace et al., 2009).

2.2.1.2 Human Studies

Neuroimaging techniques have been used to investigate the impact aerobic and resistance exercise has on the structure, connectivity, and function of the human brain (Gomez-Pinilla & Hillman, 2013; Kandola et al., 2016). The information presented will discuss the effects of aerobic exercise and resistance exercise independently for two reasons. Firstly, most research has evaluated each modality independently and, secondly, each type of exercise elicits a divergent physiological response and, therefore, may have differential impacts on the brain (Cassilhas et al., 2012).

Structural Brain Changes. Engaging in aerobic and resistance exercise is associated with various structural changes in the brain. Aerobic exercise increases white and grey matter volume in regions of the prefrontal cortex (Colcombe et al., 2006; Erickson et al., 2012; Ji et al., 2017) and the hippocampus (Den Ouden et al., 2018; Erickson et al., 2011). These brain changes are functionally significant. Prefrontal cortex volume mediates the relationship between fitness and executive functions (Weinstein et al., 2012), suggesting volumetric increases in the prefrontal cortex may underlie improvements in executive functions. Further, increased hippocampal volume induced by exercise is associated with improvements in episodic and verbal memory (Den Ouden et al., 2018; Erickson et al., 2011). These brain

changes are also in contrast to the reductions observed in hippocampal volume following exposure to chronic stress (Kim et al., 2015; Schoenfeld et al., 2017) and associated with depression and schizophrenia (Chen et al., 2020). Volumetric changes have also been demonstrated following resistance exercise. Specifically, resistance exercise has been associated with a decrease in cortical white matter atrophy (Best et al., 2015) and reductions in the volume of white matter lesions (Bolandzadeh et al., 2015; Crockett et al., 2022; Herold et al., 2019) among older adults. Given white matter abnormalities are markers of cognitive decline (Luo et al., 2020) and dementia (Wang et al., 2020), these findings suggest resistance exercise confers neuroprotective effects for these pathologies. Moreover, engaging in progressive resistance exercise increased cortical thickness in the temporal pole (Kjølhede et al., 2018) and grey matter thickness in the posterior cingulate cortex, which was correlated with improved global cognitive performance (Suo et al., 2016).

Functional Connectivity Brain Changes. Engaging in exercise alters functional connectivity across various brain regions (Won et al., 2021). Aerobic exercise has been associated with increased functional connectivity across diverse age groups, in both clinical and non-clinical populations (Bray et al., 2021; Hsu et al., 2017; Prehn et al., 2019; Weng et al., 2017). This body of evidence suggests a global impact of aerobic exercise on brain networks, such as the default mode network and the cerebellum (Ko et al., 2023; Li et al., 2017). Notably, multiple studies have identified a consistent pattern of augmented functional coherence — the improved coordination and efficiency among various brain regions working together — in response to aerobic exercise. For instance, aerobic exercise has been linked to increased functional coherence in the default mode network (Chirles et al., 2017; McGregor et al., 2018; Voss et al., 2010), the hippocampal network (Burdette et al., 2010; Flodin et al., 2017; Tozzi et al., 2016; Won et al., 2021), the executive control network (Prehn et al., 2019), and cerebellar resting state functional connectivity (Won et al., 2021). Aerobic exercise is

also associated with enhanced connectivity between different networks, such as the sensorimotor network and default mode network (McGregor et al., 2018). Furthermore, improvements in cardiorespiratory fitness associated with engaging in aerobic exercise may promote better resting state functional connectivity between areas such as the sensorimotor network and occipital cortex, and within networks including the default mode network, sensorimotor network, and thalamus (Flodin et al., 2017).

Relative to aerobic exercise, considerably less is known about the impacts of resistance exercise on functional connectivity. Nonetheless, the limited research conducted to investigate the impact of resistance exercise on brain connectivity shows promising, preliminary results. For example, higher functional activation in the right lingual gyrus during an associative memory task was observed in older adults with mild cognitive impairment after engaging in resistance exercise (Nagamatsu et al., 2012), which correlated with improvements in memory performance. Within this population, resistance exercise also augments resting-state functional connectivity, such as within the posterior cingulate cortex, the left inferior temporal lobe, the anterior cingulate cortex, and between the hippocampus and frontal lobe (Suo et al., 2016). Given connectivity within and between these brain regions is often disturbed in individuals with mild cognitive impairment or Alzheimer's disease (Allen et al., 2007; Wang et al., 2006; Wang et al., 2011), it has been postulated that resistance exercise may improve cognitive functioning in these cohorts by altering the functional connectivity of the brain.

Cellular and Molecular Structural Brain Changes. Given the technological and ethical challenges involved in investigating exercise-induced brain changes at a cellular and molecular level among humans, understanding the specific mechanisms that underpin these changes is still very much under investigation. Several potential mechanisms have been described in the literature, including possible changes in neurotransmission systems (i.e.,

serotonin, noradrenalin, and dopamine – the same neurotransmitters modulated by psychiatric medications such as antidepressants and antipsychotics (Delcourte et al., 2021; Grinchii & Dremencov, 2020; Kaar et al., 2020; Yu et al., 2020)), the endocannabinoid system (i.e., anandamide, and 2-arachidonoylglycerol) and neurotrophic factors (i.e., BDNF, IGF-1, and vascular endothelial growth factor levels) (Matei et al., 2023; Nay et al., 2021). It is beyond the scope of the thesis to describe each of these proposed molecular changes in detail, or the complex interactions between them. Given much attention has focused on two key divergent pathways proposed to result in neurotrophic changes following high intensity exercise and resistance exercise, these pathways are discussed in detail.

During high intensity exercise, the demand for energy is significantly higher than exercising at lower intensities and can exceed the oxygen supply required for metabolising glucose for energy (Vigh-Larsen et al., 2021). To meet this change in energy demands, there is an increase in the utilisation of the glycolytic metabolic pathway to produce energy (Spriet, 2022). This process results in several byproducts including lactate which, once produced, can exit the muscle tissue and enter the bloodstream (Rabinowitz & Enerbäck, 2020). Much of this lactate is circulated to the liver to be converted back into glucose, however, lactate can also be circulated to the brain (Hashimoto et al., 2021). Lactate can pass through the blood brain barrier and, when it does so, catalyses an increase in BDNF (Müller et al., 2020), a key signalling molecule for neuronal survival and growth and synaptic plasticity (Mattson et al., 2004).

Resistance exercise has also been shown to increase neurotrophic factors which drive neuroplasticity, though through different pathways (Kraemer et al., 2020). When undertaking resistance exercise, muscle fibres undergo mechanical stress and microtrauma. This type of muscular stress is crucial for stimulating muscular adaptations, including increases in muscle strength and growth (Lopez et al., 2021). Part of this adaptation process results in the

secretion of Human Growth Hormone (HGH) from the pituitary gland, which circulates through the blood stream to different organs, including the liver (Gharahdaghi et al., 2021). Upon reaching the liver, HGH triggers a cascade of responses which result in the production and release of IGF-1 from the liver into the blood stream (Jiang et al., 2020). IGF-1 can, in turn, cross the blood brain barrier. Once in the brain, IGF-1 is central to pathways that promote neuronal growth and survival, myelin production and survival, and protect neurons from amyloid-beta toxicity, a driver of Alzheimer's disease (Arjunan et al., 2023; Carro et al., 2001; Dyer et al., 2016; Reinhardt & Bondy, 1994; Walser et al., 2021).

2.2.2 Psychosocial Mechanisms

Several psychosocial changes are hypothesised to influence the mental and cognitive health benefits of physical activity. Many theoretical frameworks have proposed that optimal mental health is achieved through satisfying basic psychological needs across several key areas, including social connectedness, self-acceptance, and competence (Deci & Ryan, 2008; Ryff & Keyes, 1995), all of which can support optimal cognitive functioning (Albalooshi et al., 2020; Paiva et al., 2023; Voica et al., 2020). Indeed, physical activity offers an approach for achieving these needs by providing opportunities for social support (social connectedness), and improvements in self-esteem (self-acceptance), and self-efficacy (competence).

Physical Activity and Social Support. Participating in physical activity plays a role in strengthening social support and reducing isolation by offering opportunities for interaction and socialisation. Such benefits may be particularly pronounced in team sports and other interactive forms of group-based exercise (Golaszewski et al., 2022). For example, a study involving 1.2 million adults (aforementioned in *Section 2.1.2)* found the largest associations between exercise and lower mental health burden was found among those who participate in sports, mostly team based, compared to other types of exercise. These findings, while

correlational, suggest team-based exercise could offer superior mental health benefits compared to non-team-based activities. Further, evidence demonstrates participating in team-based sport during adolescence can subsequently promote mental health in adulthood by reducing the risk of depression and anxiety and enhancing wellbeing and coping (Panza et al., 2020), with social support potentially mediating these benefits (Babiss & Gangwisch, 2009; Jewett et al., 2014; Sabiston et al., 2016). Moreover, increased social support is associated with improved cognitive performance (Kelly et al., 2014) and reduced cognitive decline (Paiva et al., 2023). These findings suggest that providing opportunities for socialisation through shared participation in physical activity is another mechanism through which physical activity exerts positive mental and cognitive health benefits.

Physical Activity and Self-Esteem. Engaging in physical activity can improve self-esteem (Tikac et al., 2021), which can enhance wellbeing (Kim & Ahn, 2021; Shang et al., 2021) and mood (Joshanloo, 2022), and buffer against the onset of mental illness (Ahn & Fedewa, 2011). Improvements in self-esteem induced by exercise may be underpinned by the impact exercise has on physical self-perception (Anderson et al., 2006; Feuerhahn et al., 2014) and body image (Alleva et al., 2015; Campbell & Hausenblas, 2009; Hausenblas & Fallon, 2006). For example, physical self-perception has been demonstrated to mediate the association between physical activity and improvements in self-esteem, quality of life, and positive affect (Feuerhahn et al., 2014; Zamani Sani et al., 2016). Changes in body composition, such as reductions in body fat and increases in muscle mass, may contribute to these improvements (Annesi & Porter, 2015; Slentz et al., 2005), however, research indicates that self-perceptions improve regardless of these physical changes (Anderson et al., 2006; Campbell & Hausenblas, 2009).

Physical Activity and Self-Efficacy. Completing an important and effortful task, such as exercise, can foster a sense of self-efficacy (i.e., a person's belief in their ability to

succeed) (Tikac et al., 2021), which, in itself, plays a role in supporting mental health and academic performance, and increases the likelihood of ongoing participation in exercise (Rodgers et al., 2014). General improvements in self-efficacy are associated with improvements in a range of mental health outcomes, including improved quality of life (Lee & Oh, 2020) and reduced depressive symptoms (Trumpeter, 2015), and outcomes known to support academic performance, such as learning burnout (Chen et al., 2023; Usán Supervía et al., 2022). Indeed, studies have shown that self-efficacy mediates the effect of exercise on learning burnout (Fu et al., 2023). Engaging in exercise can also improve a person's confidence in their abilities to overcome barriers to exercise (Higgins et al., 2014; Seitz, 2017), which is an important predictor of their adherence to self-set exercise goals and maintain exercise habits (Middelkamp et al., 2017). Consequently, interventions focused on bolstering exercise self-efficacy can play a role in supporting sustained exercise participation. In turn, sustained participation facilitates the long term mental and cognitive health benefits associated with regular exercise. Strategies to target exercise self-efficacy could involve tailoring exercise programs to purposefully address barriers to exercise and setting achievable exercise goals.

2.3 Summary

There is robust evidence that regular physical activity provides significant positive mental and cognitive health benefits, especially when these habits are established earlier in life. The current neuroscientific evidence further indicates these advantages are particularly pronounced when activities incorporate aerobic and resistance exercises, performed at moderate to high intensities. An exercise-based intervention built on this evidence provides an opportunity to set university students up with lifelong exercise habits, thereby promoting their mental and cognitive wellbeing during their university years and beyond. The potential benefits of an exercise-based intervention are clear, however, the key to realising these

benefits is complex, dependent on supporting students to initiate and maintain a habitual exercise regime. Indeed, health behaviour change is notoriously challenging for many people.

CHAPTER THREE: Supporting Health Behaviour Change

3.1 Benefits and Challenges of Supporting Health Behaviour Change

Supporting people to change their health-related behaviours can have substantial positive impacts on addressing leading preventable causes of morbidity and premature mortality (Pourat et al., 2022). This assertion is underscored in the Wanless Report (Wanless, 2002), “Securing Our Future Health: Taking a Long-Term View", commissioned by the Chancellor of the Exchequer to review the long-term health trends affecting the National Health Service (NHS) and to make recommendations for future health care funding in the United Kingdom. In the report, Wanless outlines scenarios for the future of the NHS, based on varying levels of public engagement in health. The ’Fully Engaged Scenario’ described in the report envisages a future where there is high public engagement in health matters. In this scenario, people are more proactive about their health, leading to widespread behaviour change. As a result, there is a significant reduction in the prevalence of chronic diseases due to healthier lifestyles, which include increased physical activity, better dietary habits, and reduced tobacco and alcohol consumption. This scenario predicts the best health outcomes for the population and the most sustainable financial model for the NHS, emphasising the importance of supporting health behaviour change for profound economic and societal benefits. Therefore, the development and implementation of effective interventions that facilitate and sustain health behaviour change are of paramount importance in shaping a healthier future globally.

While Wanless’ ‘Fully Engaged’ scenario offers an optimistic vision for the future of public health, the reality is people are complex, changing behaviour is notoriously hard, and many of the mechanisms that underpin successful interventions are not well understood. The complexity of behaviour change stems from a myriad of interconnected factors that influence human behaviour. These factors are related to a person’s capability, opportunity, and

motivation to change (Michie et al., 2011a), which can vary significantly across contexts. Moreover, designing health behaviour change interventions that are both engaging and lead to sustained behaviour change beyond the acute intervention duration, presents a major challenge (Michie et al., 2011a). This challenge is reflected in the variable adherence rates, and modest effect sizes often demonstrated in traditional interventions aimed at changing health behaviours (Thomas Craig et al., 2021). Even among the breadth of interventions that have successfully supported health behaviour change, it is often unclear why or how these interventions have worked (Michie & Abraham, 2004; Nielsen et al., 2018; Sumner et al., 2018). Without understanding why these interventions are successful, the evidence based remains fragmented and uninformed. Consequently, opportunities to build on previous successes and systematically improve interventions to support health behaviour change are often missed. Conversely, understanding these causal mechanisms enables intervention designers to develop more efficient and effective behaviour change interventions and, in doing so, build an evidence base that reveals what kinds of interventions work, in what contexts, for who, and for which behaviour (Davidson & Scholz, 2020). Therefore, progressing towards the realisation of Wanless' 'Fully Engaged' scenario calls for a better understanding of behaviour change, including the complex factors that influence behaviour, what is needed to support behaviour change successfully and sustainably, and what interventions work, why, and in what ways.

3.2 Best Practice Principles for Supporting Health Behaviour Change

In response to the need to better understand what it takes to change health behaviour, including physical activity, the field of behavioural science continues to rapidly grow. This growth has led to the establishment of key principles for developing successful behaviour change interventions. The UK Medical Research Council (MRC) guidelines for developing complex interventions (Skivington et al., 2021) and National Institute for Health and Care

Excellence (NICE) (NICE Guidelines, 2007, 2014, 2020) advocate a theory-driven, evidence-based approach that incorporates stakeholder perspectives at all stages of the intervention development process. Systematic reviews of existing evidence demonstrate the effectiveness of such an approach (Taylor et al., 2012; Webb et al., 2010). The explicit use of theory allows intervention designers to identify and target influences on behaviour change (i.e., barriers and facilitators to the behaviour) and replicate interventions with fidelity (Michie et al., 2008). Involving key stakeholders (i.e., in the context of this thesis, university students, leadership, and staff) in intervention development is equally important to maximise the feasibility, adoption, and scalability potential of an intervention (Eisman et al., 2021). Effective behaviour change interventions are most often created when stakeholder perspectives are incorporated with proven evidence-based frameworks from behavioural science (Ammerman et al., 2002; Byrne, 2019).

3.3 Behavioural Intervention Development Frameworks and Tools

A multitude of evidence-based frameworks (e.g., the Behaviour Change Wheel (Michie et al., 2011a), Intervention Mapping (Eldredge et al., 2016), and the Obesity-Related Behavioural Interventions Trials model (Czajkowski et al., 2015) have been developed to guide the systematic development and implementation of behavioural interventions, understand their causal mechanisms, and build an evidence base that reveals what interventions work best, for which populations, in what contexts, and for which behaviours. Among these frameworks, the Behaviour Change Wheel (BCW) is globally recognised as one of the most well validated, theoretically derived, frameworks for developing and describing behaviour change interventions.

3.3.1 The Behaviour Change Wheel

The BCW is an intervention development process built on a synthesis of 19 behaviour change frameworks, developed through a process of theoretical analysis, empirical evidence,

expert consensus, and rigorous validation process. Deeply embedded within the BCW approach is its consideration of stakeholder perspectives regarding intervention design. The BCW has been widely used by clinicians, governments, industry and non-governmental associations around the world to create large scale change across healthcare, environmental sustainability, and workplace settings (Atkins, 2016; Gainforth et al., 2016; Munir et al., 2018). The BCW is schematically organised into three layers (see Figure 3.1) which form the basis of a systematic process for intervention development across three stages: 1) understanding the target behaviour, 2) identifying intervention options, and 3) identifying intervention content and delivery mode (Michie et al., 2014) (see Figure 3.2).

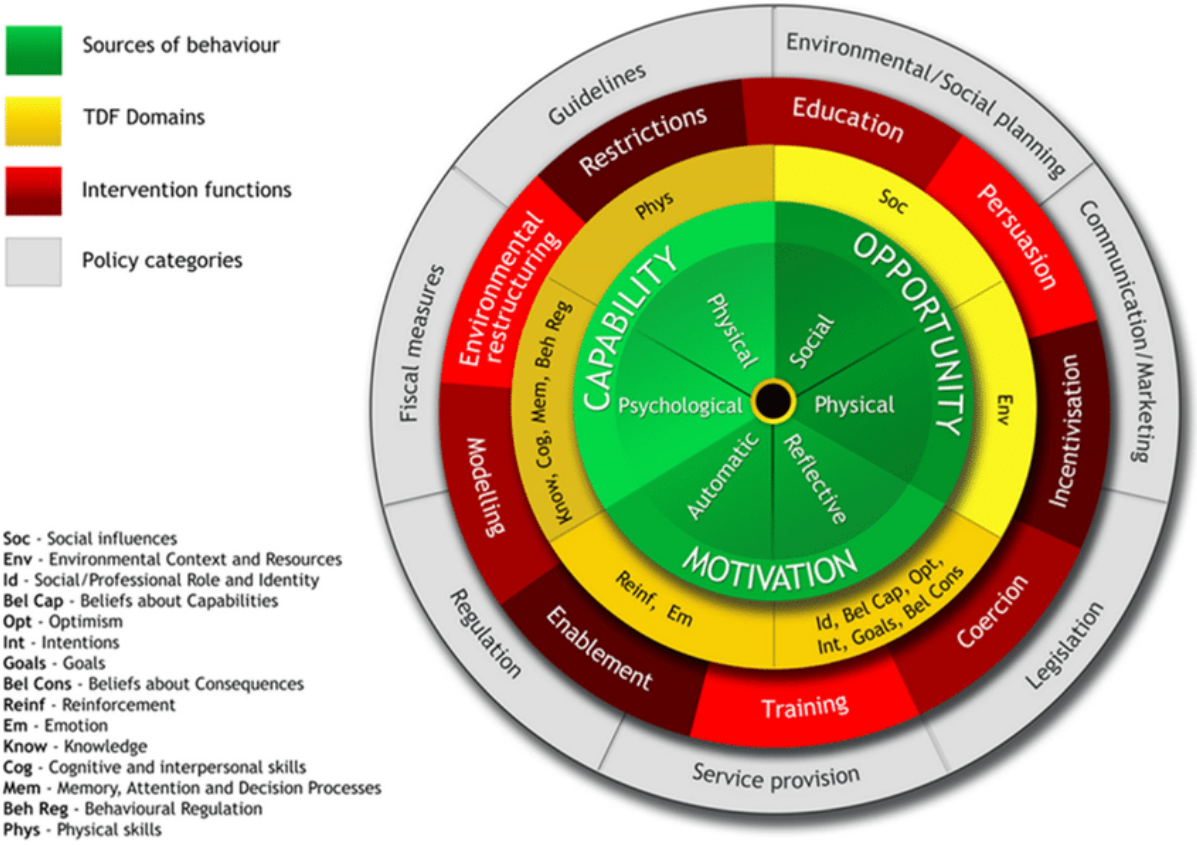

Figure 3.1 The layers of the Behaviour Change Wheel, including the COM-B model and Theoretical Domains Framework. Reproduced from Michie S, Atkins L, West R. (2014) The Behaviour Change

Wheel: A Guide to Designing Interventions. London: Silverback Publishing. www.behaviourchangewheel.com.

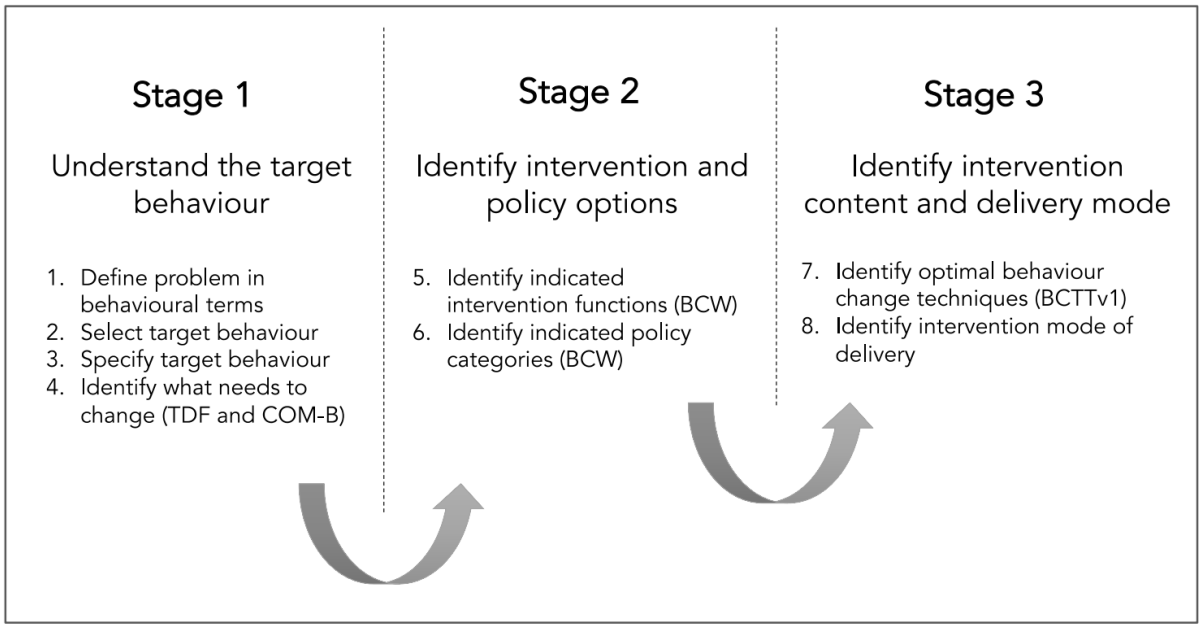

Figure 3.2 Stages involved in the development of an intervention using the BCW. Adapted from Michie S, Atkins L, West R. (2014) The Behaviour Change Wheel: A Guide to Designing Interventions. London: Silverback Publishing. www.behaviourchangewheel.com.

3.3.1.1 The Behaviour Change Wheel Process: Stage One

In the first stage of the BCW process, efforts are made to understand the determinants (i.e., the barriers and facilitators) of behaviour. This stage, often called making a 'behavioural diagnosis', involves identifying what needs to change and methodical assessment to understand and address the factors underlying the behaviour(s) of interest. To this effect, the theoretical framework(s) applied to understand the behaviour are the COM-B model and/or the Theoretical Domains Framework (TDF). Mapping the behaviour to either model alone is sufficient to identify what barriers and/or facilitators need to be targeted to change behaviour, however, these frameworks are complementary and often used in tandem to identify what needs to change at both a macro level (COM-B model) and more granular level (TDF).

The COM-B Model of Human Behaviour. The COM-B model is the central hub of the BCW (see Figure 3.1). The COM-B model is a gold-standard model developed to encompass

all types of behaviour and behaviour change at a macro level to provide a single unifying theory of behaviour (Michie et al., 2011a). The COM-B model posits that no behaviour will occur without sufficient capability, opportunity, and motivation. Where any of these are lacking, they can be strategically targeted to support increased engagement in a desired behaviour, including participation in physical activity. Within the COM-B model, capability can be psychological (e.g., knowledge to engage in the necessary processes) or physical (e.g., physical skills); opportunity can be social (e.g., interpersonal influences) or physical (e.g., environmental resources); and motivation can be automatic (e.g., emotional reactions, habits) or reflective (e.g., intentions, beliefs). The COM-B model maps onto the TDF framework (see Figure 3.1 for mapping), which provides a more granular understanding of behaviour.

The Theoretical Domains Framework. The Theoretical Domains Framework (TDF) (Cane et al., 2012) is a robust and comprehensive determinant framework widely used to understand human behaviour change. This framework was originally derived from a synthesis of 128 constructs related to behaviour change (e.g., 'competence', 'goal priority', etc.) across 33 psychological theories (e.g., social cognitive theory (Bandura, 1986), the theory of planned behaviour (Ajzen, 1991, 2012), etc.). An expert consensus approach was used to develop the TDF, wherein behavioural scientists and implementation researchers endeavoured to make the application of behaviour change theory more accessible for researchers, intervention designers, health professionals and policy planners when addressing implementation problems in healthcare. After undergoing independent validation (Cane et al., 2012), the current version (TDF v2) covers 84 theoretical constructs clustered into 14 domains (see Table 3.1 for TDF domains, definitions and constructs).

The COM-B model and TDF have been widely applied by researchers and practitioners to systematically identify which theoretical domains are most relevant for understanding health behaviour change and policy implementation across a range of contexts,

including education (Weatherson et al., 2017), healthcare (Taylor et al., 2013), and workplace environments (Garne-Dalgaard et al., 2019). In the context of developing a health behaviour change intervention for university students', the COM-B model and TDF are particularly useful frameworks to comprehensively identify the factors (i.e., barriers and facilitators) that need to change within a specific context to achieve a desired behaviour (i.e., increasing university students' engagement in exercise).

Table 3.1

The Theoretical Domains Framework (v2)

Theoretical Domain	**Definition***	**Constructs**
Knowledge	An awareness of the existence of something	Knowledge (including knowledge of condition/scientific rationale) Procedural knowledge Knowledge of task environment
Skills	An ability or proficiency acquired through practice	Skills Skills development Competence Ability Interpersonal skills Practice Skill assessment
Social/professional role and identity	A coherent set of behaviours and displayed personal qualities of an individual in a social or work setting	Professional identity Professional role Social identity Identity Professional boundaries Professional confidence Group identity Leadership Organisational commitment

Theoretical Domain	Definition*	Constructs
Beliefs about capabilities	Acceptance of the truth, reality or validity about an ability, talent or facility that a person can put to constructive use	Self-confidence Perceived competence Self-efficacy Perceived behavioural control Beliefs Self-esteem Empowerment Professional confidence
Optimism	The confidence that things will happen for the best or that desired goals will be attained	Optimism Pessimism Unrealistic optimism Identity
Beliefs about consequences	Acceptance of the truth, reality, or validity about outcomes of a behaviour in a given situation	Beliefs Outcome expectancies Characteristics of outcome expectancies Anticipated regret Consequents
Reinforcement	Increasing the probability of a response by arranging a dependent relationship, or contingency, between the response and a given stimulus	Rewards (proximal/distal, valued/not valued, probable/improbable) Incentives Punishment Consequents Reinforcement Contingencies Sanctions
Intentions	A conscious decision to perform a behaviour or a resolve to act in a certain way	Stability of intentions Stages of change model Transtheoretical model and stages of change

Theoretical Domain	Definition*	Constructs
Goals	Mental representations of outcomes or end states that an individual wants to achieve	Goals (distal/proximal) Goal priority Goal/target setting Goals (autonomous/controlled) Action planning Implementation intention
Memory, attention and decision processes	The ability to retain information, focus selectively on aspects of the environment and choose between two or more alternatives	Memory Attention Attention control Decision making Cognitive overload/tiredness
Environmental context and resources	Any circumstance of a person's situation or environment that discourages or encourages the development of skills and abilities, independence, social competence and adaptive behaviour	Environmental stressors Resources/material resources Organisational culture/climate Salient events/critical incidents Person × environment interaction Barriers and facilitators
Social influences	Those interpersonal processes that can cause individuals to change their thoughts, feelings, or behaviours	Social pressure Social norms Group conformity Social comparisons Group norms Social support Power Intergroup conflict Alienation Group identity Modelling
Emotion	A complex reaction pattern, involving experiential, behavioural, and	Fear Anxiety

Theoretical Domain	Definition*	Constructs
	physiological elements, by which the individual attempts to deal with a personally significant matter or event	Affect Stress Depression Positive/negative affect Burn-out
Behavioural regulation	Anything aimed at managing or changing objectively observed or measured actions	Self-monitoring Breaking habit Action planning

Note. Reprinted by permission from Springer Nature: Implementation Science (Validation of the theoretical domains framework for use in behaviour change and implementation research, by Cane, Connor & Michie), Copyright (2012) *All definitions are based on definitions from the American Psychological Associations' Dictionary of Psychology (Washington: 2007)

3.3.1.2 The Behaviour Change Wheel Process: Stage Two

The second stage of the BCW process guides intervention designers to transition from the behavioural diagnosis of a problem to selecting from nine intervention types (the middle layer of the wheel) (see Table 3.2 for definitions and examples of each intervention type). Intervention types are broad categories of interventions that can change behaviour. These intervention types were mapped onto the COM-B model through expert consensus. Through this consensus approach, behavioural scientists reached agreement on which intervention types were most likely to change behaviour by targeting capability, opportunity and/or motivation as required. The intervention types are also linked to seven general policy options that can be used to support the delivery of the intervention types when relevant and/or available to intervention designers.

Table 3.2

The Behaviour Change Wheel Intervention Types, Definitions and Examples

Intervention types	Definition	Example of intervention type
Education	Increasing knowledge or understanding	Providing information to promote healthy eating
Persuasion	Using communication to induce positive or negative feelings or stimulate action	Using imagery to motivate increases in physical activity
Incentivisation	Creating an expectation of reward	Using prize draws to induce attempts to stop smoking
Coercion	Creating an expectation of punishment or cost	Raising the financial cost to reduce excessive alcohol consumption
Training	Imparting skills	Advanced driver training to increase safe driving
Restriction	Using rules to reduce the opportunity to engage in the target behaviour (or to increase the target behaviour by reducing the opportunity to engage in competing behaviours)	Prohibiting sales of solvents to people under 18 to reduce use for intoxication
Environmental restructuring	Changing the physical or social context	Providing on-screen prompts for GPs to ask about smoking behaviour

Intervention types	Definition	Example of intervention type
Modelling	Providing an example for people to aspire to or imitate	Using TV drama scenes involving safe-sex practices to increase condom use
Enablement	Increasing means/reducing barriers to increase capability (beyond education and training) or opportunity (beyond environmental restructuring)	Behavioural support for smoking cessation, medication for cognitive deficits, surgery to reduce obesity, prostheses to promote physical activity

Note. Reproduced from Michie S, Atkins L, West R. (2014) The Behaviour Change Wheel: A Guide to Designing Interventions. London: Silverback Publishing. www.behaviourchangewheel.com.

In most cases more than one, and often several, potential intervention types are identified. It may not be feasible, desirable or, indeed, effective to implement all possible intervention types. Therefore, intervention designers are often tasked to make judgements about which intervention type(s) to select based on their relative effectiveness and feasibility. The BCW recommends using the APEASE criteria to help inform these decisions. The APEASE criteria are: 1) Affordability, 2) Practicability, 3) Effectiveness and cost-effectiveness, 4) Acceptability, 5) Side-effects/safety, and 6) Equity (see Table 3.3 for definitions of each criterion) and thus allows intervention designers to select interventions based on their unique circumstances, environment, and resources.

Table 3.3

The APEASE Criteria for Designing and Evaluating Behavioural Interventions

Criterion	Description
Affordability	An intervention is affordable if within an acceptable budget it can be delivered to, or accessed by, all those for whom it would be relevant or of benefit.
Practicability	An intervention is practicable to the extent that it can be delivered as designed through the means intended to the target population.
Effectiveness and cost-effectiveness	Effectiveness refers to the effect size of the intervention in relation to the desired objectives in a real-world context. Cost-effectiveness refers to the ratio of effect to cost. If two interventions are equally effective, then the most cost-effective should be chosen. If one is more effective but less cost-effective than another, other issues such as affordability, come to the forefront of the decision-making process.
Acceptability	Acceptability refers to the extent to which an intervention is judged to be appropriate by relevant stakeholders (public, professional and political). Acceptability may differ for different stakeholders.
Side-effects/safety	An intervention may be effective and practicable but have unwanted side-effects or unintended consequences. These need to be considered when deciding whether to proceed.
Equity	An important consideration is the extent to which an intervention may reduce or increase the disparities in standard of living, wellbeing, or health between different sectors of society.

Note. Adapted from Michie S, Atkins L, West R. (2014) The Behaviour Change Wheel: A Guide to Designing Interventions. London: Silverback Publishing. www.behaviourchangewheel.com.

3.3.1.3 The Behaviour Change Wheel Process: Stage Three

The Behaviour Change Technique Taxonomy. The final stage of the intervention development process includes identifying which behaviour change techniques (BCTs) can be used to support the delivery of intervention types and their appropriate modes of delivery. BCTs are defined as the observable and replicable 'active ingredients' of a behavioural interventions that can either be used on its own or in combination with other BCTs to influence behaviour. BCTs are listed and described in a 93-item taxonomy known as the Behaviour Change Techniques Taxonomy v1 (BCTTv1) (Michie et al., 2013). The BCTTv1 was developed consensually by behaviour change experts through a Delphi process to address the lack of consistent reporting of behavioural interventions in the field, and provides a standardised, reliable method of characterising and evaluating the content and delivery of BCTs. Choices about which BCTs to implement in an intervention can also be guided by the APEASE criteria (see Table 3.3).

3.4 Behavioural Intervention Evaluation

Once an intervention is developed, adhering to best practice principles for evaluating behavioural interventions necessitates early-stage pilot testing. Pilot testing can provide an estimate of preliminary efficacy and provide key insights to optimise intervention content and mode of delivery. This approach is fundamentally different from developing pharmacological treatments. To develop a pharmacological treatment, such as a drug, the treatment is the molecule and, once the molecule is identified, the goal is to rapidly trial its effectiveness in a randomised-controlled trial. Conversely, to develop a behavioural intervention, the treatment is not the desired behaviour (i.e., physical activity), the treatment is how to support people to engage in the desired behaviour. Understanding how to best support behaviour change is complex, often involving many different aspects of a person's capability, opportunity, and

motivation. Due to this complexity, the development process for behavioural interventions requires an iterative, methodical, and thorough approach to understand how to best support behaviour change. Therefore, the development of behavioural intervention often requires several rounds of small-scale iteration and evaluations to optimise a behavioural intervention before large scale evaluation. Simultaneous evaluation of the impact and implementation of behavioural interventions is a central part of this process to optimise the effectiveness, feasibility, acceptability and adoption of an intervention.

Implementation outcomes are the impacts of intentional action taken to implement, or deliver, new evidence-based practices and interventions (Proctor et al., 2011). These outcomes are distinct from treatment outcomes (i.e., efficacy, effectiveness, safety). Implementation outcomes provide a way to evaluate implementation progress and success, guide implementation activities, identify implementation processes, and can help determine whether an implementation context has the necessary preconditions to achieve its desired outcomes. Proctor and colleagues (2011) have developed a comprehensive widely adopted taxonomy to guide the selection and evaluation of implementation outcomes. Their framework conceptualises eight distinct implementation outcomes: acceptability, appropriateness, adoption, feasibility, fidelity, implementation cost, penetration, and sustainability. Importantly, this framework delineates which implementation outcomes are most relevant across three phases of implementation research: the early adoption, mid-implementation, and late sustainability period. For example, the outcomes of ‘acceptability’ and 'appropriateness' are particularly pertinent during the early implementation stages, while 'sustainability' becomes more important in the late stages of implementation. As such, early-stage piloting of a newly developed behavioural intervention will benefit from an evaluation of its acceptability and appropriateness.

Acceptability is defined as stakeholders' perception of whether an intervention is agreeable, palatable, or satisfactory. This perception is based on their knowledge of or direct experience with the intervention's content, delivery method, complexity, and credibility. Since acceptability is subject to personal perception, it can vary widely among stakeholders. Different stakeholders might have varying opinions on the same intervention, influenced by their unique needs, priorities, preferences, or expectations. Acceptability is a necessary, but insufficient, condition for the successful implementation of an intervention (Sekhon et al., 2017). For end-users, an acceptable intervention is more likely to be adhered to, leading to better intervention outcomes (Fisher et al., 2006; Hommel et al., 2013) and a lack of acceptability has consistently been identified as a significant barrier to implementation (Borrelli et al., 2005; Proctor et al., 2009).

Appropriateness, on the other hand, relates to the perceived fit, relevance, or compatibility of an intervention, such as its ability to meet end-users needs, alignment with treatment philosophy, or organisational values. Evaluating appropriateness is important for identifying potential resistance to an intervention before its adoption. For example, a stakeholder might view an intervention as incompatible with their professional skills, role expectations, or a poor fit with the organisational culture or climate, leading to implementation challenges (Proctor et al., 2011). Of note, an intervention can be seen as appropriate but not necessarily acceptable, and vice versa. For instance, students' may consider an exercise-based intervention is an appropriate approach for supporting their mental and cognitive health, however, it may not be acceptable due to the complexity involved in engaging in the intervention.

3.5 Summary, Gaps in Research and Thesis Aim

There is a compelling body of evidence demonstrating that exercise is a robust means of supporting mental and cognitive health and, therefore, holds potential for supporting these aspects of university students' health. An exercise-based approach delivers several advantages. Exercise has few unwanted or harmful side-effects, is relatively cost-effective, and can be self-sustaining. Importantly, exercise offers benefits across the spectrum of mental and cognitive health experiences. These benefits include treating, managing, and preventing poor mental and cognitive health, and optimising overall wellbeing. Moreover, an exercise-based approach has the potential to be implemented at scale, especially if the proliferation of digital tools to support exercise engagement, including phone applications and websites, are leveraged to support program content development and delivery (Amer et al., 2022; Riehl, 2022).

An exercise-based intervention informed by evidence is likely to maximise its impact on health outcomes. At present, evidence demonstrates that, while engaging in any physical activity is better than no activity, supporting students to initiate and maintain a regular exercise routine, incorporate both aerobic and resistance exercises into these routines, and moderate to high intensity training, may generate greater improvements in their mental and cognitive health. However, the majority of university students are not engaging in the level of exercise required to optimise these benefits (Kljajević et al., 2021), and many decreasing or discontinuing regular exercise upon starting university (Alkhateeb et al., 2019). Therefore, it is important to understand the factors that help or hinder students to engage in the recommended levels of exercise to support their mental and cognitive health.

Throughout the last decade, there has been more than 7,000 articles published seeking to identify the factors that influence university students' participation in physical activity. Within this literature, low rates of physical activity among students are largely attributed to

the challenges that accompany the transition to university life. For example, new academic pressures consistently shift students' priorities towards performing well at university over initiating or maintaining a regular exercise routine (Ferreira Silva et al., 2022). This barrier is just one of many other factors identified in the breadth of literature evaluating the determinants of university students' physical activity. This body of work has largely been motivated by a recognition that understanding these factors is an important step towards developing effective targeted interventions to promote active lifestyles among university students. However, this evidence is yet to be synthesised in a way that can easily be translated to achieve this goal. Indeed, such a synthesis requires framing within theoretically derived frameworks directly linked to intervention development tools, such as the BCW. Such a synthesis would enable the development of an evidence-based intervention that purposely and effectively targets the factors that influence students' participation in physical activity. Taking this approach has the potential to enhance the impacts of behavioural interventions designed to increase students' activity.

In the context of developing an evidence-based exercise intervention to support university students mental and cognitive health, educating students about the mechanisms underpinning these benefits could facilitate their engagement with and acceptance of an exercise-based intervention. While knowledge alone is not sufficient to change behaviour, it is a necessary component of behaviour change (Arlinghaus & Johnston, 2018) and can increase the acceptability of an intervention (Sekhon et al., 2017). Given students prioritise performing well at university, a neuroscience informed exercise-based intervention may be especially salient for students. For instance, students may be receptive to programs that emphasise the positive brain effects of exercise and neuroscientific evidence that shows it can optimise their cognition to study well and buffer their stress to support their academic success. A program that emphasises the positive brain benefits of exercise may also be more

acceptable than a program that focuses on treating “mental illness” (Chapman et al., 2021), especially for students who are reluctant to engage in these programs if they do not identify as someone who is mentally ill or needs mental health support. Despite the potential benefits of integrating neuroscientific insights regarding the mental and cognitive health benefits of exercise into the content and messaging of a behaviour change intervention for university students, such an approach has not been adopted or evaluated. Such an approach, developed using the BCW, may demonstrate substantial benefits for supporting’ students mental and cognitive health through physical exercise.

In light of the above, the current thesis aimed to:

1. Identify barriers and facilitators to university students’ participation in physical activity, including exercise, and map these factors to the TDF and COM-B model
2. Apply the BCW process to co-design a theoretically robust, neuroscience-informed, scalable, exercise-based intervention called the PEAK Mood, Mind and Marks program (i.e., PEAK) to support university students’ mental and cognitive health, and
3. To conduct a pilot of the PEAK program and: (i) evaluate its impacts on students’ exercise engagement and perceived mental and cognitive health, and (ii) to assess implementation outcomes.

To address the aims of the thesis, the studies to follow are:

1. Study One: Key Influences on University Students’ Physical Activity: a Systematic Review Using the Theoretical Domains Framework and the COM-B Model of Human Behaviour
2. Study Two: PEAK Mood, Mind and Marks: Development of an Intervention to Support University Students’ Mental and Cognitive Health through Physical Exercise

3. Study Three: PEAK Mood, Mind and Marks: a Pilot Study of an Intervention to Support University Students' Mental and Cognitive Health through Physical Exercise

CHAPTER FOUR: Study One. Systematic Review

4.1 Explanatory Notes

The first study in this thesis sought to conduct a systematic review to synthesise the barriers and facilitators to university students' physical activity, map these factors to the TDF and COM-B model, and rank the relative importance of TDF domains. An established process by Atkins et al., (2020) was used to (i) deductively code barriers and facilitators onto the TDF domains and COM-B subcomponents, (ii) group similar barriers and facilitators together and inductively general summary theme labels, and (iii) rank the relative importance of the TDF domains by considering the frequency across the number of studies, thematic elaboration, and evidence of mixed barriers/facilitators within each domain. Identifying the relative importance of theoretical domains is advantageous as it allows intervention designers to triage which behaviour change strategies should be prioritised in intervention development. This is the first study to synthesise university students' barriers and facilitators to physical activity in the context of behaviour change frameworks. Results from this study contribute to a comprehensive 'behavioural diagnosis' of changes needing to occur to promote students physical activity and can be used to guide intervention development.

4.2 Publication one: Key influences on university students' physical activity: a systematic review using the Theoretical Domains Framework and the COM-B model of human behaviour.

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Abstract

Background: Physical activity is important for all aspects of health, yet most university students are not active enough to reap these benefits. Understanding the factors that influence physical activity in the context of behaviour change theory is valuable to inform the development of effective evidence-based interventions to increase university students' physical activity. The current systematic review a) identified barriers and facilitators to university students' physical activity, b) mapped these factors to the Theoretical Domains Framework (TDF) and COM-B model, and c) ranked the relative importance of TDF domains.

Methods: Data synthesis included qualitative, quantitative and mixed-methods research published between 01.01.2010 - 15.03.2023. Four databases (MEDLINE, PsycINFO, SPORTDiscus, and Scopus) were searched to identify publications on the barriers/facilitators to university students' physical activity. Data regarding study design and key findings (i.e., participant quotes, qualitative theme descriptions, and survey results) were extracted. Framework analysis was used to code barriers/facilitators to the TDF and COM-B model. Within each TDF domain, thematic analysis was used to group similar barriers/facilitators into descriptive theme labels. TDF domains were ranked by relative importance based on frequency, elaboration, and evidence of mixed barriers/facilitators.

Results: Thirty-nine studies involving 17,771 participants met the inclusion criteria. Fifty-six barriers and facilitators mapping to 12 TDF domains and the COM-B model were identified as relevant to students' physical activity. Three TDF domains, environmental context and resources (e.g., time constraints), social influences (e.g., exercising with others), and goals (e.g., prioritisation of physical activity) were judged to be of greatest relative importance (identified in > 50% of studies). TDF domains of lower relative importance were intentions, reinforcement, emotion, beliefs about consequences, knowledge, physical skills, beliefs about

capabilities, cognitive and interpersonal skills, social/professional role and identity, and behavioural regulation. No barriers/facilitators relating to the TDF domains of memory, attention and decision process, or optimism were identified.

Conclusions: The current findings provide a foundation to enhance the development of theory and evidence informed interventions to support university students' engagement in physical activity. Interventions that include a focus on the TDF domains 'environmental context and resources,' 'social influences,' and 'goals,' hold particular promise for promoting active student lifestyles.

Registration: Prospero ID - CRD42021242170

Keywords: University Students; Physical Activity; Physical Exercise; Behaviour Change; COM-B; Theoretical Domains Framework; Barriers; Facilitators

Background

Physical activity (PA) has a powerful positive impact on all aspects of health. Regular PA can prevent and treat noncommunicable diseases (Naci & Ioannidis, 2013; Stensel et al., 2021), build resilience against the development of mental illness (Stubbs et al., 2018), and attenuate cognitive decline (Hotting & Roder, 2013). Given these pervasive health benefits, increasing participation in PA is recognised as a global priority by international public health organisations. Indeed, a core aspect of the World Health Organisation's action plan for a "healthier world" is to achieve a 15% reduction in the global prevalence of physical inactivity by 2030 (World Health Organization, 2019).

Despite international efforts to reduce physical inactivity, university students frequently do not meet the recommended level of PA required to attain its health benefits. Approximately 40-50% of university students are physically inactive (Keating et al., 2005), many of whom attribute their inactivity to unique challenges associated with university life. For many students, the transition to university coincides with new academic, social, financial, and personal responsibilities (Worsley et al., 2021), disrupting established routines and imposing additional barriers to the initiation or maintenance of healthy lifestyle habits such as regular PA (Romaguera et al., 2011). Students' PA tends to decline further during periods of high stress and academic pressure, such as exams and assignment deadlines (Deliens et al., 2015). This pattern has been observed across diverse university populations and cultural contexts (Buckworth & Nigg, 2004; Nelson et al., 2009; Rouse & Biddle, 2010), highlighting the importance of understanding the factors that contribute to physical inactivity among this cohort globally.

Understanding the barriers and facilitators to PA in the context of the university setting is an important step in developing effective targeted interventions to promote active lifestyles among university students. A recently published systematic review found that lack

of time, motivation, access to places to practice PA, and financial resources were primary barriers to PA for undergraduate university students (Ferreira Silva et al., 2022). A corresponding and complementary synthesis of the facilitators of PA, however, has not yet been conducted. Such a synthesis would be valuable in enabling a comprehensive understanding of the factors that influence students' PA and identifying facilitators that could be leveraged in intervention design. Furthermore, applying theoretical frameworks to understand barriers and facilitators to PA can guide the development of theory-informed, evidence-based interventions for university students that purposely and effectively target factors that influence their participation in PA.

The Theoretical Domains Framework (TDF) (Atkins et al., 2017; Cane et al., 2012; Michie, S et al., 2005) and the COM-B model of behaviour (Michie et al., 2011) are two robust, gold-standard frameworks frequently used to examine the determinants of human behaviour. The TDF is an integrated framework of 14 theoretical domains (see Additional File 1 for domains, definitions, and constructs) which provide a comprehensive understanding of the key factors driving behaviour. The TDF was developed through expert consensus, synthesising 33 psychological theories (such as social cognitive theory (Bandura, 1986, 2004) and the theory of planned behaviour (Ajzen, 1991, 2012) and 128 theoretical constructs (such as ‘competence’, ‘goal priority’, etc.) across disciplines identified as most relevant to the implementation of behaviour change interventions. Identifying the relative importance of theoretical domains allows intervention designers to triage which behaviour change strategies should be prioritised in intervention development (Atkins et al., 2020; Chung et al., 2023). The TDF has been widely applied by researchers and practitioners to systematically identify which theoretical domains are most relevant for understanding health behaviour change and policy implementation across a range of contexts, including education

(Weatherson et al., 2017), healthcare (Taylor et al., 2013), and workplace environments (Garne-Dalgaard et al., 2019).

The 14 TDF domains map onto the COM-B model (Figure 1), which is a broader framework for understanding behaviour and provides a direct link to intervention development frameworks. The COM-B model posits that no behaviour will occur without sufficient capability, opportunity, and motivation. Where any of these are lacking, they can be strategically targeted to support increased engagement in a desired behaviour, including participation in PA. Within the COM-B model, capability can be psychological (e.g., knowledge to engage in the necessary processes) or physical (e.g., physical skills); opportunity can be social (e.g., interpersonal influences) or physical (e.g., environmental resources); and motivation can be automatic (e.g., emotional reactions, habits) or reflective (e.g., intentions, beliefs). The COM-B model was developed through a process of theoretical analysis, empirical evidence, and expert consensus as a central part of a broader framework for developing behaviour change interventions known as the Behaviour Change Wheel (BCW) (Michie et al., 2011).

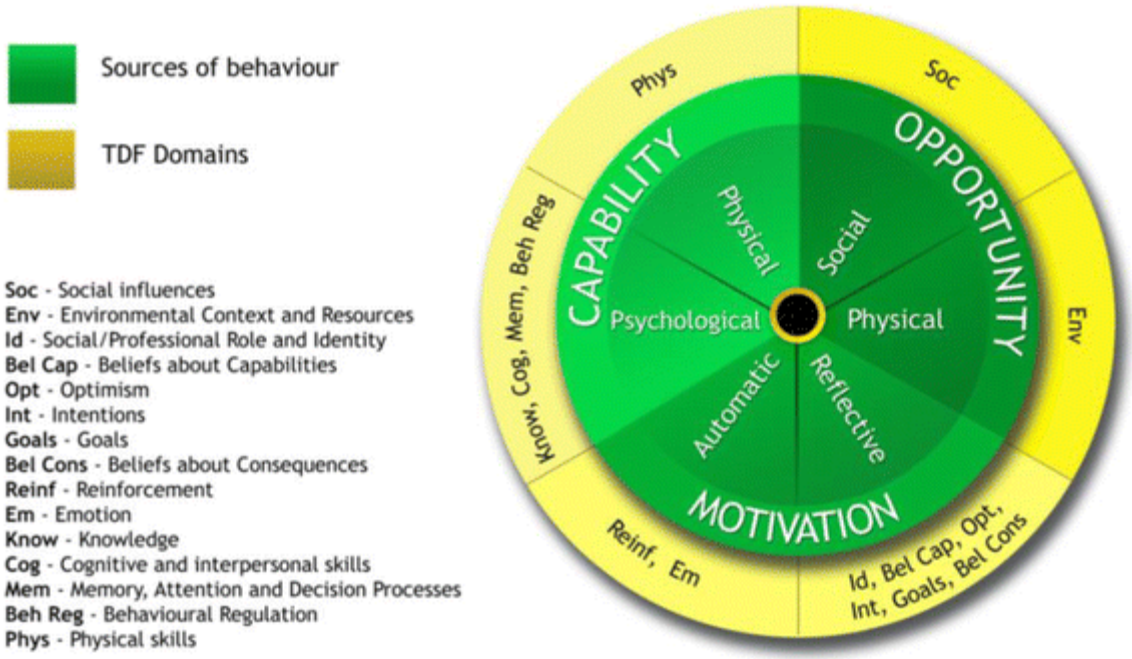

Figure 1. The TDF domains linked to the COM-B model subcomponents. Reproduced from Atkins, L., Francis, J., Islam, R. et al. (2017) A guide to using the Theoretical Domains Framework of behaviour change to investigate implementation problems. Implementation Sci 12, 77. https://doi.org/10.1186/s13012-017-0605-9

Using the TDF and COM-B model to understand the barriers and facilitators to university students' participation in PA is valuable to inform the development of effective evidence-based interventions that are tailored to address the most influential determinants of behaviour change. As such, this systematic review aimed to a) identify barriers and facilitators to university students' participation in PA, b) map these factors using the TDF and COM-B model and c) determine the relative importance of each TDF domain.

Methods

Study design

The systematic review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Page et al., 2021) (Additional File 2). The review protocol was registered on PROSPERO (CRD42021242170).

Search strategy

Search terms and parameters were developed in collaboration with a Monash University librarian with expertise in systematic review methodology. The following databases were searched on 15.03.2023 to identify relevant literature: MEDLINE, PsycINFO, and SPORTDiscus. Key articles were also selected for citation searching via Scopus. In consultation with a librarian, these databases were selected due to their unique scope, relevance, broad coverage, and utility. This process ensured the identified literature aligned with the aim and research topic of our systematic review. A 01.01.2010 - 15.03.2023 publication period was purposefully specified to account for the significant advancements in digital fitness support and tracking tools within the past decade (Fritz et al., 2014), All available records were searched using the following combination of concepts in the title or abstract of the article: 1) barriers, facilitators, or intervention[a], 2) physical activity, 3) university, and 4) students. Each search concept was created by first developing a list of search terms relevant to each concept (e.g., for the 'physical activity' concept search terms included 'physical exercise', 'physical fitness', 'sports', 'inactive', 'sedentary', etc). To create each concept, search terms were then searched collectively using the operator 'OR'. Each search concept was then combined into the final search by using the operator 'AND'.

[a] The term 'intervention' was included to identify student barriers and facilitators to engaging in implemented physical activity interventions.

Search terms related to concepts 1, 2 and 3 included indexed terms unique and relevant to each database (i.e., Medical Subject Heading Terms for MEDLINE, Index Terms for PsycINFO, and Thesaurus terms for SPORTDiscus). The search was performed according to Boolean operators (e.g., AND, OR) (see Additional File 3 for the complete search syntax for MEDLINE). Unpublished studies were not sought.

Selection criteria

Articles were included if they: (a) reported university students' self-reported barriers and/or facilitators to physical activity or exercise[b]; (b) were written in English; and (c) were peer-reviewed journal articles. Articles encompassed studies directly investigating barriers and/or facilitators to students' participation in PA and physical exercise intervention studies, where the latter reported participants' self-reported barriers and/or facilitators to intervention adherence (see Table 1 below for full criteria).

Table 1

Inclusion and Exclusion Criteria for Article Selection

Inclusion criteria	Exclusion criteria
Participants: ≥ 50% of sample are university students	Participants: Not university students
Content:	
Non-intervention studies and/or physical exercise-only intervention.	Intervention studies that targeted multiple health-related behaviours.

[b]Physical exercise is defined as "a subset of physical activity that is planned, structured, and repetitive", and purposefully focused on the improvement or maintenance of physical fitness, whereas physical activity is defined as "any bodily movement produced by skeletal muscles that results in energy expenditure" (Caspersen et al., 1985).

Outcome:	
Specific evaluation of self-reported barrier or facilitator to PA. Qualitative, quantitative, or mixed-methods.	Preferences related to PA. Associations or correlations with PA.
Context: University	Context: Other than university
Year published: 01.01.2010 - 15.03.2023	
Types of publication: Peer-reviewed journal articles	
Languages: English	

Note. Inclusion and exclusion criteria were guided by the PICOS and PICo frameworks (Tacconelli, 2010)

Study selection

Identified articles were uploaded to EndNote X9 software (The EndNote Team, 2013). A duplication detection tool was used to detect duplicates, which were then screened for accuracy by CB prior to removal. The remaining articles were uploaded to Covidence to enable blind screening and conflict resolution. Articles were screened at the title and abstract level against the inclusion and exclusion criteria by author CB, and 25% were independently screened by BP. The full-text of studies meeting the inclusion criteria was then screened

against the same criteria by CB and 25% were again independently screened by BP. Differences were resolved by an independent author (KR). Inter-rater agreement in screening between CB and BP was high (.96 for title and abstract screening, .83 for full-text screening). The decision to dual screen 25% of studies was strategically chosen to balance thoroughness with efficiency, ensuring both the validity of the screening criteria and the reliability of the primary screener's decisions. This approach aligns with the protocols used in similar systematic reviews in the field (e.g., (O'Mahony et al., 2020; Stuart & D'Lima, 2022)).

Data extraction

Key article characteristics were extracted, including the author/s, year of publication, country of origin, participant characteristics (e.g., enrolment status, exercise engagement [if reported]), sample size, research design, methods, and analytical approach. Barriers and facilitators were also extracted for each article and subsequently coded according to the 14 domains of the TDF and six subcomponents of the COM-B model. Quantitative data were only extracted if $\geq$50% of students endorsed a factor as a barrier or facilitator. This cut-off criterion was applied to maintain focus on the most common variables of influence and aligns with other reviews synthesising common barriers and facilitators to behaviour change (e.g., (Bouma et al., 2022; Garne-Dalgaard et al., 2019)).

A coding manual was developed to guide the process of mapping barriers and facilitators to the TDF and COM-B (Additional File 4). All articles were independently coded by at least two authors (CB and BS, BP or KR). The first version of the manual was developed a priori, based on established guides for applying the TDF and COM-B model to investigate barriers and facilitators to behaviour (Atkins et al., 2017; Michie et al., 2014), and updated as needed via regular consultation with a co-author and TDF/COM-B designer LA to ensure the accuracy of the data extraction. Barriers and facilitators were only coded to

multiple TDF domains if deemed essential to accurately contextualise the core elements of the barrier/facilitator, and when the data in individual papers was described in sufficient detail to indicate that more than one domain was relevant. For example, if 'lack of time due to competing priorities' was reported as a barrier to PA, this encompassed both the 'environmental context and resources' (i.e., time) and 'goals' (i.e., competing priorities) domains of the TDF. Coding conflicts were resolved via discussion with LA.

Data analysis

The following three-step method was utilised to synthesise quantitative and qualitative data:

1. Framework analysis (Gale et al., 2013) was conducted to deductively code barriers and facilitators onto TDF domains and COM-B subcomponents. This involved identifying barriers and facilitators in each article, extracting and labelling them, and determining their relevance against the definitions of the TDF domains and COM-B subcomponents. This process involved creating tables to assist the systematic categorisation of barriers and facilitators into relevant TDF domains and COM-B subcomponents.
2. Within each TDF domain, thematic analysis (Braun & Clarke, 2006) was conducted to group similar barriers and facilitators together and inductively generate summary theme labels.
3. The relative importance of each TDF domain was calculated according to frequency (number of studies), elaboration (number of themes) and the identification of mixed barriers/facilitators regarding whether a theme was a barrier or facilitator within each domain (e.g., if some participants reported that receiving encouragement from their family to exercise was a facilitator, and others reported that lack of encouragement

from their family to exercise was a barrier). Rank order was determined first by frequency, then elaboration, and finally by mixed barriers/facilitators.

This methodology follows previous studies using the TDF and COM-B to characterise barriers and facilitators to behaviour change and rank their relative importance (Atkins et al., 2020; Chung et al., 2023).

Results

Study characteristics

Following the removal of duplicates, 6,152 articles met the search criteria and were screened based on title and abstract. A total of 5,995 articles were excluded because they did not meet the inclusion criteria (see Figure 2 below for the PRISMA flowchart). After the title and abstract screening, 157 full-text articles were retrieved and assessed for eligibility. One additional article was identified and included following citation searching of selected key articles. Thirty-nine articles met the inclusion criteria (see Additional File 5 for a summary of these studies). Eight studies were conducted in the USA, seven in Canada, three in Germany, two each in Qatar, Spain, United Arab Emirates, and the United Kingdom and one each in Australia, Belgium, Columbia, Egypt, Ireland, Japan, Kuwait, Malaysia, New Zealand, Saudi Arabia, South Africa, Sri Lanka, and Uganda.

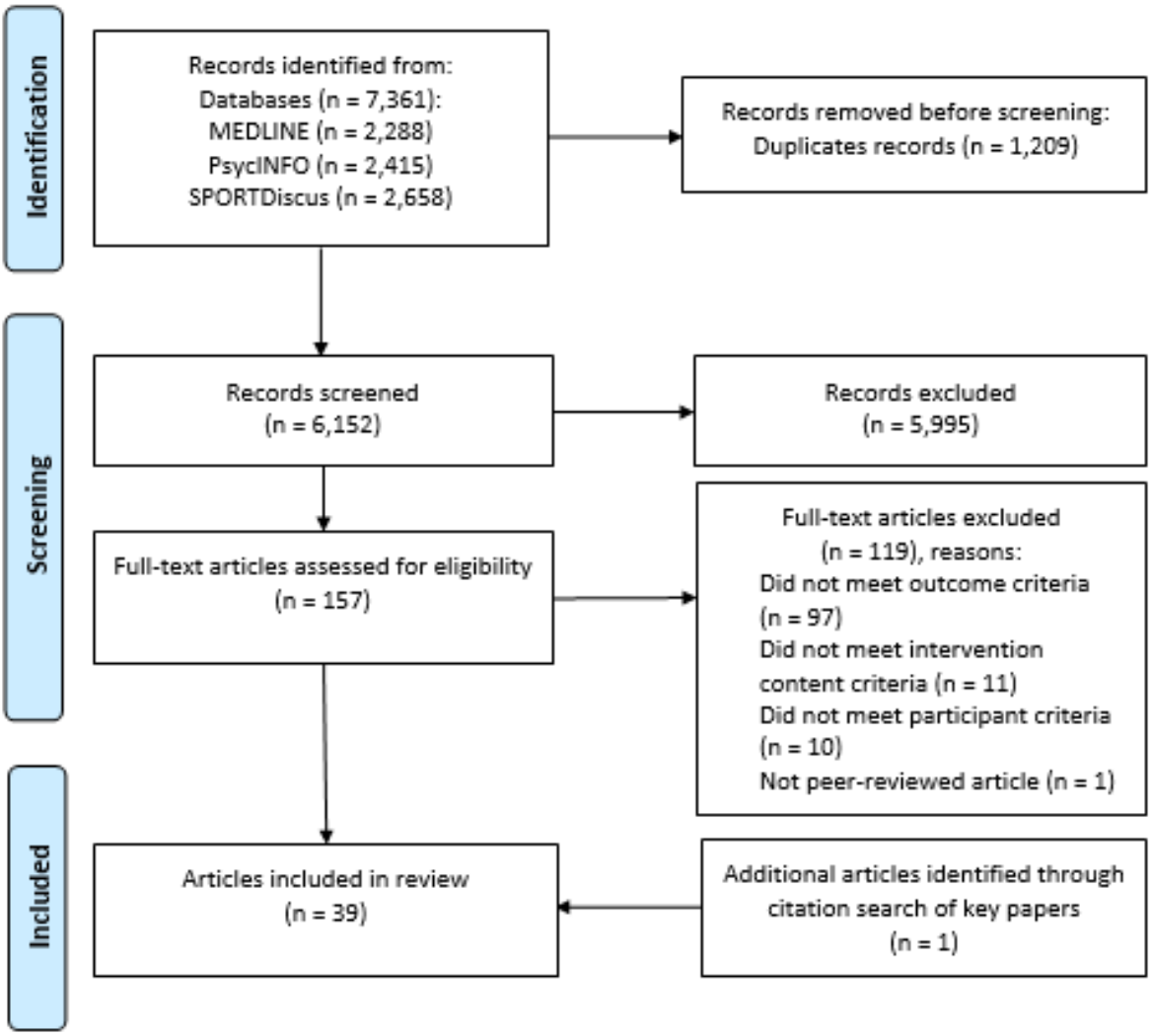

Figure 2. PRISMA flowchart illustrating the article selection process

Relative importance of TDF domains and COM-B components

Twelve of the 14 TDF domains and all six subcomponents of the COM-B model were identified as relevant to university students' PA. The rank order of relative importance of TDF domains and associated COM-B subcomponents are presented in Table 2. The three most relative important domains were identified in at least 54% of studies.

Table 2 Ranking the relative importance of each TDF domain according to the frequency of identification, thematic elaboration, and evidence of conflicting beliefs

Ranking	TDF Domain	COM-B Subcomponents	Frequency, no. of studies (%)	Elaboration, no. of themes	Evidence of mixed barriers/facilitators
1	Environmental context and resources	Physical opportunity	35(90)	12	Yes
2	Social influences	Social opportunity	28(72)	7	Yes
3	Goals	Reflective motivation	21(54)	3	Yes
4	Intentions	Reflective motivation	17(44)	3	Yes
5	Reinforcement	Automatic motivation	15(38)	8	Yes
6	Emotion	Automatic motivation	15(38)	2	Yes

7	Beliefs about consequences	Reflective motivation	12(31)	5	Yes
8	Knowledge	Psychological capability	11(28)	4	Yes
9	Physical skills	Physical capability	8(21)	3	Yes
10	Beliefs about capabilities	Reflective motivation	7(18)	2	Yes
11	Cognitive and interpersonal skills	Psychological capability	6(15)	1	Yes
12	Social/professional role and identity	Reflective motivation	3(8)	2	No
13	Behavioural regulation	Psychological capability	1(3)	2	No
14	Memory, attention and decision process	Psychological capability	0(0)	-	-
15	Optimism	Reflective motivation	0(0)	-	-

Barriers and facilitators to student's physical activity

Within the TDF domains, 56 total themes were identified, including 26 mixed barriers/facilitators, 18 facilitators and 12 barriers (Table 3). The barriers and facilitators identified within each TDF domain are summarised below (with associated COM-B subcomponent presented in parentheses), in order of relative importance:

1. Environmental context and resources (Physical Opportunity) (*n* = 90% studies)

   The most frequent barrier to PA across all TDF domains was 'lack of time', most often in the context of study demands. Time constraints were exacerbated by long commutes to university, family responsibilities, involvement in co-curricular activities, and employment commitments. Students' need for 'easily accessible exercise options, facilities and equipment' was a recurring theme. PA was deemed inaccessible if exercise facilities and other infrastructure to support PA, such as bike paths and running trails, were situated too far from the university campus or students' residences, or if fitness classes were scheduled at inconvenient times. 'Financial costs' emerged as a theme. The costs associated with accessing exercise facilities, equipment and programs consistently deterred students from engaging in PA. The desire for 'safe and enjoyable', 'weather appropriate' environments for PA were frequently reported. Participating in outdoor PA in green spaces or near water increased enjoyment, provided the environment felt safe and weather conditions were suitable for PA. Factors related to students' home, work, and university environment impacted their participation in 'incidental PA'. Incidental PA was influenced by whether students engaged in domestic house chores, and manual work, and actively commuted to university and between classes on-campus. Students' 'access to a variety of physical activities' and 'information provision regarding on-campus exercise options' impacted their PA. Students most often had access to a wide variety of physical activities,

however, it could be difficult to access information about what types of activities were available on-campus and how to sign up to participate. The 'lack of personalised physical activities to cater to individual fitness needs' was a barrier, particularly for students with low levels of PA who required beginner-oriented programs. Another barrier was the 'lack of university policy and promotion to encourage PA', which led students to perceive that there was no obligation to participate in PA and that the university did not value it. 'Health-concerning behaviours associated with university', including poor diet, increased alcohol intake and sedentary behaviour, negatively impacted students' PA. 'Listening to music while exercising' was a facilitator.

2. Social influences (Social Opportunity) (*n* = 72% studies)

   Within social influences, 'exercising with others' emerged as the most frequent theme. Doing so increased students' accountability, enjoyment and motivation, and helped them to overcome feelings of intimidation when exercising alone. Having a lack of friends to exercise with was a particular concern for students who were new to exercise or infrequently participated in PA. Receiving 'encouragement from others to be physically active', such as family members, friends, peers, and fitness instructors, shaped students' values toward PA and enhanced their motivation and self-efficacy. Students' family members, friends and teachers discouraged PA if it was not valued, or in favour of other priorities, such as academic commitments. Another recurrent theme was 'competition or relative comparison to others'. While most students were motivated by competition, a minority felt demotivated if they compared themselves to others with higher PA standards, especially if they failed to achieve similar PA goals. Sociocultural norms influenced barriers/facilitators to PA across different cultures, and between various groups, such as international versus domestic students, and women versus men. Students from Japan and Hawaii viewed PA as an important part of their

culture, in contrast to students from the Philippines who described the opposite. Participation in PA enabled international students to integrate with domestic students and learn about the local culture, however cultural segregation was a barrier to participation in university team sports. For female students from some middle-eastern countries, including Saudi Arabia, the UAE and Qatar, cultural norms made it impermissible for women to engage in PA, particularly compared to men. Religion also differentially impacted barriers/facilitators between women and men. Muslim women reported that Islamic practices, such as needing to engage in PA separately from men, be accompanied by a male family member while going outdoors, or dress modestly, posed additional barriers to PA. However, one study reported that Islamic teachings generally encouraged PA for both women and men by emphasising the importance of maintaining good health. Other gender-specific barriers were identified. Women often felt unwelcome or intimidated by men in exercise facilities, partly due to the perception that these facilities were tailored toward "masculine" sports and/or dominated by men. 'Being stared at while engaging in PA' was another barrier, impacting both women and students with a disability. A less common facilitator was the influence of both positive and negative 'exercise role models'. For example, students practiced PA because they aspired to be like someone who was physically active, or because they did not want to be like someone who was not physically active.

3. Goals (Reflective Motivation) (n = 54%)

   'Prioritisation of PA compared to other activities' was the most common theme within goals. Students frequently prioritised other activities, such as study, social activities, or work, over PA. However, those who played team sports or regularly practiced PA were more inclined to prioritise it for its recognised health benefits (i.e., stress

management), and its role in enhancing confidence. Additional facilitators included ‘engaging in PA to achieve an external goal’, such as improving one’s appearance, and ‘setting specific PA-related goals’ as a means to enhance accountability.

4. Intentions (Reflective Motivation) (*n* = 44%)

   Within intentions, ‘motivation to engage in PA’ was the most common theme. Students most often noted a lack of self-motivation for PA. Less frequent barriers included perceiving PA as an obligatory or necessary "chore", and ‘failing to follow through on intentions to engage in PA’. Conversely, ‘self-discipline to engage in PA’ emerged as a facilitator that assisted students in maintaining a regular PA routine.

5. Reinforcement (Automatic Motivation) (*n* = 38%)

   The most frequent facilitator within reinforcement was ‘experiencing the positive effects of PA’ on their health and wellbeing. These included physical health benefits (i.e., maintaining fitness), psychological benefits (i.e., stress reduction), and cognitive health benefits (i.e., enhanced academic performance). Conversely, barriers arose from ‘experiencing discomfort during or after PA’ due to pain, muscle soreness or fatigue. ‘Past and current habits and routines’ was a theme. Students were more likely to participate in PA if they had established regular exercise routines, and that forming these habits at an early age made it easier to maintain them later in life. However, maintaining a regular PA routine was difficult in the context of inflexible university schedules. Students’ ‘sense of accomplishment in relation to PA’ was a theme. Students were less likely to feel a sense of accomplishment after participating in PA if it was not physically challenging. Consistent facilitators were ‘receiving positive feedback from others’ after engaging in PA, such as compliments, and ‘receiving incentives’, such as reducing the cost of gym memberships if students participated in

more PA. ‘Experiencing a sense of achievement’ after reaching a PA-related goal or winning a sports match also served as a facilitator.

6. Emotion (Automatic Motivation) (*n* = 38%)

   ‘Enjoyment’ was the most frequently cited emotional theme. Most students reported that PA was fun and/or associated with positive feelings, however, a minority described PA as unenjoyable, boring, and repetitive. Students’ ‘poor mental health and negative affectivity’ (such as feeling sad, stressed or self-conscious, as well as fear of injury and pain), adversely impacted their motivation to be physically active.

7. Beliefs about consequences (Reflective Motivation) (*n* = 31%)

   ‘Beliefs about the physical health consequences of PA’ was the most recurrent barrier/facilitator. Most students understood that PA was essential for maintaining good health and preventing illness. However, some students who rarely or never engaged in PA believed they could delay pursuing an active lifestyle until they were older without compromising their health. Participating in PA to ‘maintain or improve one’s physical appearance’ acted as a facilitator. This motivation was most often cited in contexts such as increasing or decreasing weight, changing body shape or enhancing muscle tone. Beliefs about the positive environmental, occupational and psychological impacts of PA also served as facilitators. Students were motivated to participate in PA due to the environmental benefits of using active transport. They also acknowledged the importance of being physically fit for work and believed that being active was beneficial for mental health. ‘Receiving advice to participate in PA from a credible source’, such as a health professional, further facilitated students’ motivation to be active.

8. Knowledge (Psychological Capability) (*n* = 28%)

'Knowledge about the benefits of PA', encompassing an understanding of the various types of benefits (i.e., physical, mental, or cognitive) and the biological mechanisms by which PA brings about these changes was identified as the most common knowledge theme. Being aware of these benefits positively influenced students' motivation to be physically active. Conversely, students' lack of knowledge about the gym environment and the programs available were barriers to PA. Regarding the gym environment, students' 'lack of knowledge about how to navigate through the gym, what exercises to do, and how to use exercise equipment' amplified feelings of intimidation. Likewise, 'lack of knowledge about the types of exercise programs and activities that were available on-campus, and how to sign up to participate' were all barriers. A unique theme emerged concerning 'knowledge about how to adapt physical activities for students with a disability'. Students with a disability described how fitness instructors often had a limited understanding of how to modify activities to enable them to participate. However, students with a disability were able to overcome this barrier if they possessed their own knowledge about how to tailor physical activities to meet their specific needs.

9. Physical skills (Physical Capability) (*n* = 21%)

   The most prevalent theme within physical skills was 'having the physical skills and fitness to participate in PA'. A lack of physical skills was most frequently a hindrance to PA. Additional obstacles to PA included being physically inhibited due to a 'lack of energy' or 'physical injury'.

10. Beliefs about capabilities (Reflective Motivation) (*n* = 18%)

    Within beliefs about capabilities, 'self-efficacy to participate in PA' was the most recurrent theme. Students who doubted their success in becoming physically active or who lacked confidence in their ability to initiate PA or participate in sport were less

motivated to take part. A less frequent facilitator was students' 'self-affirmation to participate in PA', often referring to positive cognitions about one's own physical abilities.

11. Cognitive and interpersonal skills (Psychological Capability) (*n* = 15%)

    'Time-management' was the only theme identified within cognitive and interpersonal skills. Students who struggled to manage their time effectively found it difficult to incorporate regular PA into their daily routine.

12. Social/professional role and identity (Reflective Motivation) (*n* = 8%)

    The most frequent theme within social/professional role and identity was 'perceiving PA as a part of one's self-identity'. Students who engaged regularly in PA often considered it integral to their identity. Conversely, students who perceived they did not align with the aesthetic and superficial stereotypes commonly associated with the fitness industry felt less motivated to be active. A specific facilitator emerged among physiotherapy students, who were motivated to be active due to the emphasis on PA within their profession.

13. Behavioural regulation (Psychological Capability) (*n* = 3%)

    Within the domain of behavioural regulation, two facilitators were equally prevalent: 'self-monitoring of PA' and 'feedback on progress towards a PA-related goal'. By keeping track of their step count and receiving feedback on walking goals, students were motivated to exceed the average number of daily steps or achieve their personal PA targets.

14. Memory, attention, and decision process (Psychological Capability); Optimism (Reflective Motivation) (*n* = 0%)

No barriers or facilitators relating to the TDF domains of memory, attention and decision process, or optimism were identified.

Table 3. Summary of barriers to and facilitators of physical activity

COM-B Component	Theme	No. (%) of studies, (*n*=39 max)	Barrier/ facilitator/ mixed	Study ID	Example excerpts and quote(s)
Capability (Physical)	TDF Domain: Skills (Physical)				
	Having the physical skills and fitness to participate in PA	5(13)	Mixed	Barrier (Bellows-Riecken et al., 2013; Diehl et al., 2018; Ramírez-Vélez, 2015) Facilitator (Lerner et al., 2011)	Barrier *Lack of skill.* (Ramírez-Vélez, 2015) Facilitator *Improvement of skills.* (Lerner et al., 2011)

COM-B Component	Theme	No. (%) of studies, (*n*=39 max)	Barrier/ facilitator/ mixed	Study ID	Example excerpts and quote(s)
				Mixed (Snyder et al., 2017)	
	Lack of energy	2(5)	Barrier	(Bellows-Riecken et al., 2013; Walsh et al., 2018)	*"Some days my energy is low which makes it hard to get going."* (Bellows-Riecken et al., 2013)
	Physical injury	2(5)	Barrier	(Deliens et al., 2015; Forrest & Bruner, 2017)	*"I had to quit basketball because of torn ligaments"* (Deliens et al., 2015)

COM-B Component	Theme	No. (%) of studies, (*n*=39 max)	Barrier/ facilitator/ mixed	Study ID	Example excerpts and quote(s)
Capability (Psychological)	TDF Domain: Knowledge				
	Knowledge about the benefits of PA	5(13)	Mixed	Barrier (Deliens et al., 2015) Facilitator (Leinberger-Jabari et al., 2023; Othman et al., 2022; Ranasinghe et al., 2016)	Barrier "*People don't know about the benefits of physical activities*" (Burton et al., 2021) Facilitator *"If I know how the exercise activity or the exercise module can benefit me, like what I can get in return, only then am I motivated to do it".* (Othman et al., 2022)

COM-B Component	Theme	No. (%) of studies, (*n*=39 max)	Barrier/ facilitator/ mixed	Study ID	Example excerpts and quote(s)
				Mixed (Burton et al., 2021)	
	Lack of knowledge about how to navigate through the gym, what exercises to do and how to use exercise equipment	4(10)	Barrier	(LaCaille et al., 2011; Monforte et al., 2021; Othman et al., 2022; Silver et al., 2019)	*"It's a bit intimidating for one. Especially when you don't know how to navigate through the building, like what to do or maybe how to use equipment"* (Silver et al., 2019)

COM-B Component	Theme	No. (%) of studies, (*n*=39 max)	Barrier/ facilitator/ mixed	Study ID	Example excerpts and quote(s)
	Lack of knowledge about the types of exercise programs and activities that were available on-campus, and how to sign up to participate	2(5)	Barrier	(Brunette et al., 2011; Deliens et al., 2015)	*"I think some students like to try sports like hockey but they don't know where to go"* (Brunette et al., 2011)
	Knowledge about how to adapt physical activities for students with a disability to participate	2(5)	Mixed	Barrier (Monforte et al., 2021) Mixed	Barrier *"If they [staff] don't know the easy ways to adapt activities and that it's important for us to be active, then how are things ever going to change?"* (Devine, 2016)

COM-B Component	Theme	No. (%) of studies, (*n*=39 max)	Barrier/ facilitator/ mixed	Study ID	Example excerpts and quote(s)
				(Devine, 2016)	Facilitator *Denise [an undergraduate student with a disability] indicated she would modify the dance steps to be included.* (Devine, 2016)
	TDF Domain: Skills (Cognitive and interpersonal)				
	Time-management	6(15)	Mixed	Barrier (Kwan & Faulkner, 2011; Ranasinghe et al., 2016)	Barrier *Lack of appropriate time management to include exercise into daily routine.* (Ranasinghe et al., 2016) Facilitator

COM-B Component	Theme	No. (%) of studies, (*n*=39 max)	Barrier/ facilitator/ mixed	Study ID	Example excerpts and quote(s)
				Facilitator (Burton et al., 2021; LaCaille et al., 2011; J. Pan & Nigg, 2011; Wilson et al., 2019)	*"Time management had to be improved because I had more responsibilities, more of a social life and greater pressure from university work."* (Wilson et al., 2019)
	TDF Domain: Behavioural regulation				
	Self-monitoring of PA	1(3)	Facilitator	(Tong et al., 2018)	*"The important part for me is [keeping track] – I know I'm going beyond the average, like the normal number of steps for a person […]*

COM-B Component	Theme	No. (%) of studies, (*n*=39 max)	Barrier/ facilitator/ mixed	Study ID	Example excerpts and quote(s)
					- *it makes me more motivated."* (Tong et al., 2018)
	Feedback on progress towards a PA-related goal	1(3)	Facilitator	(Tong et al., 2018)	*"When I […] got 80% of my goal, [I would just] go aimlessly for a walk. So that was getting me to walk more. Solely because I was on 80% and I wanted that 100%."* (Tong et al., 2018)
Motivation (Reflective)	TDF Domain: Social professional role and identity				
	Perceiving PA as a part of one's self-identity	2(5)	Mixed	Barrier (Monforte et al., 2021)	Barrier *"It was difficult for me to make a comeback to sport and I started in a gym that I think it was horrible, to be honest, I didn't like it. I don't*

COM-B Component	Theme	No. (%) of studies, (*n*=39 max)	Barrier/ facilitator/ mixed	Study ID	Example excerpts and quote(s)
				Facilitator (Bellows-Riecken et al., 2013)	*know, maybe because I saw an aspect of sport that I didn't contemplate in my life, in my story. Which was seeing sport simply for beauty purposes, you know what I mean. For the physical appearance, more superficial. So, I have always been very sensitive towards those things, you know what I mean."* (Monforte et al., 2021) Facilitator *"It is part of my identity"* (Bellows-Riecken et al., 2013)

COM-B Component	Theme	No. (%) of studies, (*n*=39 max)	Barrier/ facilitator/ mixed	Study ID	Example excerpts and quote(s)
	Students own professional role as a health practitioner motivates PA	1(3)	Facilitator	(Ranasinghe et al., 2016)	"*We being physiotherapists, can't tell others to exercise without us doing them. There is a motivation from our profession to exercise."* (Ranasinghe et al., 2016)
	TDF Domain: Beliefs about capabilities				
	Self-efficacy to participate in PA	5(13)	Mixed	Barrier (Burton et al., 2021; Deliens et al., 2015; Kwan & Faulkner, 2011;	Barrier *"When I was very young I tried sports but I am not good at it. When we are not good at something we do not perform. So subsequently you detach from it. So after that I did not try to get involve in sports. Because I have no ability in that. I*

COM-B Component	Theme	No. (%) of studies, (*n*=39 max)	Barrier/ facilitator/ mixed	Study ID	Example excerpts and quote(s)
				Ranasinghe et al., 2016)	*tried to improve something that I am good at."* (Ranasinghe et al., 2016)
				Facilitator (Snyder et al., 2017)	Facilitator *The majority of students (n = 22) felt successful and confident in their abilities to take part in their current exercise activities.* (Snyder et al., 2017)
	Self-affirmation to participate in PA	2(5)	Facilitator	(Diehl et al., 2018; Marmo, 2013)	*"I'm here, I've gotten dressed, I've arrived at the gym, I've put in the effort, let's start and finish this workout"* (Marmo, 2013)

COM-B Component	Theme	No. (%) of studies, (*n*=39 max)	Barrier/ facilitator/ mixed	Study ID	Example excerpts and quote(s)
	TDF Domain: Intentions				
	Motivation to engage in PA	14(36)	Mixed	Barrier (Bellows-Riecken et al., 2013; Burton et al., 2021; El Gilany et al., 2011; Goldstein et al., 2018; Griffiths et al., 2022; Hilger-Kolb	Barrier *The top three perceived barriers included… lack of motivation (59.0%)* (King et al., 2014) Facilitator *Insistence and persistence in being physically active.* (Devine, 2016)

COM-B Component	Theme	No. (%) of studies, (*n*=39 max)	Barrier/ facilitator/ mixed	Study ID	Example excerpts and quote(s)
				et al., 2020; King et al., 2014; Nannyonjo et al., 2013; Othman et al., 2022; J. Pan & Nigg, 2011; Ramírez-Vélez, 2015; Snyder et al., 2017)	

COM-B Component	Theme	No. (%) of studies, (*n*=39 max)	Barrier/ facilitator/ mixed	Study ID	Example excerpts and quote(s)
				Facilitator (Devine, 2016) Mixed (LaCaille et al., 2011)	
	Perception that PA is a chore	2(5)	Barrier	(Bellows-Riecken et al., 2013; Walsh et al., 2018)	*"See it as a task or chore you have to do to get out of the way so you can do something else."* (Bellows-Riecken et al., 2013)

COM-B Component	Theme	No. (%) of studies, (*n*=39 max)	Barrier/ facilitator/ mixed	Study ID	Example excerpts and quote(s)
	Failure to follow through on intentions to engage in PA	2(5)	Barrier	(Kwan & Faulkner, 2011; Snyder et al., 2017)	*"Well, I came in here thinking I would swim everyday or something, cause they have a number of swimming pools you know. But that just didn't happen."* (Kwan & Faulkner, 2011)
	Self-discipline to engage in PA	2(5)	Facilitator	(Deliens et al., 2015; Othman et al., 2022)	*"You can be physically active when you have enough self-discipline to do it"* (Deliens et al., 2015)
	TDF Domain: Beliefs about consequences				
	Beliefs about the physical health consequences of PA	9(23)	Mixed	Barrier (Silver et al., 2019)	Barrier *Exercise could wait until graduation without compromising overall health.* (Silver et al., 2019)

COM-B Component	Theme	No. (%) of studies, (*n*=39 max)	Barrier/ facilitator/ mixed	Study ID	Example excerpts and quote(s)
				Facilitator (Deliens et al., 2015; Diehl et al., 2018; Lerner et al., 2011; Marmo, 2013; Miyawaki et al., 2019; Othman et al., 2022; J. Pan & Nigg,	Facilitator *"You need to be active to prevent yourself from having open heart surgery"* (Marmo, 2013)

COM-B Component	Theme	No. (%) of studies, (*n*=39 max)	Barrier/ facilitator/ mixed	Study ID	Example excerpts and quote(s)
				2011; Pellerine et al., 2022)	
	Maintaining or improving one's physical appearance	5(13)	Facilitator	(Diehl et al., 2018; Lerner et al., 2011; Miyawaki et al., 2019; Othman et al., 2022; Pellerine et al., 2022)	*The most cited motivators to exercise were improved [...] physical appearance.* (Pellerine et al., 2022)

COM-B Component	Theme	No. (%) of studies, (*n*=39 max)	Barrier/ facilitator/ mixed	Study ID	Example excerpts and quote(s)
	Beliefs about the environmental and occupational benefits of exercise	3(8)	Facilitator	(Bellows-Riecken et al., 2013; Brunette et al., 2011; Marmo, 2013)	*"I like the speediness of my bike and not having to rely on the buses, plus it is better for the environment"* (Bellows-Riecken et al., 2013)
	Beliefs about the psychological benefits of exercise	3(8)	Facilitator	(Diehl et al., 2018; J. Pan & Nigg, 2011; Pellerine et al., 2022)	*Psychological benefits.* (J. Pan & Nigg, 2011)

COM-B Component	Theme	No. (%) of studies, (*n*=39 max)	Barrier/ facilitator/ mixed	Study ID	Example excerpts and quote(s)
	Receiving advice to exercise from a credible source (e.g., health professionals)	2(5)	Facilitator	(Aljayyousi et al., 2019; J. Pan & Nigg, 2011)	*Being physically active for health is not a concern unless prescribed by the doctor.* (J. Pan & Nigg, 2011)
	TDF Domain: Goals				
	Prioritisation of PA compared to other activities	20(51)	Mixed	Barrier (Bellows-Riecken et al., 2013; Deliens et al., 2015; Diehl et al., 2018; El Gilany et al.,	Barrier *Being students, academic performance had become their priority and it had outweighed the perceived health benefits from exercise.* (Othman et al., 2022) Facilitator

COM-B Component	Theme	No. (%) of studies, (*n*=39 max)	Barrier/ facilitator/ mixed	Study ID	Example excerpts and quote(s)
				2011; Forrest & Bruner, 2017; Griffiths et al., 2022; Hilger-Kolb et al., 2020; King et al., 2014; Kwan & Faulkner, 2011; LaCaille et al., 2011;	*[Participants who frequently exercised] saw exercise as something that needed to be prioritised.* (Silver et al., 2019)

COM-B Component	Theme	No. (%) of studies, (*n*=39 max)	Barrier/ facilitator/ mixed	Study ID	Example excerpts and quote(s)
				Lerner et al., 2011; Marmo, 2013; Nannyonjo et al., 2013; Othman et al., 2022; J. Pan & Nigg, 2011; Pellerine et al., 2022; Ranasinghe et	

COM-B Component	Theme	No. (%) of studies, (*n*=39 max)	Barrier/ facilitator/ mixed	Study ID	Example excerpts and quote(s)
				al., 2016; Snyder et al., 2017) Mixed (Silver et al., 2019; Walsh et al., 2018)	
	Engaging in PA to achieve an external goal	4(10)	Facilitator	(King et al., 2014; Marmo, 2013; J. Pan & Nigg,	*Students chose to engage in activities because they deemed them valuable and a necessary component of achieving an external goal* (Snyder et al., 2017)

COM-B Component	Theme	No. (%) of studies, (*n*=39 max)	Barrier/ facilitator/ mixed	Study ID	Example excerpts and quote(s)
				2011; Snyder et al., 2017)	
	Setting specific PA-related goals	1(3)	Facilitator	(Tong et al., 2018)	*Many participants expressed that they benefited from goal setting. They believed that setting a goal… kept them accountable for their physical activity performance and motivated them to reach that goal* (Tong et al., 2018)
Motivation (Automatic)	TDF Domain: Reinforcement				
	Experiencing the positive benefits of PA	9(23)	Facilitator	Facilitator (Bellows-Riecken et al., 2013; Brunette et	Facilitator *"I love the therapeutic benefits of going on a run when I am stressed."* (Bellows-Riecken et al., 2013)

COM-B Component	Theme	No. (%) of studies, (*n*=39 max)	Barrier/ facilitator/ mixed	Study ID	Example excerpts and quote(s)
				al., 2011; Burton et al., 2021; Deliens et al., 2015; Diehl et al., 2018; King et al., 2014; LaCaille et al., 2011; Othman et al., 2022; Silver et al., 2019)	

COM-B Component	Theme	No. (%) of studies, (*n*=39 max)	Barrier/ facilitator/ mixed	Study ID	Example excerpts and quote(s)
	Past and current habits and routines	7(18)	Mixed	Barrier (Hilger-Kolb et al., 2020) Facilitator (Bellows-Riecken et al., 2013; Deliens et al., 2015; Diehl et al., 2018;	Barrier *"I prefer doing things regularly and somehow the hobby, the physical activity, it's suffering from this [inflexible university schedule]"* (Hilger-Kolb et al., 2020) Facilitator *In various ways, participants articulated the idea that developing an exercise habit at a young age renders benefits throughout life* (Silver et al., 2019)

COM-B Component	Theme	No. (%) of studies, (*n*=39 max)	Barrier/ facilitator/ mixed	Study ID	Example excerpts and quote(s)
				Othman et al., 2022; J. Pan & Nigg, 2011; Silver et al., 2019)	
	Experiencing discomfort during or after PA	3(8)	Barrier	(Bellows-Riecken et al., 2013; Nolan et al., 2011; Othman et al., 2022)	*"The thing about exercise that I don't like is that after exercise, especially when the body is just beginning to adapt to exercising, I'll get body aches and pain after".*(Othman et al., 2022)

COM-B Component	Theme	No. (%) of studies, (*n*=39 max)	Barrier/ facilitator/ mixed	Study ID	Example excerpts and quote(s)
	Sense of accomplishment in relation to PA	2(5)	Mixed	Barrier (Bellows-Riecken et al., 2013) Facilitator (Snyder et al., 2017)	Barrier *"[Running] never puts me outside my comfort zone or challenges me…"* (Bellows-Riecken et al., 2013) Facilitator *Over half (n = 15) cited feeling a sense of accomplishment when they exercised* (Snyder et al., 2017)
	Receiving positive feedback from others	1(3)	Facilitator	(Marmo, 2013)	*Additionally, when compliments and positive feedback were given, although not inherently persuasive in nature, students felt these messages increased their efficacy and*

COM-B Component	Theme	No. (%) of studies, (*n*=39 max)	Barrier/ facilitator/ mixed	Study ID	Example excerpts and quote(s)
					encouraged them to continue to be physically active. (Marmo, 2013)
	Receiving incentives	1(3)	Facilitator	(Burton et al., 2021)	*"Making offers will help—if they do many exercise then they have to pay less to use the gym"* (Burton et al., 2021)
	Experiencing a sense of achievement	1(3)	Facilitator	(Lerner et al., 2011)	*It was found that fun and enjoyment in physical activity/sport is associated primarily with… goal achievement/winning* (Lerner et al., 2011)
	TDF Domain: Emotion				
	Enjoyment	10(26)	Mixed	Barrier (Burton et al., 2021; Deliens et al., 2015;	Barrier *"I don't like any kind of sport"* (Deliens et al., 2015)

COM-B Component	Theme	No. (%) of studies, (*n*=39 max)	Barrier/ facilitator/ mixed	Study ID	Example excerpts and quote(s)
				Hilger-Kolb et al., 2020)	Facilitator
					"Getting the heart rate up is always enjoyable." (Bellows-Riecken et al., 2013)
				Facilitator (Aljayyousi et al., 2019; Brunette et al., 2011; Diehl et al., 2018; Miyawaki et al., 2019; J.	

COM-B Component	Theme	No. (%) of studies, (*n*=39 max)	Barrier/ facilitator/ mixed	Study ID	Example excerpts and quote(s)
				Pan & Nigg, 2011) Mixed (Bellows-Riecken et al., 2013; Othman et al., 2022)	
	Poor mental health and negative affectivity (e.g., fear, sadness, self-consciousness, stress)	8(21)	Barrier	(Burton et al., 2021; Hilger-Kolb et al., 2020;	*"My mood definitely impacts my activity behavior. Like if I'm feeling down or like I don't know it's harder for me to get to the gym and I know it's better for me to go to the gym, like I*

COM-B Component	Theme	No. (%) of studies, (*n*=39 max)	Barrier/ facilitator/ mixed	Study ID	Example excerpts and quote(s)
				Leinberger-Jabari et al., 2023; Marmo, 2013; Nannyonjo et al., 2013; Othman et al., 2022; Ramírez-Vélez, 2015; Silver et al., 2019)	*always know I'm going to feel better, but sometimes I just don't feel like it or I'm super down or I don't know and then I just even feel like doing anything"* (Marmo, 2013)

COM-B Component	Theme	No. (%) of studies, (*n*=39 max)	Barrier/ facilitator/ mixed	Study ID	Example excerpts and quote(s)
Opportunity (Physical)	TDF Domain: Environmental context and resources				
	Lack of time	25(64)	Barrier	(Awadalla et al., 2014; Bellows-Riecken et al., 2013; Burton et al., 2021; Chaabna et al., 2022; Cooke et al., 2013; Deliens et al., 2015; Diehl et al.,	*"I became aware of the barriers … where you'll be studying at night time and you wouldn't have time to do any exercise and you're working all day, so …"* (Cooke et al., 2013)

COM-B Component	Theme	No. (%) of studies, (*n*=39 max)	Barrier/ facilitator/ mixed	Study ID	Example excerpts and quote(s)
				2018; El Gilany et al., 2011; Forrest & Bruner, 2017; Goldstein et al., 2018; Griffiths et al., 2022; Kwan & Faulkner, 2011; LaCaille et	

COM-B Component	Theme	No. (%) of studies, (*n*=39 max)	Barrier/ facilitator/ mixed	Study ID	Example excerpts and quote(s)
				al., 2011; Leinberger-Jabari et al., 2023; Lerner et al., 2011; Musaiger et al., 2014; Nannyonjo et al., 2013; Othman et al., 2022; J. Pan & Nigg, 2011;	

COM-B Component	Theme	No. (%) of studies, (*n*=39 max)	Barrier/ facilitator/ mixed	Study ID	Example excerpts and quote(s)
				Pellerine et al., 2022; Quintiliani et al., 2012; Romaguera et al., 2011; Silver et al., 2019; Snyder et al., 2017; Wilson et al., 2019)	

COM-B Component	Theme	No. (%) of studies, (*n*=39 max)	Barrier/ facilitator/ mixed	Study ID	Example excerpts and quote(s)
	Easily accessible exercise options, facilities and equipment	24(62)	Mixed	Barrier (Diehl et al., 2018; Forrest & Bruner, 2017; Hilger-Kolb et al., 2020; Kwan & Faulkner, 2011; Nannyonjo et al., 2013; Nolan et al., 2011;	Barrier *"I know some people did not do it (exercise program), because they would have to go all the way down to lower residence to take the class … they wanted to join but it was a pain to go down (to lower residence) …"* (Forrest & Bruner, 2017) Facilitator "*Here on this university campus all sports facilities are close to one another and therefore it 'invites' to be physically active"* (Deliens et al., 2015)

COM-B Component	Theme	No. (%) of studies, (*n*=39 max)	Barrier/ facilitator/ mixed	Study ID	Example excerpts and quote(s)
				Ramírez-Vélez, 2015; Ranasinghe et al., 2016; Silver et al., 2019)	
				Facilitator (Deliens et al., 2015; LaCaille et al., 2011; J. Pan & Nigg,	

COM-B Component	Theme	No. (%) of studies, (*n*=39 max)	Barrier/ facilitator/ mixed	Study ID	Example excerpts and quote(s)
				2011; Quintiliani et al., 2012; Snyder et al., 2017)	
				Mixed (Aljayyousi et al., 2019; Bellows-Riecken et al., 2013; Brunette et	

COM-B Component	Theme	No. (%) of studies, (*n*=39 max)	Barrier/ facilitator/ mixed	Study ID	Example excerpts and quote(s)
				al., 2011; Burton et al., 2021; Devine, 2016; El Gilany et al., 2011; Leinberger-Jabari et al., 2023; Monforte et al., 2021; Othman et al.,	

COM-B Component	Theme	No. (%) of studies, (*n*=39 max)	Barrier/ facilitator/ mixed	Study ID	Example excerpts and quote(s)
				2022; Pellerine et al., 2022)	
	Financial costs	10(26)	Mixed	Barrier (Bellows-Riecken et al., 2013; Burton et al., 2021; Griffiths et al., 2022; LaCaille et al., 2011; Nannyonjo et	Barrier *"In all kinds of sports price is often a barrier to participate…"* (Deliens et al., 2015) Facilitator *Furthermore, free student recreation center memberships and intramural sports attracted increased participation due to financial pressures, such as the cost of equipment, and the*

COM-B Component	Theme	No. (%) of studies, (*n*=39 max)	Barrier/ facilitator/ mixed	Study ID	Example excerpts and quote(s)
				al., 2013; Ramírez-Vélez, 2015) Facilitator (Diehl et al., 2018; Monforte et al., 2021; Wilson et al., 2019) Mixed	*expense participating in club sports.* (Wilson et al., 2019)

COM-B Component	Theme	No. (%) of studies, (*n*=39 max)	Barrier/ facilitator/ mixed	Study ID	Example excerpts and quote(s)
				(Deliens et al., 2015)	
	Weather appropriate for PA	7(18)	Mixed	Barrier (Burton et al., 2021; Deliens et al., 2015; Hilger-Kolb et al., 2020; Monforte et al., 2021; Musaiger et al., 2014; J.	Barrier *The climate is not suitable for practising exercise.* (Musaiger et al., 2014) Facilitator *"We went snowboarding and skating. I like these two winter sports, because in Chine, in my city, there is hardly any snow in winter so there is no chance to do that."* (Brunette et al., 2011)

COM-B Component	Theme	No. (%) of studies, (*n*=39 max)	Barrier/ facilitator/ mixed	Study ID	Example excerpts and quote(s)
				Pan & Nigg, 2011) Facilitator (Brunette et al., 2011)	
	Safe and enjoyable environment	6(15)	Mixed	Barrier (El Gilany et al., 2011; Nannyonjo et al., 2013) Facilitator	Barrier *Lack of safe sporting places.* (El Gilany et al., 2011) Facilitator *…safe surroundings that encouraged walking recreationally* (Quintiliani et al., 2012)

COM-B Component	Theme	No. (%) of studies, (*n*=39 max)	Barrier/ facilitator/ mixed	Study ID	Example excerpts and quote(s)
				(Hilger-Kolb et al., 2020; Quintiliani et al., 2012) Mixed (Bellows-Riecken et al., 2013; Monforte et al., 2021)	
	Incidental PA (at home, work or university)	5(13)	Mixed	Barrier	Barrier

COM-B Component	Theme	No. (%) of studies, (*n*=39 max)	Barrier/ facilitator/ mixed	Study ID	Example excerpts and quote(s)
				(Quintiliani et al., 2012)	*Students employed in sedentary jobs (e.g., administrative assistant, tutor) perceived their job had a negative impact on their physical activity.* (Quintiliani et al., 2012)
				Facilitator	
				(Aljayyousi et al., 2019; Nannyonjo et al., 2013; J. Pan & Nigg, 2011)	Facilitator *Including PA into commute/going to places (walk to school, take stairs)* (J. Pan & Nigg, 2011)
				Mixed	

COM-B Component	Theme	No. (%) of studies, (*n*=39 max)	Barrier/ facilitator/ mixed	Study ID	Example excerpts and quote(s)
				(Von Sommoggy et al., 2020)	
	Access to a variety of physical activities	4(10)	Mixed	Barrier (Hilger-Kolb et al., 2020) Facilitator (Brunette et al., 2011; Diehl et al., 2018;	Barrier *Others named that the kind of sport they were interested in, was not offered by the university sports programme* (Hilger-Kolb et al., 2020) Facilitator *"The program offers every kind of activity imaginable, from climbing to kayaking and even field trips"* (Diehl et al., 2018)

COM-B Component	Theme	No. (%) of studies, (*n*=39 max)	Barrier/ facilitator/ mixed	Study ID	Example excerpts and quote(s)
				LaCaille et al., 2011)	
	Information provision regarding on-campus exercise options	4(10)	Mixed	Barrier (Hilger-Kolb et al., 2020; Kwan & Faulkner, 2011; Von Sommoggy et al., 2020) Facilitator	Barrier *"It's not like we get a lot of information about sports teams and stuff… the [athletic centre] website is so stupid! Even when you try and find out the information, you get sent to this link and that, you get a schedule… it's like why am I wasting my time? Had I had more info, I would have been more motivated."* (Kwan & Faulkner, 2011) Facilitator

COM-B Component	Theme	No. (%) of studies, (*n*=39 max)	Barrier/ facilitator/ mixed	Study ID	Example excerpts and quote(s)
				(Monforte et al., 2021)	*Other participants went further to add that their associations provide information on PA opportunities*. (Monforte et al., 2021)
	Lack of personalised physical activities to cater to individual fitness needs	3(8)	Barrier	(Diehl et al., 2018; El Gilany et al., 2011; Kwan & Faulkner, 2011)	Barrier *Some students expressed the need for more beginner courses to accommodate first-time participants* (Diehl et al., 2018)
	Lack of university policy and promotion to encourage PA	3(8)	Barrier	(Deliens et al., 2015; Ranasinghe et al., 2016; Von	*The Institute (university curriculum and structure) has not promoted or motivated them to do sports or physical activity.* (Ranasinghe et al., 2016)

COM-B Component	Theme	No. (%) of studies, (*n*=39 max)	Barrier/ facilitator/ mixed	Study ID	Example excerpts and quote(s)
				Sommoggy et al., 2020)	
	Health-concerning behaviours associated with university	2(5)	Barrier	(Deliens et al., 2015; Marmo, 2013)	*A second key environmental component that could serve as a barrier to activity was the college scene itself. Students recognized how habits such as eating poorly, drinking, and physical inactivity increased during college.* (Marmo, 2013)
	Listening to music while exercising	1(3)	Facilitator	(Bellows-Riecken et al., 2013)	*Listening to music while exercising."* (Bellows-Riecken et al., 2013)
	TDF Domain: Social influences				

COM-B Component	Theme	No. (%) of studies, (*n*=39 max)	Barrier/ facilitator/ mixed	Study ID	Example excerpts and quote(s)
Opportunity (Social)	Exercising with others (impacts accountability, support, enjoyment, friendships etc.)	25(64)	Mixed	Barrier (Bellows-Riecken et al., 2013; Hilger-Kolb et al., 2020; Kwan & Faulkner, 2011; J. Pan & Nigg, 2011; Ramírez-Vélez, 2015; Ranasinghe et	Barrier *Infrequent exercisers described how the absence of having friends to exercise with was a real barrier.* (Silver et al., 2019) Facilitator *Having an exercise partner and having a friend to exercise with were found as important cues to action in this study.* (King et al., 2014)

COM-B Component	Theme	No. (%) of studies, (*n*=39 max)	Barrier/ facilitator/ mixed	Study ID	Example excerpts and quote(s)
				al., 2016; Silver et al., 2019; Tong et al., 2018) Facilitator (Aljayyousi et al., 2019; Burton et al., 2021; Devine, 2016; Diehl et al., 2018;	

COM-B Component	Theme	No. (%) of studies, (*n*=39 max)	Barrier/ facilitator/ mixed	Study ID	Example excerpts and quote(s)
				Forrest & Bruner, 2017; Leinberger-Jabari et al., 2023; Lerner et al., 2011; Marmo, 2013; Monforte et al., 2021; Quintiliani et al., 2012;	

COM-B Component	Theme	No. (%) of studies, (*n*=39 max)	Barrier/ facilitator/ mixed	Study ID	Example excerpts and quote(s)
				Wilson et al., 2019)	
				Mixed (Brunette et al., 2011; Deliens et al., 2015; King et al., 2014; LaCaille et al., 2011; Miyawaki et al., 2019;	

COM-B Component	Theme	No. (%) of studies, (*n*=39 max)	Barrier/ facilitator/ mixed	Study ID	Example excerpts and quote(s)
				Othman et al., 2022)	
	Encouragement from others to be physically active (e.g., friends, family, teachers etc.)	12(31)	Mixed	Barrier (Burton et al., 2021; Devine, 2016; El Gilany et al., 2011; Ranasinghe et al., 2016)	Barrier *"Most of my teachers, parents and others motivated to get education and go to the university. So most our target was to go to a university and get a degree which will help to get a job and settle in life. Teachers told us 'Don't do sports! Concentrate on education!' They did not encouraged us to do sports"* (Ranasinghe et al., 2016)
				Facilitator	Facilitator

COM-B Component	Theme	No. (%) of studies, (*n*=39 max)	Barrier/ facilitator/ mixed	Study ID	Example excerpts and quote(s)
				(Burton et al., 2021; Monforte et al., 2021; Othman et al., 2022)	*"Well, my dad is pretty pro-working out and staying fit. I think he started a few years ago, and noticed the benefits. So he wants me to do some bodybuilding and stuff… he is like anything you want to take, just take it and I'll go pay for it."* (Kwan & Faulkner, 2011)
				Mixed (Aljayyousi et al., 2019; Deliens et al., 2015; Kwan & Faulkner,	

COM-B Component	Theme	No. (%) of studies, (*n*=39 max)	Barrier/ facilitator/ mixed	Study ID	Example excerpts and quote(s)
				2011; Silver et al., 2019; Snyder et al., 2017)	
	Competition or relative comparison to others	7(18)	Mixed	Facilitator (Bellows-Riecken et al., 2013; Deliens et al., 2015; Diehl et al., 2018; Miyawaki et al., 2019)	Barrier *Some participants mentioned that comparison to higher standards could be rather demotivating and confronting, especially when they failed to achieve as many steps as others.* (Tong et al., 2018) Facilitator

COM-B Component	Theme	No. (%) of studies, (*n*=39 max)	Barrier/ facilitator/ mixed	Study ID	Example excerpts and quote(s)
				Mixed (Marmo, 2013; Monforte et al., 2021; Tong et al., 2018)	*In the exercise group…both men and women were more likely to be motivated to exercise for enhancement of competitiveness* (Miyawaki et al., 2019)
	Sociocultural norms and religion	6(15)	Mixed	Barrier (Burton et al., 2021; Ranasinghe et al., 2016;	Barrier *… strict rules 'in terms of religion and culture' were imposed from her upbringing, impeding her use of the campus athletic facility. Another woman explained that 'culture does influence*

COM-B Component	Theme	No. (%) of studies, (*n*=39 max)	Barrier/ facilitator/ mixed	Study ID	Example excerpts and quote(s)
				Silver et al., 2019)	*whether you exercise' in describing a sharp contrast between her cultural upbringing and the norms inside a college campus athletic facility.* (Silver et al., 2019)
				Mixed (Aljayyousi et al., 2019; Brunette et al., 2011; J. Pan & Nigg, 2011)	Facilitator *PA is an important part of the Japanese culture.* (J. Pan & Nigg, 2011)
	Gender	6(15)	Mixed	Barrier (Burton et al., 2021;	Barrier *"I don't feel comfortable sometimes because it's filled with guys and they just stare and look*

COM-B Component	Theme	No. (%) of studies, (*n*=39 max)	Barrier/ facilitator/ mixed	Study ID	Example excerpts and quote(s)
				LaCaille et al., 2011; Nannyonjo et al., 2013; Ranasinghe et al., 2016; Silver et al., 2019) Mixed (Aljayyousi et al., 2019)	*at you, and I don't feel comfortable when people watch me work out"* (Silver et al., 2019) Facilitator *...culture was seen as a facilitator for physical activity from the males' perspectives.* (Aljayyousi et al., 2019)

COM-B Component	Theme	No. (%) of studies, (*n*=39 max)	Barrier/ facilitator/ mixed	Study ID	Example excerpts and quote(s)
	Being stared at while engaging in PA	4(10)	Barrier	(LaCaille et al., 2011; Monforte et al., 2021; Othman et al., 2022; Silver et al., 2019)	*The experience of being stared at by others can have negative effects on people with disabilities.* (Monforte et al., 2021)
	Exercise role models (positive and negative)	3(8)	Facilitator	(Burton et al., 2021; Deliens et al., 2015; Marmo, 2013)	*"That person doesn't work out; I don't want to become that."* (Marmo, 2013)

Note. Excerpts from authors interpretations of barriers and facilitators to exercise are italicised without quotation marks. Direct participant quotes are italicised with quotation marks. PA: Physical activity.

Discussion

This systematic review used the TDF and COM-B model to identify barriers and facilitators to PA among university students and rank the relative importance of each TDF domain. It is the first review to apply these frameworks in the context of increasing university students' participation in PA. Twelve TDF domains across all six sub-components of the COM-B model were identified. The three most important TDF domains were 'environmental context and resources', 'social influences', and 'goals'. The most common barriers and facilitators were 'lack of time', 'easily accessible exercise options, facilities and equipment', 'exercising with others', and 'prioritisation of PA compared to other activities'.

The most common barrier to PA was perceived lack of time. This is consistent with previous findings among university students (Ferreira Silva et al., 2022; Pan et al., 2022) and across other populations (Weatherson et al., 2017), For students, lack of time was frequently attributed to a combination of competing priorities and underdeveloped time management skills. Students predominantly prioritised study over PA, as performing well at university is a valued goal and there is a common perception that spending time exercising (at the expense of study) will impede their academic success (Hilger-Kolb et al., 2020; Kwan & Faulkner, 2011). Evidence from cognitive neuroscience research, however, suggests that this is a mistaken belief. In addition to its broad physical and mental health benefits, a growing body of evidence demonstrates regular PA can change the structure and function of the brain.

These changes can, in turn, enhance numerous aspects of cognition including memory, attention and processing speed (Den Ouden et al., 2018; Hotting & Roder, 2013; Maleki et al., 2022; Müller et al., 2020), and buffer the negative impact of stress on cognition (Nicastro & Greenwood, 2016), all of which are important for academic success. However, students are typically unaware of the brain and cognitive health benefits of PA and its

potential to improve academic performance, particularly compared to the physical health benefits (Diehl et al., 2018; Lerner et al., 2011; Miyawaki et al., 2019). Interventions that position participating in PA as a conduit for helping, rather than hindering, academic goals could increase the relative importance of PA to students, and therefore increase their motivation to regularly engage in it. The impact that interventions of this nature have on students' PA is yet to be empirically assessed.

Ineffective time management also contributed to students' perceived lack of time for PA. Students reported tendencies to procrastinate in the face of overwhelming academic workloads, which left limited time for PA (Kwan & Faulkner, 2011). Additionally, students lacked an understanding of how to organise time for PA around academic timetables, social and family responsibilities, co-curricular activities, and employment commitments (Deliens et al., 2015; Kwan & Faulkner, 2011; Nannyonjo et al., 2013; Ranasinghe et al., 2016). To address these challenges, efforts to develop students' time management skills will be useful for enabling students to regularly participate in PA. Goal-setting and action planning are two specific examples of such skills that can be integrated into interventions to help students to initiate and maintain a PA routine (Fleig et al., 2013). For example, goal-setting could involve setting a daily PA goal, and action planning could involve planning to engage in a particular PA at a particular time on certain days.

While the most common determinants of university students' PA levels were not influenced by specific demographic characteristics, several barriers disproportionately impacted women and students with a disability. These findings are in keeping with evidence that PA is lower among these equity-deserving groups compared with the general population (Carroll et al., 2014; Chaabna et al., 2022). For women, particularly those from middle eastern cultures, restrictions were often tied to religious practices and sociocultural norms

that limited their opportunities to engage in PA (Aljayyousi et al., 2019; Othman et al., 2022; Silver et al., 2019). Additionally, a substantial number of women felt intimidated or self-conscious when exercising in front of others, especially men (LaCaille et al., 2011; Silver et al., 2019). They also felt that exercise facilities were more often tailored towards the needs of men, leading to a perception that they were unwelcome in exercise communities (Othman et al., 2022; Silver et al., 2019). Consequently, women expressed a desire for women-only spaces to exercise, to help them overcome these gender-specific barriers to PA (Aljayyousi et al., 2019; Burton et al., 2021; Silver et al., 2019). Furthermore, students with a disability faced physical accessibility barriers and perceived stigmatisation that deterred them from PA (Devine, 2016; Monforte et al., 2021). The lack of accessible exercise facilities, and suitable equipment, programs, and education regarding how to adapt physical activities to accommodate their needs, limited their opportunity and ability to participate (Devine, 2016). Moreover, students with a disability felt stigmatised by others for not fitting into public perceptions of 'normality' or the aesthetic values and beauty standards often portrayed by the fitness industry (Monforte et al., 2021). These barriers for both equity-deserving groups of students are deeply rooted in historical stereotypes that have traditionally excluded women and people with a disability from engaging in various types of PA (Ferez, 2012; Ferez et al., 2020). Despite growing awareness of these issues, PA inequalities persist due to narrow sociocultural norms, and a lack of diverse representation and inclusion in the fitness industry and associated marketing campaigns (Rasmussen et al., 2021; Richardson et al., 2017). A concerted effort to address PA inequalities across the university sector and fitness industry more broadly is needed. One approach for achieving this is to develop interventions that are tailored to the unique needs of equity-deserving groups, emphasise inclusivity, diversity, and empowerment, and feature women and people with a disability being active.

The “This Girl Can” (Sport England, 2015) and “Everyone Can” (ukactive, 2017) multimedia campaigns are two examples of health behaviour interventions that were co-developed with key stakeholders (i.e., women and people with a disability, respectively) to tackle PA inequalities. The “This Girl Can” campaign has reached over 3 million women and girls, projecting inclusive and positive messages that aim to empower them to be physically active. Following the widespread reach of the “This Girl Can” campaign, the “Everybody Can” campaign was launched to support the inclusion of people with a disability in the PA sector. Although not tailored for university students, these campaigns provide a useful example for developing interventions that are specifically designed to address key barriers preventing women and people with a disability from participating in PA.

Across the tertiary education sector globally, efforts to elevate opportunities and motivation to include PA as a core part of the student experience will be beneficial for promoting students’ PA at scale. Two intervention approaches that can be implemented to facilitate such an endeavour are environmental restructuring and enablement (Michie et al., 2011). These intervention approaches should involve the provision of accessible low-cost exercise options, facilities, and programs, integrating PA into the university curriculum, and mobilising student and staff leadership to encourage students’ participation in PA (Deliens et al., 2015). Although there is evidence that these approaches can be effective in promoting sustained PA throughout students’ university years and beyond (Kim & Cardinal, 2016), implementation measures such as these are complex. Implementation requires aligning student activity levels with broader university goals and is further complicated by having to compete with other funding priorities and resource allocations. Notably, due to the negative impact of the COVID-19 pandemic on university students’ physical and mental health (Ro et al., 2021; Wang et al., 2020), the post-pandemic era has seen many universities prioritise enhancing student health and wellbeing alongside more traditional strategic goals like

academic excellence and workforce readiness. Despite the potential for PA to be used as a vehicle for supporting these strategic goals there is an absence of data on the extent to which this is occurring in the university sector. The limited evidence in this area suggests that some universities have made efforts to support students' mental health by referring students who access on-campus counselling services to PA programs (Brunton & Mackintosh, 2017). However, the uptake and efficacy of such initiatives is rarely assessed, and even less is known about whether PA is being used to support other strategic goals, such as academic success. Therefore, while the potential is there for the university sector to use PA to support students' mental health and academic performance, to be successful this needs to become a strategic university priority. Given that these strategic priorities are set at the senior leadership level, engaging senior university staff in intervention design and promotion efforts is important to enhance the value of PA in the tertiary education sector.

Implications for intervention development

The current findings provide a high-level synthesis of the most common barriers and facilitators to university students' physical activity. These findings can be leveraged with behavioural intervention development tools and frameworks (e.g., the BCW (Michie et al., 2011), Obesity-Related Behavioural Intervention Trials model (Czajkowski et al., 2015), Intervention Mapping (Eldredge et al., 2016), and the Medical Research Council guidelines for developing complex interventions (Craig et al., 2008; Skivington et al., 2021)) to develop evidence-based interventions and policies to promote PA. Given the TDF and COM-B model are directly linked to the BCW framework, applying this process may be particularly useful to translate the current findings into an intervention.

Additionally, current findings can be triangulated with data directly collected from key stakeholders to assist the development of context-specific interventions. Best practice principles for developing behavioural interventions recommend this approach to ensure a

deep understanding of the barriers and facilitators that need to be targeted to increase the likelihood of behaviour change (Michie et al., 2011). Consulting stakeholders directly (i.e., university students and staff) to understand their perspectives on the barriers and facilitators to students' PA also enables an intervention to be appropriately tailored to the target population's needs and implementation setting. Studies continue to demonstrate the effectiveness of this approach, especially when framed within the context of frameworks directly linked to intervention development frameworks, such as the TDF (Ndupu et al., 2023).

Strengths and limitations

The findings of this review should be considered with respect to its methodological strengths and limitations. The credibility and reliability of the research findings are supported by a systematic approach to screening and analysing the empirical data, alongside the use of gold-standard behavioural science frameworks to classify barriers and facilitators to PA. The inclusion of qualitative, quantitative and mixed-methods studies of both barriers and facilitators to students' PA allowed for a comprehensive understanding of the factors that influence students' PA that have not previously been captured. While the present review elucidates students' own perspectives of the factors that influence their activity levels, other stakeholders such as university staff, will also influence the adoption, operationalisation, and scale of PA interventions in a university setting. It will be important for future research to explore factors that influence university decision-makers in these roles to inform large-scale strategies for promoting students' PA. Additionally, only one study included in the review used the TDF to explore barriers and facilitators to PA (Burton et al., 2021). Therefore, it is possible that certain TDF domains may not have been identified because students were not asked relevant questions to assess the influence of those domains on their PA. For instance, domains such as 'memory, attention, and decision process', and 'optimism' are likely to play

a role in understanding the barriers and facilitators to PA despite not being identified in this review. Moreover, quantitative data were only extracted if ≥50% of students endorsed the factor as a barrier or facilitator to PA. This threshold was purposefully applied to maintain a focus on the TDF domains most universally relevant to the broad student population in the context of understanding their barriers and facilitators to PA. It is possible that less frequently reported barriers and facilitators, which may not be as prominently featured in the results, could be relevant to specific groups of students, such as those identified as equity-deserving. Lastly, a quality appraisal of the included studies was not undertaken. This decision was informed by the aim of the review, which was to describe and synthesise the literature to subsequently map data to the TDF and COM-B, rather than to assess the effectiveness of interventions or determine the strength of evidence. However, this decision, combined with dual screening 25% of studies and excluding unpublished studies and grey literature, may introduce sources of error and bias which should be considered when interpreting the results presented.

Conclusion

PA is an effective, scalable, empowering means of enhancing physical, mental and cognitive health. This approach could help students reach their academic potential and cope with the many stressors that accompany student life, in addition to setting a strong foundation for healthy exercise habits for a lifetime. As such, understanding the barriers and facilitators to an active student lifestyle is beneficial. This systematic review applied the TDF and COM-B model to identify and map students' barriers and facilitators to PA and, in doing so, provides a pragmatic, theory-informed, and evidence-based foundation for designing future context specific PA interventions. The findings from this review highlight the importance of developing PA interventions that focus on the TDF domains 'environmental context and resources', 'social influences', and 'goals', for which intervention approaches could involve

environmental restructuring, education, and enablement. If successful, such strategies could make a significant contribution to improving the overall health and academic performance of university students.

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CHAPTER FIVE: Study Two. Intervention Development

5.1 Explanatory Notes

Study One identified common barriers and facilitators to students' physical activity globally. Triangulating data from multiple sources is recommended to obtain a deep understanding of what needs to change for a target behaviour to occur (i.e., engaging in exercise) (Michie et al., 2011b). As such, Study Two extended findings from Study One by establishing an in-depth context-specific understanding of the barriers and facilitators that impact Australian University students' engagement in exercise by conducting focus groups with university students, and interviews with staff and senior leadership. This information was integrated to develop the PEAK program, a behavioural intervention designed to increase students' engagement in exercise to enhance their mental and cognitive health. Study Two describes how PEAK was developed by following the three stages of the BCW: 1) understand the target behaviour, 2) identify intervention options, and 3) identify intervention content and delivery mode.

Study Two is the first study to apply the BCW process to develop an exercise-based intervention to support university students' mental and cognitive health. In doing so, this study provides a comprehensive, structured, and replicable approach to intervention development, and identifies intervention options and BCTs most likely to be effective in promoting students' engagement in exercise.

5.2 Publication two: PEAK Mood, Mind and Marks: development of an intervention to improve university students' mental and cognitive health through physical exercise

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Abstract

Background: Concerns about mental and cognitive health are common among university students. Engaging in regular physical exercise has been shown to enhance both mental health and cognitive performance, yet most students are not participating in the level of exercise required to obtain these benefits. The Behaviour Change Wheel (BCW) provides a framework for developing behavioural interventions that are informed by theory, evidence, and stakeholder perspectives. The current study applied the BCW to develop the PEAK Mood, Mind and Marks program (i.e., PEAK), a behaviour change intervention designed to increase university students' exercise for the benefit of their mental and cognitive health.

Methods: PEAK was developed across three stages of the BCW: 1) understand the target behaviour, 2) identify intervention options, and 3) identify intervention content and delivery mode. Development was informed by triangulated data from a systematic literature review, co-design consultations with key stakeholders, and knowledge of relevant experts. Consultations with stakeholders involved focus groups with 25 university students and individual interviews with 10 university leaders and staff to identify barriers and facilitators to students' exercise engagement and the adoption and implementation of PEAK by universities. Template analysis was used to code transcripts to the capability, opportunity, and motivation (COM-B) model of behaviour. The BCW was applied to identify the most appropriate intervention types and behaviour change techniques (BCTs).

Results: Thirty-one barriers and facilitators were identified and mapped to seven intervention types (Education; Modelling; Persuasion; Environmental Restructuring; Incentivisation; Training; and Enablement) and 26 BCTs, which were delivered across digital and in-person channels. The final intervention consisted of multiple components targeting students'

capability (e.g., increasing knowledge about the mental and cognitive health benefits of exercise), opportunity (e.g., providing a flexible range of accessible exercise options and social support), and motivation (e.g., increasing the perceived importance of exercise) to exercise.

Conclusions: University students and staff describe a need and appetite for more empowering, scalable solutions to support students' mental and cognitive health. Exercise-based approaches that are informed by theory, evidence, and stakeholder perspectives, such as PEAK, have the potential to address this need. Current findings will inform a pilot of PEAK to evaluate its efficacy and implementation.

Keywords: University Students; Co-design; Physical Exercise; Mental Health; Cognitive Health; Behavioural Intervention; Behaviour Change Wheel; COM-B

Background

The mental and cognitive health of university students is of growing concern for the global tertiary education sector. A multinational study of approximately 14,000 university students estimated that 35% met the criteria for at least one anxiety, mood, or substance disorder (Auerbach et al., 2018). Poor mental health is often associated with cognitive difficulties in areas such as memory, attention and processing speed (Abramovitch et al., 2021; Mboya et al., 2020). Cognitive concerns are common even among students who do not meet the criteria for a mental illness. For instance, an Australian survey of 901 university students found that more than 60% were concerned about their cognition, including their ability to recall memories and concentrate, irrespective of their mental health status (Bird et al., 2023). Given that mental and cognitive health are important determinants of academic success, degree completion and future career prospects (Cranford et al., 2009; Elion et al., 2012; Grotan et al., 2019), there is a pressing need for effective strategies to address these issues.

Promoting university students' engagement in physical exercise has the potential to enhance their mental health and cognitive performance. There is robust evidence that regular exercise can reduce the severity of anxiety and depression (Ashdown-Franks et al., 2020) and, when performed at moderate to high intensities, can have comparable therapeutic effects to psychotherapy and pharmacotherapy (Singh et al., 2023). Even three exercise sessions per week has been associated with significant reductions in days of poor mental health (Chekroud et al., 2018). Importantly, the same exercise prescriptions that benefit mental health also benefit cognition. Regular exercise can increase cognitive performance across numerous domains including executive functions (Voelcker-Rehage et al., 2011), attention (de Sousa et al., 2019) and memory (Stroth et al., 2009). The mental and cognitive health benefits of

exercise are partly attributed to exercise-induced neuroplasticity, including alterations in neurotrophin availability and brain volume, connectivity, and functioning, especially in regions such as the hippocampus that are involved in learning, memory, and emotional processing (Burdette et al., 2010; Hotting & Roder, 2013; Lippi et al., 2020). The benefits of exercise are well-established; however, most university students are not currently engaging in the frequency or intensity of exercise that best supports optimal mental and cognitive health. Globally, only 13-32% of university students exercise three or more times a week (Haase et al., 2004). Low rates of exercise among students are largely attributed to the unique challenges that often accompany the transition to university life, such as new academic pressures, social adjustments, and financial responsibilities (Worsley et al., 2021), which disrupt established routines and pose additional barriers to the initiation or maintenance of regular exercise (Romaguera et al., 2011).

Although initiating or maintaining health behaviours is challenging, many of the key principles for developing successful behaviour change programs are well established. The UK Medical Research Council (MRC) guidelines for developing complex interventions (Skivington et al., 2021) and National Institute for Health and Care Excellence (NICE) (NICE Guidelines, 2007, 2014, 2020) advocates a theory-driven, evidence-based approach that incorporates stakeholder perspectives at all stages of the intervention development process. Systematic reviews of existing evidence demonstrate the effectiveness of such an approach (Taylor et al., 2012; Webb et al., 2010). The explicit use of theory allows intervention designers to identify influences on behaviour change (i.e., barriers and facilitators to the behaviour) and to replicate interventions with fidelity (Michie et al., 2008). Involving key stakeholders (in the context of this research, university students, leadership, and staff) in intervention development is equally important for maximising intervention

engagement, acceptability, feasibility, and scalability within a university setting (Eisman et al., 2021).

The person-based approach is a widely adopted method used to involve stakeholders in the development and implementation of health behaviour change interventions (Yardley, Morrison, Bradbury & Muller, 2015). This approach aims to ensure that the views, needs, and experiences of stakeholders are meaningfully addressed. By adopting a person-based approach, interventions can be tailored to meet stakeholders needs more effectively, thereby increasing intervention engagement and acceptability. Acceptability, in this context, is defined as the extent to which stakeholders consider an intervention to be appropriate, according to anticipated or experienced cognitive and emotional reactions to the intervention (Sekhon et al., 2017). An acceptable intervention is more likely to be adhered to, leading to better intervention outcomes (Fisher et al., 2006; Hommel et al., 2013). Effective behaviour change interventions are most often created when stakeholder perspectives are incorporated with proven evidence-based frameworks from behavioural science (Ammerman et al., 2002; Byrne, 2019).

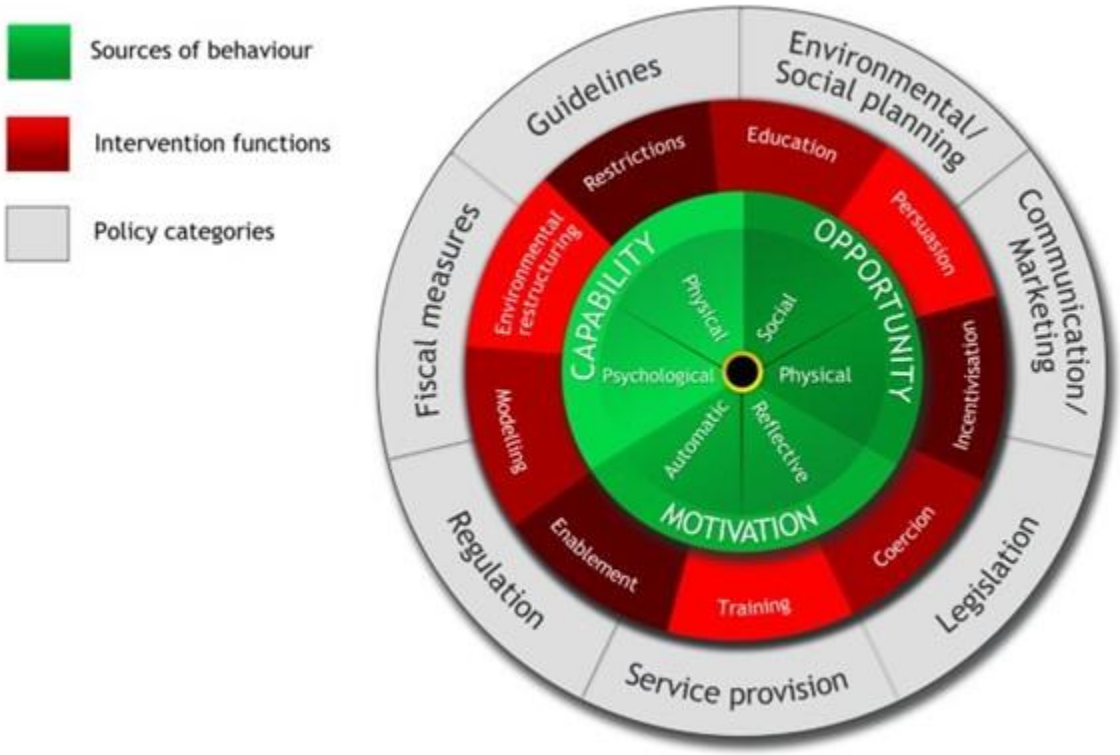
The Behaviour Change Wheel (BCW) is globally recognised as one of the most well validated, theoretically derived, frameworks for developing and describing behaviour change interventions (Michie et al., 2011). The BCW has been widely used by clinicians, governments, industry and non-governmental associations around the world to create large scale change across healthcare, environmental sustainability, and workplace settings (Atkins, 2016; Gainforth et al., 2016; Munir et al., 2018). The BCW is built on a synthesis of 19 behaviour change frameworks schematically organised into three layers (see Figure 1) which form the basis of a systematic process for intervention development across three stages: 1) understanding the target behaviour, 2) identifying intervention options, and 3) identifying

intervention content and delivery mode (Michie et al., 2014). The theoretical framework used to understand the behaviour is the COM-B model, which posits that no behaviour will occur without sufficient capability, opportunity, and motivation. Within the COM-B model, capability can be psychological (e.g., knowledge to engage in the necessary processes) or physical (e.g., physical skills); opportunity can be social (e.g., interpersonal influences) or physical (e.g., environmental resources); and motivation can be automatic (e.g., emotional reactions, habits) or reflective (e.g., intentions, beliefs). This model highlights that where any of these are lacking, they can be strategically targeted to increase the likelihood of a person changing their behaviour.

The second stage of intervention development involves selecting from nine intervention types that were mapped onto the COM-B model through expert consensus (see Additional File 1 for definitions and examples of each intervention type). Through this process, behavioural scientists reached an agreement on which intervention types were most likely to change behaviour by targeting capability, opportunity and/or motivation as required. The intervention types are also linked to seven general policy options that can be used to support the delivery of the intervention types when relevant and/or available to intervention designers.

Figure 1

The Three Layers of the Behaviour Change Wheel. Reproduced from (Michie et al., 2014)



The final stage of the intervention development process includes identifying which behaviour change techniques (BCTs) can be used to support the delivery of intervention types and appropriate modes of delivery. BCTs are defined as the observable and replicable 'active ingredients' of behaviour change interventions that influence behaviour as described in a BCT taxonomy (BCTTv1) (Michie et al., 2013). The taxonomy was developed through a Delphi process to provide an extensive, consensually agreed, and standardised categorisation of 93 BCTs used in behaviour change interventions.

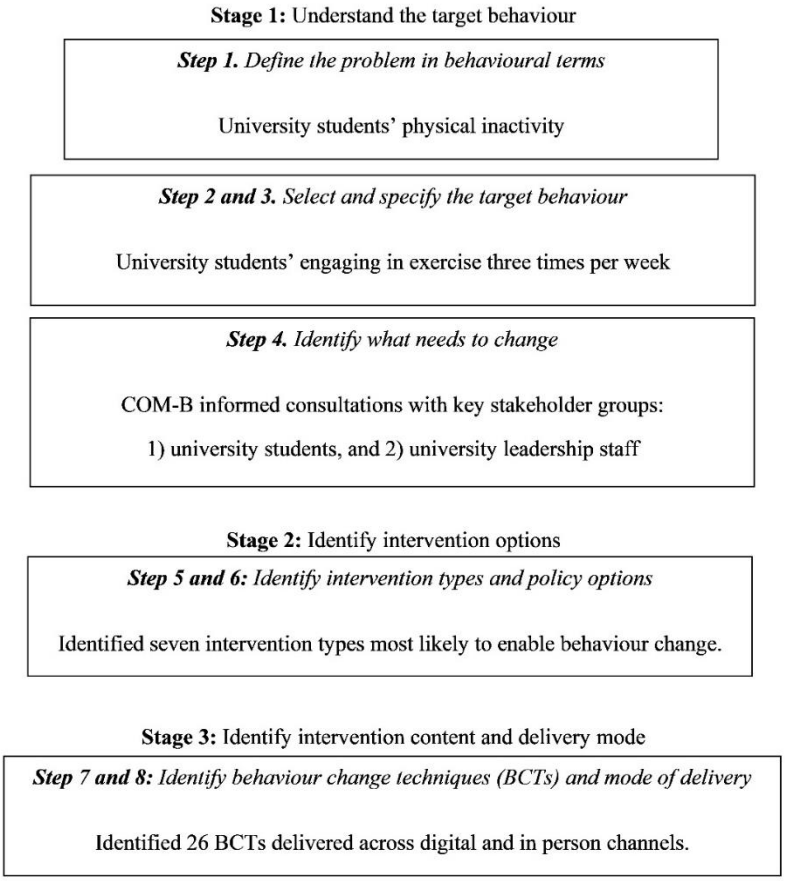
The BCW provides a rigorous theoretically derived framework to guide the development of a behavioural intervention aiming to support university students' engagement in exercise to improve their mental and cognitive health. As the BCW has not yet been applied to design an intervention of this kind, the current study aimed to apply the BCW process to develop the PEAK Mood, Mind and Marks program (i.e., PEAK).

Methods

This study was approved by the Monash University Human Research Ethics Committee (Reference Number 27730). The BCW process outlines eight steps across the three stages of the intervention development process, each of which was followed to develop PEAK (see Figure 2). An iterative feedback loop approach was taken, wherein findings from each step fed into the next step of the development process and were also fed back to refine previous steps. Results for steps one through three have been described in the methods below to provide contextual information for the qualitative research methods described in step four.

Figure 2

The Eight Steps of the Behaviour Change Wheel applied to Develop the PEAK Mood, Mind, and Marks Program



Stage 1: Understand the target behaviour

Step 1: Define the problem in behavioural terms

The first step was to identify the problem behaviour that the intervention needed to address (e.g., physical inactivity). This included specifying: 1) who was performing the behaviour, and 2) what the behaviour involved. Most students are currently not engaging in the frequency or intensity of exercise that best supports peak mental and cognitive health. Interventions that support students to engage in regular exercise will therefore be beneficial.

Step 2 and Step 3: Select and specify the target behaviour

The target behaviour was for students to build up to engaging in three or more exercise sessions per week. The target exercise frequency was informed by evidence that suggests exercising three times per week may generate the largest improvements in mental health (Chekroud et al., 2018). A session was defined as purposeful and effortful exercise that lasted for 10-minutes or longer. This definition is in keeping with the International Physical Activity Questionnaire, an internationally recognised, widely used, and validated measure of physical activity (Craig et al., 2003). The behaviour was specified with regards to who needed to perform the target behaviour, what they needed to do differently to achieve the desired change, when, where, how often they needed to do it and with whom (Table 1).

Table 1

Specification of the Target Behaviour

Target behaviour	Engage in exercise that lasts for 10-minutes or longer three or more times per week
Who needs to perform the behaviour?	Undergraduate university students at Monash University

What do they need to do differently to achieve the desired change?	Engage in exercise that lasts for 10-minutes or longer three or more times per week
When do they need to do it?	Any day throughout a 12-week university teaching semester
Where do they need to do it?	Any environment conducive for exercise (e.g., at home, on-campus, at the gym, etc.)
How often do they need to do it?	Three or more times per week
With whom do they need to do it?	Alone or with others

Note. Adapted from (Michie et al., 2011)

Step 4: Identify what needs to change

Triangulating data from multiple sources is recommended to obtain a deep understanding of what needs to change for the target behaviour to occur. Data was triangulated from three sources:

(a) *Systematic review.* The research team conducted a systematic review of peer-reviewed research on university students' barriers and facilitators to exercise (Brown et al., 2024). This synthesis was couched within the COM-B model.

(b) *Key stakeholder perspectives.* An empirical study using a qualitative co-design approach was conducted with university students, senior leadership, and staff at Monash University to explore barriers and facilitators to students' engagement in exercise and identify program messaging, content, and delivery methods that would support the acceptability, feasibility, adoption, and scalability of PEAK.

(c) *Expert knowledge.* The expertise of the intervention design team contributed to understanding the target behaviour and design of program content. The team consisted of experts in behavioural science and implementation science (CB, BS,

KR, BP, and LA), psychologists (CB, BS, and KR), a senior exercise physiologist (SH), a co-author of The Behaviour Change Wheel: A Guide to Designing Interventions (LA), and two undergraduate university student ambassadors (see acknowledgements).

Triangulated data was mapped to the COM-B categories to identify what barriers and facilitators in relation to students' capability, opportunity and/or motivation needed to be targeted to maximise the likelihood of behaviour change. The BCW refers to this process as the behavioural diagnosis.

Key stakeholder perspectives: participants

University students

Twenty-five undergraduate university students (M age = 21.28, SD = 2.32 years; 17 women, eight men) from Monash University participated in this study. The study was advertised via flyers on-campus and social media posts. Stratified random sampling was used to recruit students based on their typical weekly exercise engagement, and whether they were domestic or international students (Table 2), ensuring the sample was representative of the university population and offered a diversity of perspectives. All students provided informed consent and were reimbursed a $50AUD gift voucher.

Table 2

University Student Characteristics

Demographic	Frequency (%)
Typical exercise engagement per week	
0	8(32)
1-2 sessions	3(12)

3+ sessions	14(56)
Enrolment status	
Domestic	16(64)
International	9(36)
Faculty enrolment	
Arts	3(12)
Business and Economics	4(16)
Education	3(12)
Engineering	2(8)
Information Technology	2(8)
Law	1(4)
Medicine, Nursing and Health Sciences	6(24)
Science	4(16)

Senior leadership and staff

Ten senior leaders and staff at Monash University (four women, six men) participated in this study. Stratified purposeful sampling was employed to ensure a range of perspectives were captured across different levels of seniority. Invitations to participate were disseminated via email. Staff varied across disciplines and included representatives from the university chief-suite, university exercise facilities, student mental health support facilities, student residential services, student association groups, and unit co-ordinators. These staff members were purposefully invited to participate because their support of the program and institutional knowledge is necessary for the widespread adoption and scale of the PEAK program. All staff provided informed consent to participate in the study.

Key stakeholder perspectives: data collection

University students

Four focus groups were conducted with undergraduate students, lasting for ~2.5hrs duration and ranging in size from four to seven participants. Groups were held in-person at the university campus, co-facilitated by two authors (CB and RS or KR or BP), and audio-recorded in full. At the beginning of each focus group, students were shown a video "*Exercising smart: how being active can help you perform better in your studies*" (view the video online at https://vimeo.com/ymcavictoria/download/535721809/3ed49f4683), which aimed to communicate the mental, cognitive, and brain health benefits of exercise. This video was created by young adults to address issues that affect young adults as part of the Virtual Y co-design series (YMCA, 2020), a joint initiative between the YMCA and VicHealth. The video was shown to facilitate discussions about students' existing knowledge (or lack thereof) of how exercise impacts mental, cognitive and brain health, and whether learning this information influenced their motivation to exercise.

The interview schedule was guided by the COM-B model and aimed to facilitate discussion on: 1) the perceived need for mental and cognitive health support, 2) appetite for an exercise-based program to provide this support, 3) barriers and facilitators to exercise, 3) acceptable, accessible delivery channels, and 4) strategies to increase the adoption and acceptability of PEAK (see Additional File 2 for the focus group interview schedule).

Students' demographic data regarding age, gender, exercise history, enrolment faculty and status was collected online using the Qualtrics platform (Qualtrics, 2005) before they participated in the study.

Senior leadership and staff

Individual semi-structured interviews were conducted with staff, lasting for ~1hr duration. Interviews were conducted online via Zoom platform (Zoom, 2011), individually

facilitated by authors (CB or RS or KR), and audio-recorded in full for subsequent anonymised transcription.

The interview schedule was guided by the COM-B model and aimed to facilitate discussion on: 1) the need for PEAK, 2) anticipated barriers and facilitators to the implementation, adoption and scale of PEAK, and 3) the capacity for staff to provide resource support for PEAK (see Additional File 3 for the semi-structured interview schedule).

Key stakeholder perspectives: data analysis

Focus group and interview audio recordings were anonymously transcribed verbatim. Transcripts were analysed using template analysis (Brooks, McCluskey, Turley & King, 2015)—a thematic analytic method—which permits a combination of both a priori themes relevant to the research question (e.g., barriers and facilitators to the implementation of PEAK) alongside inductive coding to develop additional emergent themes. A priori themes were guided by the six categories of the COM-B model. While template analysis was conducted with a psychological lens, the eclectic research expertise of the authors provided an opportunity for input from a wider range of perspectives and disciplines (e.g., behavioural science, neuropsychology, clinical psychology, implementation science and evaluative synthesis).

Preliminary coding was conducted independently by two authors (CB and BP or RP) using a priori themes to identify which COM-B categories were relevant to design and/or implement PEAK. Codes were clustered into meaningful groups in which hierarchical and lateral relationships between themes were defined. The authors met to discuss the coding of the two transcripts (designed to increase calibration between authors) and establish an initial template for coding the remaining transcripts. The initial template was further refined through

systematic coding of the remaining transcripts conducted by two authors (CB and BP or RP). The final template was re-applied to the full dataset by two authors (CB and BP or RP).

Stage 2: Identify intervention options

Step 5 and 6: Identify intervention types and policy options

The intervention types most likely to affect behaviour change were selected based on the COM-B behavioural diagnosis conducted in Step 4. The relevant intervention types were assessed using the APEASE criteria: 1) Affordability, 2) Practicability, 3) Effectiveness and cost-effectiveness, 4) Acceptability, 5) Side-effects/safety, and 6) Equity (see Additional File 4 for definitions of each criterion). The APEASE criteria was developed as part of the BCW process to enable intervention designers to select feasible intervention types before trialling an intervention. In the context of developing an intervention to increase students' engagement in exercise, intervention types were selected on the basis they satisfied the following criteria:

1. Affordability and Practicability: The intervention type could affordably and practicably be delivered to and accessed by university students within the time, budget, and resources available.
2. Effectiveness and cost-effectiveness: The intervention type had the potential to effectively increase students' engagement in exercise within a real-world context and could be delivered at minimal cost.
3. Acceptability: University students and staff deemed the intervention type acceptable and appropriate.
4. Side-effects/safety: There were no adverse side-effects associated with the intervention type.

5. Equity: The intervention type had the potential to reduce health and wellbeing disparities between various student groups, such as domestic and international students, and women and men.

As policy levers were not deemed to be relevant at this stage of development, identifying policy options as stipulated in step 6 of the BCW process was not undertaken.

Stage 3: Identify intervention content and delivery mode

Step 7 and 8: Identify behaviour change techniques and mode of delivery

The BCW process describes links between intervention types and individual BCTs. From the list of 93 BCTs identified in the BCTTv1, the most appropriate techniques were selected for the program to facilitate the desired behaviour change. The content and mode of delivery for each BCT was further operationalised to create the overall PEAK program. These decisions were informed by iterative discussions between the intervention design team, including regular consultations with student ambassadors. A 12-week pilot was then planned to run coincident with a full university teaching semester.

Results

Stage 1: Understanding the problem

Steps one through to three have been described in the methods above. This research has generated new findings from steps four through to eight, which are described below.

Step 4: Identify what needs to change

There is a need for programs to support students' mental and cognitive health

The consultations revealed a clear need and appetite for new approaches to better support university students' mental and cognitive health.

Students stated they were struggling with their mental health. Feeling stressed, isolated, burnt out, depressed, anxious and sleep deprived were pervasive and normalised aspects of university life:

> *"...we know that pretty much every student is suffering, it's what becomes normalised, and what's become normalised is not sleeping for multiple days to finish off your assignments." Focus group four, female student*

> *"We just need more support. It doesn't matter what time it is, COVID, not COVID. Students always need support, because we don't get it enough. Even though we have families and friends, uni life is a hard life. It's hard to manage your life, studying, maybe working, exercising, socialising. It's really hard to manage all of it for anyone, especially at this young age." Focus group two, female student*

International students reported that the absence of familial support and challenges associated with adjusting to a new culture exacerbated their feelings of depression, isolation, and helplessness. These mental health difficulties further diminished their motivation for exercise and impaired their ability to focus:

> *"I had depression, because I was living alone and I haven't seen my family in almost two years. As an international student, you - you're feeling all that stuff. You don't want to exercise. You can't focus on studies." Focus group two, female student*

Staff were also concerned about the growing prevalence and impact of mental health issues among students, including depression, anxiety, and stress. They emphasised the

academic ramifications of these challenges, noting a marked increase in students' requests for special consideration and extensions for assignments and exams throughout the year.

Although staff articulated a clear concern for student wellbeing, students were sceptical about the university's genuine investment in their mental health. This scepticism was fuelled by dissatisfaction with the existing options available to support their mental health at the university, which included once-off wellbeing events and initiatives, such as R U OK? Day, lecture slides that routinely directed students to contact mental health helplines or the medical centre on-campus, and student counselling services. Students described most of these efforts as tokenistic, "box-ticking" gestures designed to fulfill administrative requirements and shift accountability rather than offering genuine sustainable support:

> *"…there's one thing I hate about the units… they start off every week's content by saying, just a reminder, if you are having mental health issues, please contact these helplines, they are there to help blah, blah, blah… To me, it just sounds like, okay, we just got pressure from our superiors to give you a lot of pressure, and if you're struggling, this is someone else's problem." Focus group four, male student*

Student counselling services were received positively by a minority of students who found specific counsellors helpful and responsive to their mental health challenges, however, the majority were dissatisfied with the service. Students found it difficult to access an appointment due to long wait times and saw the service as reactive and deficit-based, designed to treat mental health issues after they have already manifested, rather than adopting a proactive, strength-based approach to build resilience against the onset of mental health challenges:

"…there's not much like helping I guess like the average student… in terms of counselling services it's hard to get to… it's targeted towards like a lot of the stress and in need of help like now. If you're kind of before that stage, it's really hard to get a counsellor because there's just so many students and there's only so many counsellors…getting any help before that point it's really difficult. I know that I've been deterred from getting counselling because of all these wait times..." Focus group three, female student

International students were particularly disillusioned by the lack of mental health support given their significant financial contributions to the institution. They reported the university treated them like "cash cows", exploiting their financial investment without providing adequate help in return.

Students reported an absence of programs specifically designed to support their cognitive health; a gap acknowledged by some staff members. Students and staff concurred on the need for meaningful, proactive, and strength-based programs designed to promote sustainable benefits for students mental, cognitive and brain health or, in students' own words, their "mood, mind and marks". Students agreed the program messaging and content needed to be positively framed, relevant to their goals, and avoid the stigma surrounding "mental health" terminology:

"Something to do with mental health sounds very scary. Even if all the population has mental health issues, I would still avoid these kind of programs…Even if I'm the one who needs it for example, I'll still be like, I'm not a psychopath or I'm not a crazy one…instead of negatively sounding words, we should use positively sounding words" Focus group two, female student

"…instead of specifically saying mental health, it would maybe be better to replace it with mood, or a word that is related to mental health that maybe has less stigma. There is a reality where people could read that and subconsciously be turned away from it, or consciously, either way." Focus group four, female student

Barriers to and facilitators of university students' exercise

Consultations with students revealed barriers to and facilitators of exercise across five of the six categories of the COM-B model: psychological capability, physical opportunity, social opportunity, automatic motivation, and reflective motivation (see Additional File 5 for example quotes relevant to each theme). No themes emerged in relation to students' physical capability.

Psychological Capability

With respect to psychological capability, three themes emerged: knowledge, time management skills, and tracking and receiving feedback.

While students were aware of the broad health benefits of exercise, the majority lacked specific knowledge about the neurophysiological mechanisms that contribute to exercise-induced improvements in mental, cognitive and brain health. Furthermore, they were unaware of the potential for exercise to improve their academic performance, particularly during the exam period. There was consensus among the students that learning this information would motivate them to be more active.

Some students reported they lacked knowledge in exercise domains such as: how to execute proper form and technique while exercising, use exercise equipment, and manage the physical consequences and risks associated with exercise (i.e., muscle soreness, fatigue, and

injury). Students noted that it would be helpful to receive instruction and advice from a credible source to address these gaps in their knowledge.

Poor time management skills emerged as a prominent barrier to exercise among students. Transitioning into university was often associated with new academic responsibilities and social opportunities that overwhelmed their ability to allocate time for exercise alongside other commitments. Students described an interest in learning time management skills to help them initiate and maintain a consistent exercise regime.

The majority of students described how tracking and receiving feedback on their exercise progress via digital tools, such as apps and fitness monitors, was motivating, provided the tool was quick and easy to use. However, they held mixed opinions regarding whether it was useful to track and receive feedback on the impact of exercise on their mental health and cognition. Some students believed this type of information would incentivise them to continue to exercise if they gained knowledge of the positive changes in their mental health and cognition, while others were concerned that it would be tedious to track these outcomes in addition to their exercise progress.

Physical Opportunity

Five themes were identified within physical opportunity: a lack of time, the need for a variety of flexible exercise options, prompts to exercise, financial costs associated with exercise, and the utility of using the university's digital education platform (i.e., Moodle) to deliver PEAK.

A major barrier to exercise was not having enough time. However, when prompted, some students acknowledged that perceived time constraints were often due to prioritising

other activities, such as studying, over exercise, rather than lacking enough time in a day to exercise.

A key facilitator identified by students was the need for choice; they valued the availability of a wide variety of flexible exercise options. Students wanted exercise options that could accommodate their location (i.e., indoors, outdoors, at home, on-campus, and at a gym), variable weather conditions, and preferences regarding exercise delivery (i.e., in-person and digital), type (i.e., aerobic and resistance training), and interpersonal format (i.e., with others and alone). There was a consensus that introductory exercise options aimed at beginners could reduce anxiety associated with being new to a gym or other exercise environment and help them build foundational exercise skills and confidence. Furthermore, there was a preference for exercise modalities that did not require specialised equipment. The collective sentiment was that students wanted PEAK to offer a range of exercise options that could flexibly accommodate any logistical constraints, exercise preference, and skill levels.

The concept of using prompts to facilitate exercise was broadly welcomed. Students believed that timely prompts to exercise could help them to remember to follow through on their intention to exercise, particularly during periods of high stress such as the examination period when they are more likely to forego exercise.

The financial costs associated with engaging in exercise emerged as both a barrier and a facilitator. The cost of gym memberships and exercise programs was generally seen as a barrier to participation. Therefore, most students expressed their preference for PEAK to be free. However, some students felt that making a modest financial commitment could serve as a form of accountability, pushing them to take full advantage of the services for which they have paid.

Students had mixed feelings about using existing university academic content platforms, such as Moodle, for delivering PEAK. Some were sceptical that they would actively engage with the program on Moodle because they often ignore non-academic resources on such a platform. However, other students thought that effective advertising and an engaging program design could counteract this issue and saw advantages in using Moodle given it is frequently accessed for academic content.

Social Opportunity

Four themes emerged within students' social opportunities: the impact of exercising with others, receiving encouragement from others to exercise, the impact of exercise role models, and the importance of a supportive exercise community.

Exercising with others yielded multiple advantages for students, enhancing not only their motivation to attend workouts but also their level of physical exertion during these sessions. Committing to exercise with someone also created a sense of accountability. External encouragement to exercise and reminders from friends or partners who were not exercise companions also bolstered students' commitment to be active. Most students attested that exercising with friends enhanced enjoyment. Exercising with others to meet new people was particularly relevant for students who found it challenging to make friends at university. However, as one student pointed out, preferences for social or solitary exercise could fluctuate within a week, depending on one's emotional state. Therefore, while the benefits of social exercise are manifold, the availability of choice between group and solitary exercise options was deemed important.

Students indicated a strong desire for exercise role models and champions to promote the adoption of PEAK. Specifically, students expressed a preference for the program to be

promoted by people actively involved in student life, rather than university staff who were less relatable and accessible. Hearing transformational stories related to the physical benefits of exercise—especially from a person students could identify with—also served as a powerful motivator. Witnessing or hearing about the tangible benefits that others have gained from regular exercise helped students visualise their own potential for change.

Being part of a supportive and inclusive exercise community had a positive impact on students' exercise experience. Several students mentioned instances where other more advanced exercisers would proactively offer advice and encouragement to those new to exercise. This support helped to foster a sense of community and inclusivity, making the gym environment less daunting for those new to the gym, and motivating them to return for subsequent sessions.

Automatic Motivation

Regarding automatic motivation, six themes were identified: feeling tired, poor mental health, feeling self-conscious, enjoyment, having a routine, and receiving incentives.

A common barrier was feeling too tired to exercise. Many students noted that while they may have time to exercise at the end of the day, their energy was significantly depleted, making the prospect of exercise less appealing. The issue of "feeling too tired" was particularly salient during stressful academic periods, where students reported that maintaining a consistent exercise regimen felt almost insurmountable.

Students reported that when their mental health felt poor, such as feeling stressed, sad, or depressed, they were less likely to exercise. Students recognised that the relationship between their mental state and exercise was bidirectional and noted a paradox; while poor

mental health often led to a lack of motivation to exercise, the absence of exercise further exacerbated their stress and negative emotional states. This recognition was typically not enough to support action.

Feeling self-conscious, judged, or intimidated while exercising in front of others was a barrier. Many students felt insecure or embarrassed about the way they looked while exercising, particularly if they believed they were being observed by others. For example, some female students indicated feeling uncomfortable or judged while exercising with male friends who made unsolicited comments about their bodies. The fear of making mistakes or appearing inexperienced in the gym setting was another source of intimidation associated with exercise.

Students expressed a strong desire for exercise to be enjoyable. The concept of 'fun' was frequently mentioned, with students recalling positive experiences engaging in playful exercises such as dodgeball or listening to music while exercising to enhance enjoyment. Some students found less strenuous exercises, such as walking and cycling, to be more pleasurable than higher-intensity exercise options, whereas other students enjoyed the sense of satisfaction often associated with engaging in physically challenging, higher-intensity exercise options.

Students overwhelmingly reported that the establishment of a consistent routine—encompassing not just exercise but also sleep and diet—played a pivotal role in sustaining their exercise regimen over time. The term "momentum" was recurrently used, indicating that the routine itself served as a self-reinforcing mechanism. The students indicate that the predictability of a set routine reduced the cognitive load associated with planning and decision-making, thereby lowering the psychological barriers to exercise. Students found that

once exercise became integrated into their daily routine, it was perceived less as an optional activity and more as a non-negotiable commitment.

The idea of receiving rewards to incentivise their participation in PEAK resonated strongly with students. Various forms of incentives were suggested by students, including: coffee and food vouchers; money; course credit; and, free or discounted access to specialised exercise classes. Students suggested a tiered system of rewards, where meeting specific exercise goals each week or month would lead to a reward.

Reflective Motivation

Three core themes were identified within reflective motivation: priorities, exercise goals, and beliefs about the impact of exercise.

Students consistently deprioritised exercise in favour of their academic responsibilities. Despite the acknowledgement that exercise could potentially boost students' academic productivity, many students shared the opinion that the time and energy spent exercising would detract from the time that could be spent studying.

The ability to set and achieve specific exercise goals emerged as a facilitator of sustained exercise. Students emphasised that goals needed to be self-selected, specific, achievable, and personalised to their preferences, exercise skills and fitness level. For those who were new to exercise, starting small and gradually increasing the intensity or duration of exercise made initiating and maintaining a regular exercise routine feel less daunting.

Most students believed that engaging in exercise had a notable positive impact on their mental health and wellbeing. Exercise was considered an effective means of managing stress, offering a psychological 'buffer' against the pressures of university life. Some students

noted that even shorter sessions of exercise resulted in perceptible mood elevation. Exercise was also seen as a vehicle for positively impacting self-esteem and sense of self-achievement. Notably, the mental health benefits of exercise were observed across a variety of exercise modalities, including walking, running, dancing, team sports and strength and resistance training. However, one student believed that shorter sessions of less intense exercise was more effective in enhancing her mood, as opposed to vigorous, high-intensity workouts, which made her feel unhappy and uncomfortable.

Students reflected on the impact exercise had on their cognition, physical health and appearance. Regarding the cognitive impact, most believed it was easier to concentrate on single tasks and reduce task-switching and mental drift following exercise. However, some found it difficult to think critically and problem-solve directly after engaging in vigorous exercise. The physical impact of exercise also elicited mixed responses. Some students believed exercise increased their energy, while others felt that it expended energy they needed to reserve for academic tasks. Other physical health and aesthetic benefits of exercise, such as improved fitness, weight loss and muscle toning, were additional motivators for maintaining an active lifestyle.

Barriers to and facilitators of the sustained implementation and scale of PEAK

Staff anticipated barriers to and facilitators of the sustained implementation and scale of PEAK across three of the six categories of the COM-B model: physical opportunity, social opportunity, and reflective motivation (see Additional File 6 for example quotes relevant to each theme). No themes emerged in relation to psychological capability, physical capability, or automatic motivation.

Physical Opportunity

Staff emphasised the need for PEAK to be affordable for the university and well-resourced. Multiple staff members pointed to financial and operational constraints that could impede the program's scalability. Any significant extra workload for staff to run the program was noted as a limiting factor. However, several staff identified possible solutions to mitigate these challenges. They suggested that leveraging digital delivery platforms and integrating PEAK with pre-existing university services, such as on-campus exercise facilities and counselling services, could both reduce operational costs and enhance support for the program.

Social Opportunity

Staff emphasised that the successful adoption and sustainability of PEAK would require a multi-level approach, involving both top-down organisational support and bottom-up student leadership support. Endorsement from senior leadership would lend credibility to the program and was deemed necessary for sustainable resource allocation, program integration, and acceptance within the university. The need for bottom-up support from students to champion PEAK was equally important for gaining students' trust in the program. Staff felt that messages about PEAK would be better received and accepted if they came from peers, such as student ambassadors, rather than from faculty or administration. Partnerships with local and national external bodies and organisations invested in student wellbeing (e.g., Universities Australia, the National Association of Australian University Colleges and Beyond Blue) could provide an avenue for scaling the program by offering additional resources and a broader platform for program implementation.

Reflective Motivation

There was consensus that the program would most likely be successful (i.e., adopted and supported) if its goals aligned with the strategic focus of the university. Current university priorities that could be leveraged were supporting students' mental health (especially in the aftermath of the COVID-19 pandemic), maximising academic performance, and sense of belonging to the university, elevating the university's reputation for academic excellence, attracting international students to enrol in the university, and reduce institutional financial costs associated with students accessing counselling services or dropping out of university due to poor mental health. Therefore, measuring the impact of the program on these variables was deemed important for garnering long-term support from university leadership and senior staff.

Data triangulation

Based on the triangulated results of the qualitative research, systematic review, and expert knowledge, thirty-one key barriers and facilitators to university students' exercise were targeted in the intervention design (Table 3). Barriers and facilitators spanned six COM-B categories: psychological capability (n = 7), physical capability (n = 1), physical opportunity (n = 7), social opportunity (n = 4), reflective motivation (n = 5) and automatic motivation (n = 7).

Stage 2: Identify intervention options

Step 5 and 6: Identify intervention types and policy options

Seven intervention types (Table 3) were selected for the program based on the APEASE criteria: education, modelling, persuasion, environmental restructuring, incentivisation, training and enablement (see Additional File 1 for definitions of intervention

types). The intervention types 'coercion' and 'restriction' were excluded because they did not satisfy the APEASE criteria. Specifically, coercion was not deemed acceptable or appropriate by university students and staff (acceptability) and bore the risk of unintended consequences, such as student disengagement from the program and adverse impacts on their wellbeing (side-effects/safety). Restriction did not satisfy the criteria because it was not practical to reduce the opportunity for students to engage in competing behaviours (practicability).

Stage 3: Identify intervention content and delivery mode

Step 7 and 8: Identify behaviour change techniques and mode of delivery

Twenty-six BCTs were selected to enact the relevant intervention types (Table 3, see Additional File 7 for definitions of each BCT). The content and mode of delivery for each BCT was operationalised into eight core program components:

1) A "Kick Off session" for program onboarding,

2) A new menu of free exercise options each week curated by an exercise physiologist (SH) and exercise goal,

3) Twelve weekly educational and motivational videos (see Additional File 8 for video topics and links or view videos online at https://youtube.com/playlist?list=PLHKkW53lhmzRRKdL8M5TyBoZiIAm-WrwY&si=akmm0QjyXtQbV5So),

4) "PEAK Points" reward system,

5) WhatsApp social support group,

6) “PEAK Packs” exercise group,

7) Exercise and wellbeing trackers,

8) Program outcome reports.

These eight core components were designed to be delivered over multiple digital channels and a small number of in-person activities. Digital channels included Moodle, WhatsApp, Qualtrics, text message, and email. These channels were specifically chosen for their cost-effectiveness, to adhere to budget constraints during the development phase and to maximise the program's potential for scale.

The program duration was set at 12-weeks to coincide with the full academic semester at Monash University. The sequence of educational and motivational video content was strategically ordered by the design team to correspond with the typical fluctuation in students’ motivation to exercise throughout the semester.

Table 3

Behaviour Change Wheel Process Applied to Develop the PEAK Mood, Mind and Marks Program

Data source (systematic review/stakeholders/experts) **Student barriers and facilitators to engaging with PEAK**	**COM-B category**	**Intervention types**	**BCT/s**	**Text description**	**Mode of delivery**
"Kick Off session" PEAK program onboarding					
Experts. Students need information about the PEAK program including its purpose, what participation involves, and potential benefits	PSYCH CAP	EDUCATION	Instruction on how to perform a behaviour[a] Information about emotional consequences[b] Information about health consequences[b]	Students will be invited to attend a "Kick Off Session" to learn about PEAK's purpose, how to participate[a], and how exercise can improve mental and cognitive health[b].	In-person
Student stakeholders. Being part of a supportive exercise community is beneficial for students*	SOC OPP	ENABLEMENT	Social support (unspecified)	Students will have the opportunity to meet peer participants and the PEAK program design team at the onboarding "Kick Off Session".	In-person
Menu of exercise options and goal					
Systematic review and student stakeholders. Limited financial means constrain students' ability to pay for exercise options* Students need [a range of] accessible exercise options that can flexibly accommodate their location, weather conditions, and exercise preferences* Students want exercise options that can flexibly cater to their preference for exercising alone or with others*	PHYS OPP	ENABLEMENT	Restructuring the physical environment	Each week, students will be given access to a new menu of free exercise options that comprise: aerobic and resistance training options; beginner and advanced options; digital and in-person training options; options that do not require exercise equipment.	Digitally via Moodle

Data source (systematic review/stakeholders/experts) **Student barriers and facilitators to engaging with PEAK**	**COM-B category**	**Intervention types**	**BCT/s**	**Text description**	**Mode of delivery**
Student stakeholders. Students hold mixed opinions on whether it is helpful/unhelpful to use existing university digital platforms like Moodle to deliver the program Beginners need introductory exercise options to build confidence and learn basic exercise skills Students need exercise options that don't require the use of equipment					
Systematic review and student stakeholders. Students need [a range of] accessible exercise options that can flexibly accommodate their location, weather conditions, and exercise preferences* Limited financial means constrain students' ability to pay for exercise options* Students want exercise options that can flexibly cater to their preference for exercising alone or with others*	PHYS OPP	ENABLEMENT	Adding objects to the environment	Students will be given an "exercise starter kit" which includes an exercise mat, drink bottle and towel to enable online exercise options at home, a calendar to schedule their exercise sessions, and 12 free passes to access the university gym and/or group exercise sessions on-campus.	In-person
Systematic review and experts. Receiving advice from trusted experts or credible sources regarding exercise is motivating.	REF MOT	PERSUASION	Credible source	Students will be informed that the exercise options were curated by a senior exercise physiologist.	Digitally via Moodle

Data source (systematic review/stakeholders/experts) **Student barriers and facilitators to engaging with PEAK**	**COM-B category**	**Intervention types**	**BCT/s**	**Text description**	**Mode of delivery**
Systematic review and student stakeholders. Students lack knowledge about how to exercise	PSYCH CAP	EDUCATION	Instruction on how to perform a behaviour[a]	Fitness and/or gym instructors will provide instruction[a] and demonstration[b] of how to perform various exercises while prompting students to engage in same[c].	Digitally via Moodle and in-person
Systematic review. Having the physical skills to engage in exercise is important for students	PHYS CAP	TRAINING	Demonstration of the behaviour[b] Behavioural practice/rehearsal[c]		
Systematic review and student stakeholders. Students find it motivating to set exercise goals	REF MOT	ENABLEMENT	Goal setting (behaviour)[a] Action planning[a]	Students will be informed that the core PEAK program exercise goal is to build up to exercising three or more times per week for 12-weeks[a].	Digitally via Moodle and in-person
Twelve weekly educational and motivational videos					
Systematic review and student stakeholders. Having a routine helps students to fit exercise into their schedule*	AUTO MOT	ENVIRONMENTAL RESTRUCTURING	Prompts/cues[a]	***Week 1. "Expert tips for creating an exercise routine"*** The following expert-endorsed strategies for creating an exercise routine will be depicted: 1) Visualise desired exercise outcomes and place reminders of this in visible locations[a] 2) Use a calendar to plan exercise sessions in advance[b] 3) Track weekly exercise sessions[c] 4) Create "IF this, THEN that" exercise plans to overcome foreseeable barriers to exercise[a] 5) Start with small exercise activities that can piggyback off existing routines and habits[a]	Digitally via Moodle
		ENABLEMENT	Goal setting (behaviour)[b] Action planning[b] Self-monitoring of behaviour[c]		

Data source (systematic review/stakeholders/experts) **Student barriers and facilitators to engaging with PEAK**	**COM-B category**	**Intervention types**	**BCT/s**	**Text description**	**Mode of delivery**
Systematic review and student stakeholders. Students lack time management skills to fit exercise into their routine	PSYCH CAP	EDUCATION	Not specified		
Student stakeholders. Students are motivated by the positive impact that exercise has on their thinking skills*	REF MOT	EDUCATION PERSUASION	Information about health consequences	***Week 2. "Too many assignments to exercise? Exercising your way to PEAK marks"*** A student struggling to concentrate, remember things, and problem-solve will be shown. Evidence regarding how exercise can improve these three cognitive functions will then be provided.	Digitally via Moodle
Systematic review and student stakeholders. Students may feel self-conscious when exercising around others	AUTO MOT	PERSUASION	Framing/reframing	***Week 3. "Overcoming self-consciousness"*** Feeling self-conscious while exercising will be normalised and students will be encouraged to adopt a new and empowering perspective to embrace the way their body looks and feels while exercising rather than feeling self-conscious. These messages will be shown alongside rolling footage of culturally, gender, and age diverse students exercising together.	Digitally via Moodle
Systematic review and student stakeholders. Students can find it difficult to prioritise exercise over other activities*	REF MOT	PERSUASION	Framing/reframing	***Week 4. "But what if I don't have time to exercise?"*** A psychologist will reframe the belief that "I don't have enough time to exercise" to "I don't prioritise exercise", and encourage students to re-prioritise exercise by remembering why they signed up to the PEAK program.	Digitally via Moodle

Data source (systematic review/stakeholders/experts) **Student barriers and facilitators to engaging with PEAK**	**COM-B category**	**Intervention types**	**BCT/s**	**Text description**	**Mode of delivery**
Systematic review and student stakeholders. Students are motivated by the positive impact that exercise has on their mental health and wellbeing* Students don't feel like exercising when they are tired* Students don't feel like exercising when their mental health is poor*	REF MOT AUTO MOT	EDUCATION PERSUASION	Information about emotional consequences[a] Information about health consequences[b]	***Week 5. "Too stressed to exercise? Exercising your way to PEAK mood"*** A stressed and inactive student with low mood and low energy will be shown in the context of relatable student life. This will be followed by footage of the same student using exercise to cope with stress, improve their mood[a] and increase their energy[b]. Education regarding the mental health benefits of exercise will be introduced alongside this footage[a].	Digitally via Moodle
Student stakeholders. Knowledge of how exercise impacts mental, cognitive and brain health is helpful*	PSYCH CAP	EDUCATION	Information about emotional consequences[a] Information about health consequences[b]	***Week 6. "Strong lungs, strong brain: the beauty of breathlessness"*** An animation will be used to explain the neurophysiological processes underlying how training at higher intensities can improve mental[a] and brain health[b]. An example of how breathlessness can be used as a practical way of assessing exercise intensity will also be provided[b].	Digitally via Moodle
Student stakeholders. Knowledge of how exercise impacts mental, cognitive and brain health is helpful*	PSYCH CAP	EDUCATION	Information about health consequences	***Week 7. "Strong body, strong brain: the beauty of strength training"*** An animation will be used to explain the neurophysiological processes underlying how strength and resistance training can improve brain health and cognitive health.	Digitally via Moodle

Data source (systematic review/stakeholders/experts) **Student barriers and facilitators to engaging with PEAK**	**COM-B category**	**Intervention types**	**BCT/s**	**Text description**	**Mode of delivery**
Systematic review and student stakeholders. Students can find it difficult to prioritise exercise over other activities*	REF MOT	PERSUASION	Valued self-identity	***Week 8. "Connecting with your WHY"*** A psychologist will facilitate a self-reflection exercise for students, designed to help them identify the specific benefits they seek from physical activity and to explore how these benefits align with their core values.	Digitally via Moodle
Systematic review and student stakeholders. Having a routine helps students to fit exercise into their schedule* *Systematic review.* Students dislike experiencing discomfort during exercise	AUTO MOT	PERSUASION ENABLEMENT	Information about health consequences[a] Self-talk[b] Social support (unspecified)[c] Action planning[d]	***Week 9. "Expert tips for sustaining an exercise routine"*** The following expert-endorsed strategies for sustaining an exercise routine will be depicted: 1) Expect to miss sessions sometimes, but don't let lapses stop you 2) Get comfortable with being uncomfortable; pushing beyond your comfort zone results in the biggest benefits of exercise[a]; remind yourself the effort is short but the rewards are long-lasting[b] 3) Create accountability by exercising with others[c] or booking an exercise class in advance[d]	Digitally via Moodle
Systematic review and student stakeholders. Having a routine helps students to fit exercise into their schedule*	AUTO MOT	PERSUASION	Framing/reframing[a] Information about health consequences[b]	***Week 10. "Consistency trumps perfection; why habits are the gold"*** Experiencing setbacks in maintaining an exercise routine will be normalised, and students will be encouraged to adopt the perspective that "doing something is better than nothing"[a] with regards to long-term maintenance of consistent exercise habits[b] .	Digitally via Moodle

Data source (systematic review/stakeholders/experts) **Student barriers and facilitators to engaging with PEAK**	**COM-B category**	**Intervention types**	**BCT/s**	**Text description**	**Mode of delivery**
Systematic review and student stakeholders. Students are motivated by the positive impact that exercise has on their mental health and wellbeing* Students don't feel like exercising when they are tired* Students don’t feel like exercising when their mental health is poor*	REF MOT AUTO MOT	EDUCATION PERSUASION	Information about emotional consequences[a] Information about health consequences[b]	***Week 11. "But what if I don't feel like exercising?!"*** A student staying at home on the couch, feeling "too tired, stressed and flat" to exercise, will be shown alongside the negative consequence that skipping exercise has on reinforcing unhealthy habits[b]. The same student will overcome their fatigue by engaging in exercise, subsequently improving their mood[a], increasing their satisfaction and maintaining their exercise habits[b].	Digitally via Moodle
Student stakeholders. Students are motivated by the positive impact that exercise has on their thinking skills* *Systematic review and student stakeholders.* Students can find it difficult to prioritise exercise over other activities*	REF MOT	PERSUASION	Framing/reframing	***Week 12. "SWOTVAC is coming... keep moving!"*** A student debating whether to exercise during their exam preparation week (SWOTVAC) will be shown. During this debate, information will be provided regarding how exercise can help students better manage their stress, improve their thinking skills and ultimately help (rather than hinder) their exam performance.	Digitally via Moodle
"PEAK Points" reward system					

Data source (systematic review/stakeholders/experts) **Student barriers and facilitators to engaging with PEAK**	**COM-B category**	**Intervention types**	**BCT/s**	**Text description**	**Mode of delivery**
Systematic review and student stakeholders. Students respond positively to incentives that encourage them to exercise	AUTO MOT	INCENTIVISATION	Material incentive (behaviour)[a] Non-specific incentive (behaviour)[a] Material reward (behaviour)[b] Non-specific reward (behaviour)[c]	Students will receive notification that they are eligible to earn one 'PEAK Point' for each completed exercise session[a]. These accrued points may be redeemed for either on-campus coffee vouchers[b] or for personalized small group training sessions led by a senior exercise physiologist[c]	Digitally via text message
WhatsApp group					
Systematic review and student stakeholders. Encouragement from others to exercise helps students to keep accountable to their exercise routine Students respond positively to relatable exercise role models and champions who support and encourage exercise* *Student stakeholders.* Being part of a supportive exercise community is beneficial for students*	SOC OPP	ENABLEMENT	Social support (unspecified)	Students will receive encouragement to exercise from the PEAK design team, including two PEAK student ambassadors.	Digitally via WhatsApp

Data source (systematic review/stakeholders/experts) **Student barriers and facilitators to engaging with PEAK**	**COM-B category**	**Intervention types**	**BCT/s**	**Text description**	**Mode of delivery**
Systematic review and student stakeholders. Students respond positively to relatable exercise role models and champions who support and encourage exercise*	SOC OPP	MODELLING	Credible source	Two PEAK student ambassadors will share their exercise journey and experiences with students.	Digitally via WhatsApp
Student stakeholders. Students lack knowledge about how to manage the physical consequences (e.g., muscle soreness) and risks (e.g., injury) associated with exercise *Systematic review.* Students dislike the unpleasant physical consequences of exercise, such as muscle soreness and fatigue	PSYCH CAP AUTO MOT	EDUCATION	Information about health consequences	A senior exercise physiologist will share two educational videos of himself titled ***"The truth about delayed onset muscle soreness (DOMS)"*** and ***"Managing exercise fatigue and recovery".*** During these videos, he will explain how to manage the physical consequences of exercise (e.g., muscle soreness and fatigue), prevent injury, and optimise recovery following exercise.	Digitally via WhatsApp
Systematic review and experts. Students' beliefs in their ability to exercise and perceiving it as a part of their identity is important	REF MOT	PERSUASION	Credible source[a] Verbal persuasion about capability[b]	A senior exercise physiologist[a] will share a motivational video of himself titled ***"Busting exercise myths"***. During this video, he will target students' self-efficacy to exercise by challenging misconceived beliefs that people need to be "good" at exercise and/or self-identify as "sporty" to reap the benefits of exercise[b].	Digitally via WhatsApp
"PEAK Packs" exercise groups					
Systematic review and student stakeholders. Exercising with others is beneficial for students	SOC OPP	ENVIRONMENTAL RESTRUCTURING	Restructuring the social environment	Students will have the option to exercise with others in the PEAK program either with a pre-selected group of friends or by joining a curated group of fellow participants, termed a "PEAK Pack". Within these PEAK Packs, students will be integrated into dedicated WhatsApp sub-groups, which operate alongside the main WhatsApp group encompassing all participants.	In-person and digitally via WhatsApp

Data source (systematic review/stakeholders/experts) **Student barriers and facilitators to engaging with PEAK**	**COM-B category**	**Intervention types**	**BCT/s**	**Text description**	**Mode of delivery**
			Social support (unspecified)	Students will be encouraged to exercise with others in their PEAK Pack and to support each other's exercise engagement.	
Exercise and wellbeing trackers					
Student stakeholders. Prompts to exercise are a helpful reminder for students	PHYS OPP	ENVIRONMENTAL RESTRUCTURING	Prompts/cues[a]	Students will be sent an "Exercise Tracker" each week[a] to track the number, type and duration of exercise they complete[b].	Digitally via Qualtrics link embedded in text message
Systematic review and student stakeholders. Tracking and receiving feedback on exercise progress is motivating for students*	PSYCH CAP	EDUCATION	Self-monitoring of behaviour[b]		
Student stakeholders. Students hold mixed opinions on whether it is/is not helpful to track and receive feedback on the impact of exercise on mental health and cognition*	PSYCH CAP	EDUCATION	Self-monitoring of outcome(s) of behaviour[a] Monitoring of emotional consequences[b]	Students will be sent a "Wellbeing Tracker" tri-weekly to track the impact exercise has[a] on their wellbeing and cognition[b].	Digitally via Qualtrics link embedded in text message
Program outcome reports					

Data source (systematic review/stakeholders/experts) **Student barriers and facilitators to engaging with PEAK**	**COM-B category**	**Intervention types**	**BCT/s**	**Text description**	**Mode of delivery**
Systematic review and student stakeholders. Tracking and receiving feedback on exercise progress is motivating for students* *Student stakeholders.* Students hold mixed opinions on whether it is/is not helpful to track and receive feedback on the impact of exercise on mental health and cognition*	PSYCH CAP	EDUCATION PERSUASION	Feedback on behaviour[a] Feedback on outcome(s) of behaviour[b]	A personalised "PEAK Outcome Report" will be provided to each student at the conclusion of PEAK. This report will comprise: the number of days they exercised per week[a]; the total number of minutes spent exercising[a]; and their mental, and cognitive health outcomes[b].	Digitally via email

Note. *Barrier/facilitator to exercise targeted in multiple aspects of the program. Psych Cap: Psychological Capability; Phys Cap: Physical Capability; Phys Opp: Physical Opportunity; Soc Opp: Social Opportunity; Ref Mot: Reflective Motivation; Auto Mot: Automatic Motivation.

Discussion

This research is the first to describe how the BCW was applied to develop PEAK, a multichannel intervention designed to engage university students in three or more exercise sessions per week for the benefit of their mental and cognitive health. The triangulated findings from the stakeholder consultations, systematic review, and expert consensus identified 31 barriers and facilitators affecting students' capability, opportunity, and motivation to engage in exercise. Seven intervention types were identified as relevant and subsequently mapped onto 26 BCTs.

Students confirmed a clear need for mental health support and highlighted an absence of programs to adequately address these concerns. These findings call for sustainable, proactive programs within the university setting that can concurrently support students' mental and cognitive health. Harnessing the well-established mental and cognitive health benefits of exercise (Ashdown-Franks et al., 2020; Mandolesi et al., 2018; Singh et al., 2023) offers a solution to address this unmet need. This approach has demonstrated value in numerous other contexts and populations. For example, integrating exercise as a routine part of psychiatric care has gained considerable attention in recent years due to the growing body of evidence supporting its efficacy in treating a range of mental disorders (Stubbs & Rosenbaum, 2018). Similarly, workplace wellness interventions are increasingly focused on improving the mental wellbeing and productivity of employees by implementing strategies to increase physical activity and reduce sedentary behaviour (Buckingham et al., 2019; Edwardson et al., 2018). These examples demonstrate the potential of adopting exercise-based approaches, such as PEAK, in the tertiary education sector to offer similar mental and cognitive health benefits for students. Targeting university students is particularly important,

as it provides an opportunity to set young adults up for a lifetime of healthy exercise habits, establishing a foundation for mentally healthy and productive communities and workforces.

University staff expressed a strong interest in endorsing programs that align with institutional goals, such as supporting student wellbeing and academic performance, advancing the university's reputation for academic excellence, increasing student enrolment, and strengthening students' sense of belonging to the university. A program that can successfully support students' mental and cognitive health aligns well with these institutional goals. Such a program is especially needed for international students given they are an underserved, equity-deserving cohort who may be particularly vulnerable to experiencing poor mental health (Shadowen et al., 2019). A program designed to support students' mental and cognitive health also has the potential to enhance the student experience and improve their academic performance, thereby promoting the university's academic reputation on a competitive global stage. A strong reputation can lead to higher world university rankings and increased visibility in the academic community, which can attract academically talented students, domestically and internationally, to enrol in the university. This holds significance given the recent decline in international student enrolment in universities across several countries (Buckner et al., 2022; New Zealand Government, 2023; Parliament of Australia, 2021), which has consequential adverse economic ramifications (Thatcher et al., 2020). Therefore, strategies to reverse this trend are increasingly important for universities.

Of equal importance is a program that can strengthen students' sense of belonging to the university. A strong sense of belonging can increase students' academic motivation, enjoyment of their studies, and engagement with the university (Lawson & Lawson, 2013; Ulmanen et al., 2016), all of which heavily influence institutional performance indicators such as academic success and student retention rates (Crawford et al., 2023; Pedler et al.,

2022; Thomas et al., 2014). The need for interventions that address students' sense of belonging is particularly relevant following the COVID-19 pandemic, which restricted students' opportunities for peer interaction and engagement with the university community. Interventions that aim to foster students' sense of belonging to the university should focus on enhancing peer-to-peer interaction (Watson et al., 2010). PEAK was designed with this specific goal in mind, offering students opportunities to connect with each other and build a community of like-minded peers via their participation in exercise and shared experience of the program.

Strengths and limitations

This study provides a thorough example of how to apply the BCW to integrate theory, evidence, stakeholder perspectives, and expert knowledge into the development of a health behaviour change intervention. Describing this process in detail enables other intervention designers to pilot the intervention with fidelity to test its possible impact across various other university settings. The methodology aligns with the MRC guidelines and the NICE recommendations, thereby ensuring adherence to best practice principles for intervention development. Another strength lies in the purposeful recruitment of students and staff in the stakeholder engagement process. This recruitment strategy enabled a diversity of perspectives to be captured and addressed in the intervention design. However, there are limitations to consider. Using the BCW process can be time-intensive, which may pose challenges for the rapid development and implementation of interventions. Moreover, the absence of students with physical mobility limitations in the sample could partially account for the lack of identified barriers or facilitators related to physical capability in the qualitative data.

Conclusion

Behaviour change interventions have the potential to embed regular exercise into the lifestyles of university students to improve their mental and cognitive health. The current study describes how PEAK was developed, and the evidence, theory and stakeholder perspectives used to inform its creation. Using this systematic approach was demonstrated to be effective at translating BCTs into the core components of PEAK, and optimising its feasibility, adoption, and scalability potential. This work offers a replicable roadmap for others seeking to develop behaviour change interventions and will inform an empirical study assessing the efficacy and implementation of PEAK.

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CHAPTER SIX: Study Three. Intervention Pilot

6.1 Explanatory Notes

Best practice approaches for developing behavioural interventions like PEAK involves small-scale pilot studies and iteration before large scale evaluation and dissemination (Craig et al., 2008; Czajkowski et al., 2015; Michie et al., 2011b; Skivington et al., 2021). Early iterative testing provides critical insights that can be used to refine the program content and delivery to optimise the acceptability, feasibility, usability, and efficacy of the program. Evaluation of both the programs impact on behavioural and health outcomes and implementation outcomes is useful to inform how well the program is meeting the needs of those who take part, and how the program content and implementation can be improved. As such, Study Three was a pilot of PEAK, evaluating its impacts on students' exercise engagement and perceived mental and cognitive health. Implementation outcomes including student engagement in PEAK, barriers and enablers to engagement, the acceptability and appropriateness of PEAK, and mechanisms of behaviour change were also evaluated. These implementation outcomes were selected based on common leading indicators of implementation success that are particularly pertinent in the early implementation stages (Nilsen, 2015; Proctor et al., 2011).

6.2 Publication three: PEAK Mood, Mind and Marks: a pilot study of an intervention to support university students' mental and cognitive health through physical exercise

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Abstract

Introduction: Regular exercise has the potential to enhance university students' mental and cognitive health. The PEAK Mood, Mind and Marks program (i.e., PEAK) is a neuroscience-informed intervention developed using the Behaviour Change Wheel to support students to exercise three or more times per week to benefit their mental and cognitive health. This pilot study assessed the impact of PEAK on exercise, mental and cognitive health, and implementation outcomes.

Methods: PEAK was delivered to 115 undergraduate university students throughout a 12-week university semester. The primary outcome was weekly exercise frequency. Secondary outcomes were: time spent engaged in moderate-vigorous exercise, sedentary behaviour and perceived mental health and cognitive health. All were measured via online self-report questionnaires. Qualitative interviews with 15 students investigated influences on engagement, the acceptability and appropriateness of PEAK, and its mechanisms of behaviour change. Paired t-tests, Wilcoxon Signed-Rank tests, and template analysis were used to analyse quantitative and qualitative data, respectively.

Results: On average, 48.4% of students engaged in the recommended frequency of three or more exercise sessions per week. This proportion decreased towards the end of PEAK. Sedentary behaviour significantly decreased from baseline to end-point, and moderate-vigorous exercise significantly increased among students' who were non-exercisers. Mental wellbeing, stress, loneliness, and sense of belonging to the university significantly improved. There were no significant changes in psychological distress. Concentration, memory, and productivity significantly improved. Sixty-eight percent of students remained engaged in one or more components of PEAK at end-point. Qualitative data indicated students found PEAK

to be acceptable and appropriate, and that it improved aspects of their capability, opportunity, and motivation to exercise.

Conclusions: Students are receptive to an exercise-based program to support their mental and cognitive health. Students exercise frequency decreased; however, these figures are likely a conservative estimate of students exercise engagement. Students valued the neuroscience-informed approach to motivational and educational content and that the program's goals aligned with their academic goals. Students identified numerous areas PEAK's content and implementation can be optimised, including use of a single digital delivery platform, more opportunities to connect with peers and to expand the content's cultural inclusivity.

Keywords: University Students; Physical Exercise; Mental Health; Cognitive Health; Brain Health; Behavioural Intervention; Implementation Evaluation; COM-B

1. INTRODUCTION

The mental and cognitive health of university students play a pivotal role in their academic success and post-university career prospects. However, a large proportion of students experience difficulties with these aspects of health. Globally, 35% of university students meet criteria for one or more mental illnesses (Auerbach et al., 2018), 65% report high levels of psychological distress (headspace & National Union of Students, 2016), and 36% report feeling lonely (Diehl et al., 2018). Concerns about cognitive performance are similarly common, with 60% describing their cognitive capacity as sub-optimal in domains including memory and concentration (Bird et al., 2023). Addressing students' mental and cognitive health challenges is important for supporting students' broader quality of life and academic performance.

Promoting regular physical exercise[3] has the potential to be an effective and empowering approach to address these concerns. A robust body of evidence demonstrates that regular exercise has substantial positive impacts on mental and cognitive health. For example, regular exercise, especially when performed at moderate to vigorous intensities, can be as effective as psychotherapy and pharmacotherapy in reducing symptoms of depression and anxiety (Singh et al., 2023). Beneficial mental health effects have also been established in other stress-related disorders, schizophrenia, and substance-use disorders (Firth et al., 2015; Stubbs et al., 2017; Wang et al., 2014; Wang et al., 2019). Exercise is also associated with powerful reductions in the overall burden of poor mental health. For example, a study involving 1.2 million adults (Chekroud et al., 2018) demonstrated that people who were physically active in the preceding month had 43% fewer days of poor mental health during the month compared to those that were not active. Interestingly the benefits were non-linear,

[3] Exercise is defined as "planned, structured, and repetitive bodily movement done to improve or maintain one or more components of physical fitness" (Caspersen et al., 1985).

with greatest benefits associated with exercising three to five times per week for 30 - 60 minutes per session. These findings are consistent with a large body of longitudinal research demonstrating that engaging in exercise regularly is associated with improved mental health among a range of clinical and non-clinical populations (Schuch et al., 2018), including university students (Donnelly et al., 2024). Specifically, engaging in regular exercise can buffer the negative effects of stress on mental and physical health (Klaperski & Fuchs, 2021; Wunsch et al., 2017), enhance psychological wellbeing (Gondoh et al., 2009), reduce psychological distress (Sfendla et al., 2018) and, especially when performed with other people, can reduce social isolation and loneliness (Brady et al., 2020; McAuley et al., 2000).

A large and growing body of evidence has also demonstrated that exercise confers significant cognitive health benefits. Cognitive health benefits encompass improvements in memory, heightened efficiency of attentional processes, and strengthened executive-control processes (Chieffi et al., 2017; Colcombe & Kramer, 2003; Grego et al., 2004; Winter et al., 2007). Within this literature, the impacts of different types of exercise have been evaluated, with most attention focused on aerobic exercise and, increasingly, resistance training. Regular aerobic exercise can induce improvements in memory and executive functioning skills (Hoffmann et al., 2021), including working memory, cognitive flexibility, and inhibitory control (Xiong et al., 2021). Similarly, improvements in executive functioning skills have been demonstrated following regular resistance training, such as selective attention and inhibitory control (Liu-Ambrose et al., 2010; Liu-Ambrose et al., 2008). While studies investigating the cognitive benefits of exercise have tended to focus on older adults, prospective studies have reported positive associations between exercise and cognitive function among young adults (Gaertner et al., 2018), suggesting that higher levels of exercise may help to maintain cognitive health throughout adulthood.

A key mechanism by which engaging in exercise is thought to promote mental and cognitive health is via its impacts on neuroplasticity (El-Sayes et al., 2019; Kandola et al., 2019; Phillips, 2017). When performed regularly and at moderate and vigorous intensities, exercise can have profound effects on the structure, connectivity, and functioning of the brain (Cabral et al., 2019; de Sousa et al., 2019; El-Sayes et al., 2019). While the molecular mechanisms of exercise-induced neuroplasticity are only partially understood, one key pathway that has been extensively studied is the impact of exercise intensity on brain-derived neurotrophic factor (BDNF) (Antunes et al., 2020; Jeon & Ha, 2017), a key signalling molecule involved in neuroplastic changes related to learning and memory (Mattson et al., 2004). During vigorous intensity exercise, the demand for energy rapidly escalates, which triggers a series of processes that increases circulating lactate (MacIntosh et al., 2021; Ohkuwa et al., 2009). Circulating lactate can pass through the blood brain barrier and, when it does so, catalyses an increase in BDNF (Müller et al., 2020). A second neuroplastic mechanism that has been much studied is the impact of resistance training on insulin-like growth factor 1 (IGF-1) (Jiang et al., 2020). When engaging in resistance exercise, Human Growth Hormone is secreted from the pituitary gland, which promotes the release of IGF-1 from the liver into the bloodstream (Kraemer et al., 2017; Kraemer & Ratamess, 2005). IGF-1 can, in turn, cross the blood brain barrier (Liu et al., 2001; Pan & Kastin, 2000). Once in the brain, IGF-1 plays a critical role in brain development and cognition and, at low levels, is a marker of cognitive decline and dementia (Frater et al., 2018). Exercise-induced neuroplastic changes have been linked to improvements in mental and cognitive health outcomes, including depression (Paolucci et al., 2018; Yeh et al., 2015), psychological wellbeing (Gondoh et al., 2009), episodic and verbal memory (Den Ouden et al., 2018; Erickson et al., 2011), and global cognitive performance (Suo et al., 2016). Educating students about these neuroscientific mechanisms could enhance students' engagement in an exercise-based

intervention for the benefit of their mental and cognitive health (Brown, Richardson, Halil-Pizzirani, Hughes, et al., 2024). While knowledge alone is not sufficient to change behaviour, it is a necessary component and can increase the acceptability of an intervention (Arlinghaus & Johnston, 2018; Sekhon et al., 2017).

An exercise-based intervention may be appealing to students if it aligns with their academic goals. Students understandably tend to prioritise performing well at university over initiating or maintaining a regular exercise routine (Brown, Richardson, Halil-Pizzirani, Atkins, et al., 2024). Therefore, programs that emphasise the positive brain effects of exercise and neuroscientific evidence that demonstrates exercise can optimise cognition and buffer stress to support academic performance could be particularly engaging (Brown, Richardson, Halil-Pizzirani, Hughes, et al., 2024). Offering students' a program to support their mental and cognitive health may also help universities to achieve strategic priorities, including attracting and retaining students, by strengthening students' sense of belonging to the university (Lawson & Lawson, 2013; Ulmanen et al., 2016).

The PEAK Mood, Mind, and Marks program (i.e., PEAK) was co-designed with university students, staff, and senior leadership (Brown, Richardson, Halil-Pizzirani, Hughes, et al., 2024). PEAK is a neuroscience-informed behaviour change program designed to increase university students' engagement in exercise. The program content and messaging were designed to target students' barriers and facilitators to behaviour change, including their goals to excel academically. This approach distinguishes PEAK from other health behaviour change interventions for university students, testing a novel strategy to support students to exercise regularly for the benefit of their 'mood, mind, and marks'.

Best practice for developing behavioural interventions like PEAK includes multiple rounds of small-scale piloting and iteration before large scale evaluation and roll out (Craig et

al., 2008; Czajkowski et al., 2015; Michie et al., 2011; Skivington et al., 2021). This kind of early iterative testing provides critical insights that can be used to refine the program design to optimise the acceptability, feasibility, usability, and efficacy of the program. Evaluation of behavioural and health impacts and implementation outcomes is useful to inform how well the program is meeting the needs of the students who take part, and how the program can be improved. Thus, the aim of the present study was to conduct a pilot of the PEAK Mood, Mind and Marks program and: (i) evaluate its impacts on students' exercise engagement and perceived mental and cognitive health, and (ii) to assess implementation outcomes across student engagement, barriers and enablers to engagement, the acceptability and appropriateness of PEAK, and mechanisms of behaviour change.

2. MATERIALS AND METHODS

2.1 Study design

A quasi-experimental single-arm pilot study design was adopted and the simultaneous assessment of program impact and implementation outcomes (see (Curran et al., 2012)) was conducted (see Additional File 1 for CONSORT flow diagram). This design is especially pertinent for evaluating programs in the tertiary education system because such a design can be used to evaluate the success of implementation strategies in the engagement and uptake of PEAK at the individual-level. The program was piloted throughout July – November 2022, coincident with the second semester of an Australian university teaching period. The Template for Intervention Description and Replication (TIDieR) checklist is provided in Additional File 2.

2.2 Participants

Students were eligible if they were aged 18 years or over, currently enrolled in an undergraduate degree at Monash University (Melbourne, Australia), and able to provide voluntary informed consent. Exclusion criteria included self-reported contraindications to safe engagement in regular exercise as identified by the Physical Activity Readiness Questionnaire (PAR-Q) (Thomas et al., 1992) (e.g., a heart condition, high blood pressure, or chest pain while participating in physical activiry), or lifetime diagnosis of an eating disorder.

Stratified random sampling was used to enrol students based on whether they were domestic or international students, ensuring the representation across these two groups was approximately equal to assess the suitability and impact of PEAK for both cohorts. Recruitment was conducted throughout May – July 2023 via advertisements placed on-campus and student social media pages. Eligibility for participation was determined via a brief online screening questionnaire. All participants provided informed consent online and the study was approved by the Monash University Human Research Ethics Committee (#32395).

2.3 Intervention

For a detailed description of the intervention co-design process, program content, and delivery methods see Brown et al. (in review). In brief, PEAK was developed using the Behaviour Change Wheel (BCW) (Michie et al., 2011), a gold-standard behavioural interventions development framework, and heavily informed by co-design consultations with students, staff, and senior leadership. This resulted in a 12-week semester-long program focused on supporting students to engage in three or more sessions of exercise per week, with a session understood to be 10-minutes or more of exercise. PEAK was designed to target students' capability, opportunity, and motivation to exercise (see (Brown, Richardson, Halil-Pizzirani, Atkins, et al., 2024) for a systematic review) by implementing eight core program

components (see Table 1 for a description of each component). Program components were delivered via digital channels (i.e., Moodle, WhatsApp, Qualtrics, text message, email) and a small number of in-person activities at Monash University. A stratified sample of domestic and international students participated in the co-design and evaluation of PEAK, offering a diversity of perspectives to develop an inclusive program.

Neuroscience informed two key elements of the program: 1) incorporation of both moderate to vigorous intensity and resistance exercise options and 2) education about the brain, cognitive, and mental health mechanisms and impacts of these types of exercise. Specifically, each week, students were given access to a new menu of exercise options curated by a senior exercise physiologist (SH) that featured moderate to vigorous intensity aerobic and resistance exercises (see Additional File 3 for exercise options offered to students). Aerobic exercise options were purposefully selected with the physiological goal to elevate students' heart rate. Resistance training options were purposefully selected with the physiological goal to systematically fatigue targeted muscle groups through applying force or weight. During the "Kick Off session" PEAK program onboarding and throughout the educational and motivational videos, students' were educated about the positive brain effects of exercise and neuroscientific evidence that demonstrates exercise can optimise cognition and buffer stress to support academic performance. Students were also informed about evidence for two key neurobiological mechanisms (i.e. augmentation of BDNF and IGF-1 release) through which moderate to vigorous intensity exercise and resistance exercise can differentially support mental and cognitive health by changing the structure and function of the brain.

Table 1

PEAK Program Components, Mode of Delivery and Delivery Schedule

Program component	Description	Mode of delivery	Delivery schedule
"Kick Off session" PEAK program onboarding	Students were invited to attend a "Kick Off Session" to learn about PEAK's purpose, how to participate, and how exercise can improve mental and cognitive health. Students had the opportunity to meet peer participants and the PEAK program team at the session.	In person	Baseline
Menu of exercise options and goal	Students were informed that the core PEAK program exercise goal is to build up to exercising three times per week for 12-weeks.	Digitally via Moodle and in person	Baseline
	Students were given an "exercise starter kit" which included an exercise mat, drink bottle and towel to enable online exercise options at home, a calendar to schedule their exercise sessions, and 12 free passes to access the university gym for gym use and/or group exercise sessions on-campus.	In person	Baseline
	Each week, students were given access to a new menu of free exercise options curated by a senior exercise physiologist that comprised: aerobic and resistance training options; beginner and advanced options; digital and in-person training options; options that did not require exercise equipment.	Digitally via Moodle	Week 1 - 12

Twelve weekly educational and motivational videos*	Each week, students received a new educational or motivational video designed to target common barriers to exercise most often experienced by university students. Core messages reiterated across these videos included: how to build and sustain a regular exercise routine; how to overcome common student' barriers to exercise; how the mental and cognitive health impacts of regular exercise can support academic performance; the key neuroscientific mechanisms through which high intensity exercise and resistance exercise can change the structure and function of the brain to support mental and cognitive health.	Digitally via Moodle	Week 1 - 12
"PEAK Points" reward system	Students received a notification that they were eligible to earn one 'PEAK Point' for each completed exercise session. Points could be redeemed for coffee vouchers for the student union on-campus café or small group training sessions led by the PEAK team exercise physiologist.	Digitally via text message	Week 1 - 12
WhatsApp social support group	Students were added to a WhatsApp group to: receive encouragement and support to exercise from the PEAK design team and	Digitally via WhatsApp	Week 1 - 12

	provide/receive peer support from other students; share their experience of participating in exercise; co-ordinate times to meet up to exercise with peers; and ask the PEAK design team any questions about PEAK and/or exercise.		
"PEAK Packs" exercise group	Students had the option to take part in PEAK in a group called a 'PEAK Pack'. These could be formed with existing friends, or by asking the program team to place a student in a group of demographically similar students. A separate WhatsApp groups was created for each PEAK Pack to help members coordinate with and support each other.	In person and digitally via WhatsApp	Week 1 - 12
Exercise and wellbeing trackers	Students were sent an "exercise tracker" each week to track the number, type and duration of exercise they completed.	Digitally via Qualtrics link embedded in text message	Week 1 - 12
	Students were sent a "wellbeing tracker" tri-weekly (i.e., once every three weeks) to track the impact exercise had on their mental wellbeing and cognition.	Digitally via Qualtrics link embedded in text message	Week 3, 6, and 9
Program outcome reports	A personalised "PEAK Outcome Report" was provided at the conclusion of the program. This report included the number	Digitally via email	Week 13

of days the student had exercised per week; the total number of minutes spent exercising; and their mental, and cognitive health outcomes.

Note. *Access video content from: https://youtube.com/playlist?list=PLHKkW53lhmzRRKdL8M5TyBoZiIAm-WrwY&si=akmm0QjyXtQbV5So. Adapted from Brown C, Richardson K, Halil-Pizzirani B, Hughes S, Atkins L, Perowne R, Pitt J, Yücel M, Segrave R. (2023) PEAK Mood, Mind and Marks: Development of an Intervention to Support University Students' Mental and Cognitive Health through Physical Exercise. Manuscript in review for publication at BMC Public Health.

2.4 Behavioural and Health Outcome Measurement Procedures

Behavioural and health outcomes were tracked via self-report questionnaires sent by text message using the Qualtrics platform (see Table 2 for data collection schedule). If students did not complete a survey within 24-hours, a single reminder text was sent.

Exercise frequency and duration were measured each week for the duration of the program via a one-minute "exercise tracker" survey. All other behavioural and health outcomes were assessed at baseline (i.e., "week 0") and at end-point (i.e., "week 12") via a ten-minute assessment battery. Key mental and cognitive health outcomes and sense of belonging to the university were assessed once every three weeks via a four-minute "wellbeing tracker" assessment battery outlined below.

Table 2

Behavioural and Health Outcome Data Collection Tools and Schedule

Outcome	Scale/measurement tool	Collection schedule			
		Baseline	Weekly	Tri-weekly	End-point
Exercise					

Exercise frequency	Exercise tracker		X		
Exercise duration (minutes)	Exercise tracker				
Moderate-vigorous exercise	International Physical Activity Questionnaire	X			X
Sedentary behaviour	International Physical Activity Questionnaire	X			X
Mental health					
General mental wellbeing	Short Warwick-Edinburgh Mental Wellbeing Scale	X		X	X
Stress and coping	Perceived Stress Scale 4	X		X	X
Loneliness	Campaign to End Loneliness Tool	X		X	X
Psychological distress	Kessler Psychological Distress Scale	X			X
Cognitive health					
Concentration	VAS: Vague – Laser-like focus	X		X	X
Memory	VAS: Very forgetful – Rock-solid memory	X		X	X
Productivity	VAS: Unproductive – Highly productive	X		X	X
Belonging to the university					

Sense of belonging to the university	VAS: Very weak – Very strong	X	X	X

2.5 Participant characteristics

Information regarding students' age, gender, domestic vs international student enrolment status, year of undergraduate degree, residential status (i.e., "off-campus" or "on-campus"), and current exercise engagement (i.e., whether they identified as a "non-exerciser", "sometimes-exerciser" or "regular-exerciser") were collected at baseline.

2.6 Behavioural and health outcomes

Exercise frequency

The primary outcome variable was the proportion of students who engaged in three or more exercise sessions per week throughout the program, in keeping with the primary behavioural goal of the program. This was assessed by asking students to report the number of exercise sessions they engaged in each week via the "exercise tracker" survey.

Exercise duration

Students were asked the number of minutes each exercise session they participated in each week via the "exercise tracker". Students were told at the start of the program that an 'exercise session' was defined as ten-minutes or more of purposeful exercise.

Moderate-vigorous exercise and sedentary behaviour

The International Physical Activity Questionnaire (IPAQ) (C. L. Craig et al., 2003) was used to assess (i) the number of hours spent engaging in moderate-vigorous exercise in the past week, and (ii) the number of hours spent sedentary on a typical weekday during the past week.

Mental and cognitive health

Wellbeing was measured with the Short Warwick-Edinburgh Mental Wellbeing Scale (SWEMWBS) (Stewart-Brown et al., 2009): The SWEMWBS is a seven-item measure of psychological wellbeing over the previous two weeks. It contains five response categories on a Likert-scale that are summed to provide a raw score that is transformed into metric scores ranging from 7-35.

Stress and coping were measured with the Perceived Stress Scale 4 (PSS-4) (Cohen et al., 1983): The PSS-4 is four-item measure of the degree to which situations in one's life are appraised as stressful and how well one feels they are coping with them over the past week. The scale has five response options on a Likert-scale which are summed to provide a score ranging from 0-16.

Loneliness was measured with the Campaign to End Loneliness Measurement Tool (CELMT) (Campaign to End Loneliness Measurement Tool, n.d.): The CELMT is a three-item measurement tool for assessing people's experience of loneliness. Students were asked to answer each item using a five-point Likert scale. Scores are summed to give an overall loneliness score that ranges from 0 – 12.

Psychological distress was measured with the Kessler Psychological Distress Scale (K10) (Kessler et al., 2002). The K-10 is a 10-item questionnaire intended to yield a global measure of distress based on questions about anxiety and depressive symptoms that a

respondent has experienced in the most recent month. Students were asked to rate items on a five-point Likert scale. Response items are summed to provide a score ranging from 10 – 50.

Concentration, memory, and productivity was measured with Visual Analogue Scales (VAS): Students were asked to rate their concentration (from Vague to Laser-like focus), memory (from Very forgetful to Rock-solid memory), and productivity (from Unproductive to Highly productive) over the past week from 0-100 on a 100-point VAS.

Belonging to the university

Sense of belonging to the university was measured with a Visual Analogue Scale (VAS): Students were asked to rate the strength of their sense of belonging to the university (from Very week to Very strong) over the past week from 0-100 on a 100-point VAS.

2.7 Implementation outcomes

Implementation outcomes included student engagement in PEAK, factors influencing engagement, the acceptability and appropriateness of PEAK, and mechanisms of behaviour change. The selection of these outcomes was based on common leading indicators of implementation success (Nilsen, 2015; Proctor et al., 2011).

Participant engagement

Students' engagement in each component of PEAK was measured via attendance records and digital analytics.

Factors influencing engagement, intervention acceptability and appropriateness, and mechanisms of behaviour change

Semi-structured interviews were conducted with a subset of 15 students at the conclusion of the program to understand barriers to their engagement in PEAK, the acceptability and appropriateness of the program, and the mechanisms of behaviour change. Recruitment was stratified to obtain perspectives from students with low (n = 5) vs. moderate (n = 7) vs. high engagement in the program (n = 3), international (n = 8) vs. domestic (n = 7) students, and women (n = 8) vs. men (n = 7). The semi-structured interview schedule was guided by the COM-B model (see Additional File 4 for interview guide). Questions were designed to investigate:

1. Factors influencing engagement (i.e., what helped and/or hindered students' engagement in the program components?)
2. Intervention acceptability (i.e., how agreeable, palatable, or satisfactory were the program components) and appropriateness (i.e., how relevant, fitting, and compatible were the program components?)
3. Mechanisms of behaviour change (i.e., how did the program influence students' capability, opportunity, and motivation to exercise?)

Interviews were conducted online via the Zoom platform (Zoom, 2011), individually facilitated by authors (CB, RS or KR) and took approximately 40 - 60 minutes. Interviews were audio recorded and transcribed verbatim by a professional transcription service.

2.8 Data analysis

2.8.1 Behavioural and health outcomes

Quantitative data was analysed using Statistical Package for Social Sciences (SPSS) version 29. Only students who completed both the baseline and end-point assessments were included in the analyses (n = 45). Descriptive statistics were used to characterise all

behavioural and health outcomes and observe patterns of change in these variables across time. Paired-samples t-tests were used to investigate mean differences in moderate-vigorous exercise, sedentary time, mental and cognitive health outcomes, and sense of belonging to the university between baseline and end-point.

As students differed in how regularly they were exercising before beginning PEAK, an exploratory analysis was conducted to examine whether baseline exercise levels impacted engagement in moderate-vigorous exercise and sedentary behaviour from baseline to end-point. Students were grouped according to whether they identified as a "non-exerciser" (n = 11), "sometimes-exerciser" (n = 27) or "regular-exerciser" (n = 7) at baseline. Data were non-normally distributed among these sub-groups. As such, a series of Wilcoxon Signed-Rank tests were used to investigate potential differences in median moderate-vigorous exercise and sedentary behaviour between baseline and end-point among these groups. Alpha was set at .05, two-tailed for all analyses.

2.8.2 Implementation outcomes

Participant engagement

Descriptive statistics were used to characterise students' engagement in each of the components of PEAK.

Factors influencing engagement, intervention acceptability and appropriateness, and mechanisms of behaviour change

Transcripts were analysed using template analysis (King, 1998)—a thematic analytic method (Clarke & Braun, 2017)—which permits a combination of both a priori themes relevant to the research question (e.g., whether PEAK impacted students' capability,

opportunity and motivation to exercise) alongside inductive coding to develop additional emergent themes. A priori themes were guided by the six categories of the COM-B model. While template analysis was conducted with a psychological lens, the eclectic research expertise of the authors provided an opportunity for input from a wider range of perspectives and disciplines (e.g., behavioural science, neuropsychology, clinical psychology, implementation science and evaluative synthesis).

Preliminary coding was conducted independently by two authors (CB, KR) using a priori themes to identify which COM-B categories were relevant to the design and/or implementation of PEAK. Codes were clustered into meaningful groups in which hierarchical and lateral relationships between themes were defined. The authors met to discuss coding of the two transcripts (designed to increase calibration between authors) and establish an initial template for coding the remaining transcripts. The initial template was further refined through systematic coding of the remaining transcripts conducted by two authors (CB and KR or BS or SH). The final template was re-applied to the full dataset by one author (CB).

3. RESULTS

3.1 Participant characteristics

One hundred and fifteen undergraduate students signed up to the PEAK program pilot study. Of these, 74 (*M* age = 20.32, *SD* = 1.38 years; 46 women, 25 men, 4 non-binary gender) completed the online baseline assessment battery and their participant characteristics are detailed in Table 3. Students varied regarding their enrolment status (41 domestic, 33 international) and exercise history at baseline (21 “non-exercisers”, 38 “sometimes-exercisers”, 15 “regular-exercisers”).

Table 3

Participant Characteristics

Demographic	Frequency (%)
Gender	
Women	46(62)
Men	25(34)
Non-binary	4(5)
Enrolment status	
Domestic	41(55)
International	33(45)
Undergraduate year level	
First	14(19)
Second	21(28)
Third	30(41)
Fourth	5(7)
Fifth	4(5)
Residential status	
Off-campus	49(66)
On-campus	25(34)
Exercise history at baseline	
Non-exerciser	21(28)
Sometimes exerciser	38(51)
Regular exerciser	15(20)

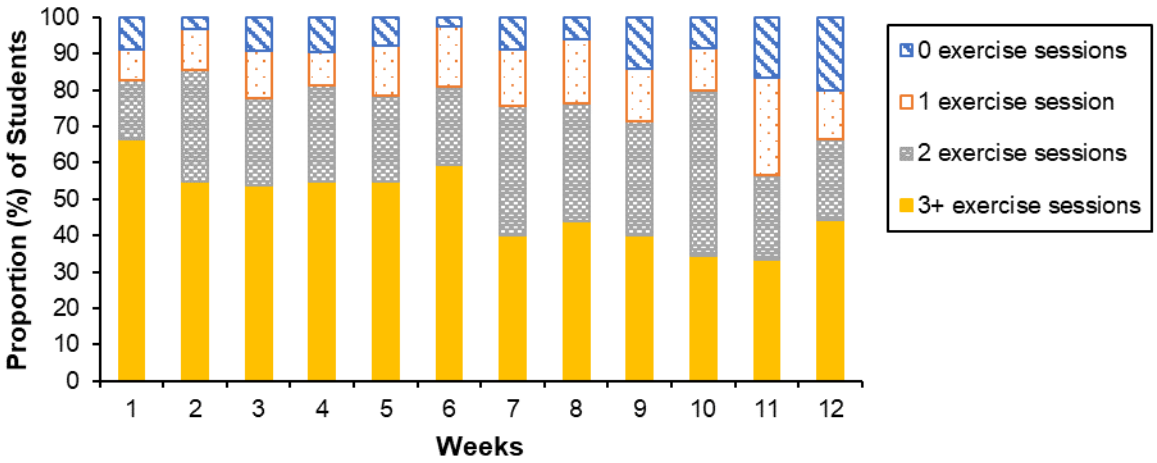
3.2 Behavioural and health outcomes

Exercise frequency

Across the program, the average proportion of students who met the program target of exercising three or more times per week was 48.38% (*SD* = 10.49). When viewed week by week, the proportion of students engaging in three or more sessions per week decreased from week one (66.67%) to week 12 (44.44%) and fluctuated throughout the program (Figure 1). Of note, these figures are a conservative estimate as low engagement in the exercise tracker limited the amount of quantitative data available to evaluate exercise frequency (see Table 4). Qualitative findings revealed that students were often engaging in exercise sessions they did not record via the exercise tracker, due to the burdensome nature of the data collection method (see section 3.3).

Figure 1

Average Weekly Number of Exercise Sessions



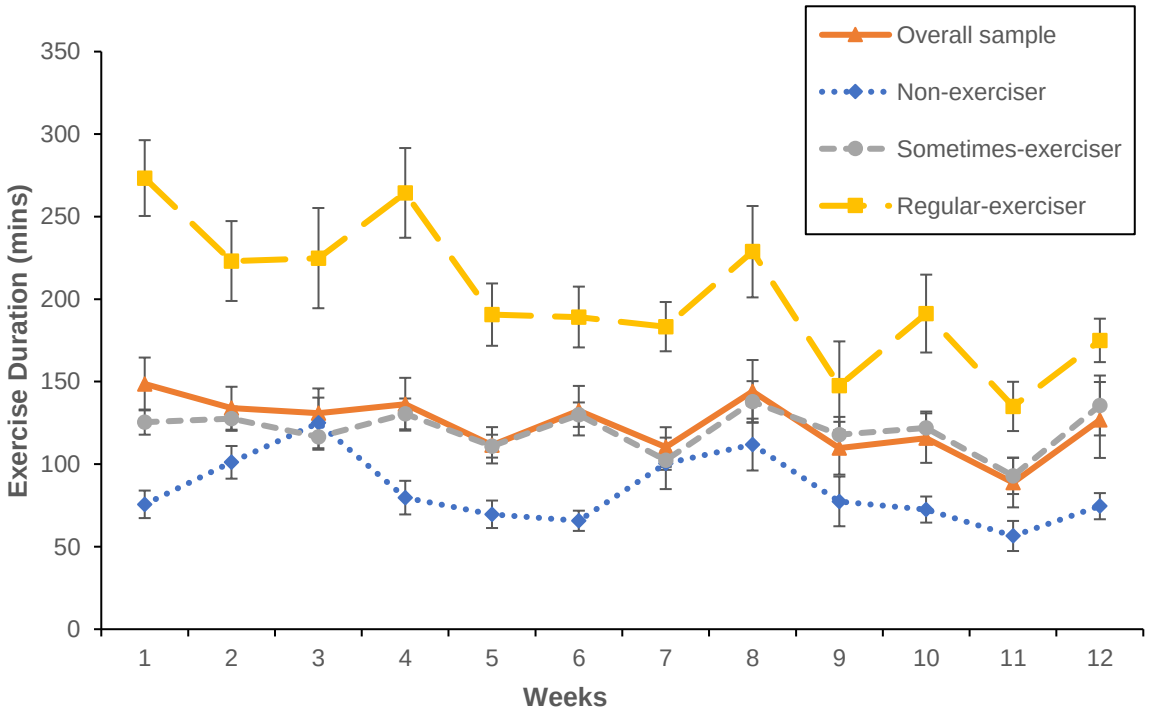
Note. Week 12 = end-point

Exercise duration

Students spent an average of 124.10 (*SD* = 17.16) minutes per week exercising throughout PEAK, with the cumulative duration decreasing gradually throughout the program from a mean of 148.61 minutes (*SD* =133.54) in week one to 126.78 minutes (*SD* = 153) in week 12 (Figure 2).

Figure 2

Mean Weekly Exercise Duration throughout PEAK



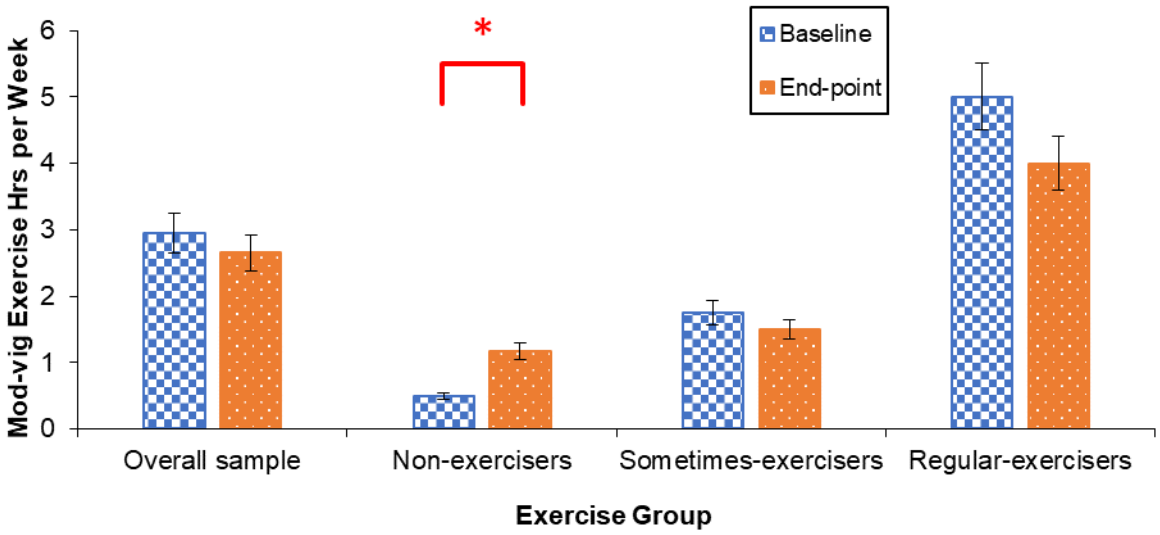
Note. Week 12 = end-point. Error bars represent standard error of the mean.

Moderate-vigorous exercise and sedentary behaviour

Students who identified as "non-exercisers" at the beginning of the program reported an increase in the number of hours spent engaging in moderate-vigorous exercise from baseline to end-point ($Z = 2.30$, $p = .022$, $r = .49$) (Figure 3). No change in moderate-vigorous exercise were observed for students who identified as "sometimes-exercisers" or "regular-exercisers".

Figure 3

Mean Hours Spent Engaging in Moderate-vigorous Exercise per Week at Baseline and End-point

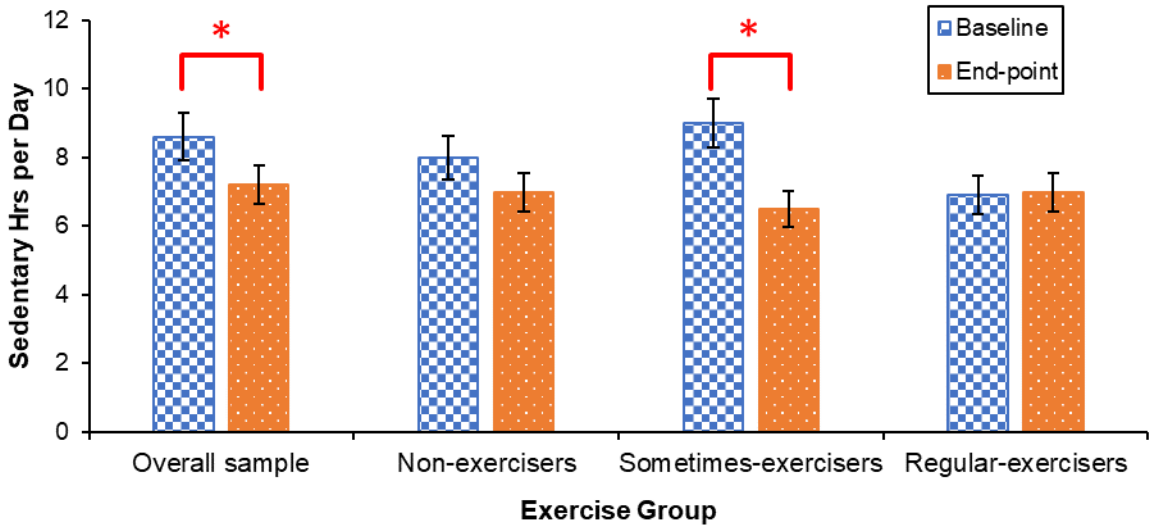


Note. Error bars for the overall sample represent standard error of the mean, and error bars for non-exercisers, sometimes-exercisers, and regular-exercisers represent interquartile range. *p <.05

Across all students, daily sedentary behaviour decreased from baseline to end-point, [$t(44) = 2.38$, $p = .022$, *Cohen's d* = 3.94, 95% CI (.05, .65)] (Figure 4). Students who identified as a "sometimes-exerciser" at the beginning of the program also reported a decrease in daily sedentary behaviour ($Z = 2.45$, $p = .014$, $r = .33$). No change in daily sedentary behaviour were observed for students who identified as "non-exercisers" or "regular-exercisers".

Figure 4

Mean Daily Sedentary Behaviour at Baseline and End-point



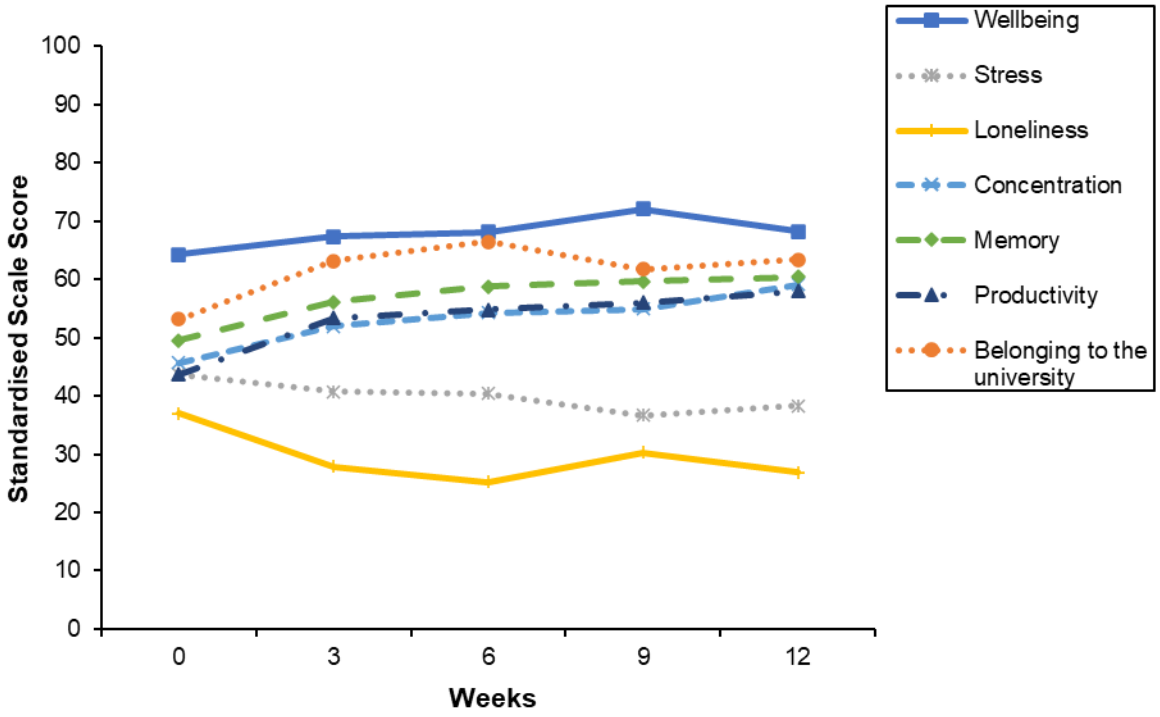
Note. Error bars for the overall sample represent standard error of the mean, and error bars for non-exercisers, sometimes-exercisers, and regular-exercisers represent interquartile range. *p <.05

Mental and cognitive health and sense of belonging to the university

There was a pattern of improvement in mental and cognitive health outcomes and students' sense of belonging to the university throughout PEAK (Figure 5) (see Additional File 5 to view this data stratified across students exercise history at baseline).

Figure 5

Mean Mental Wellbeing, Stress, Loneliness, Concentration, Memory, Productivity and Belonging to the University throughout PEAK

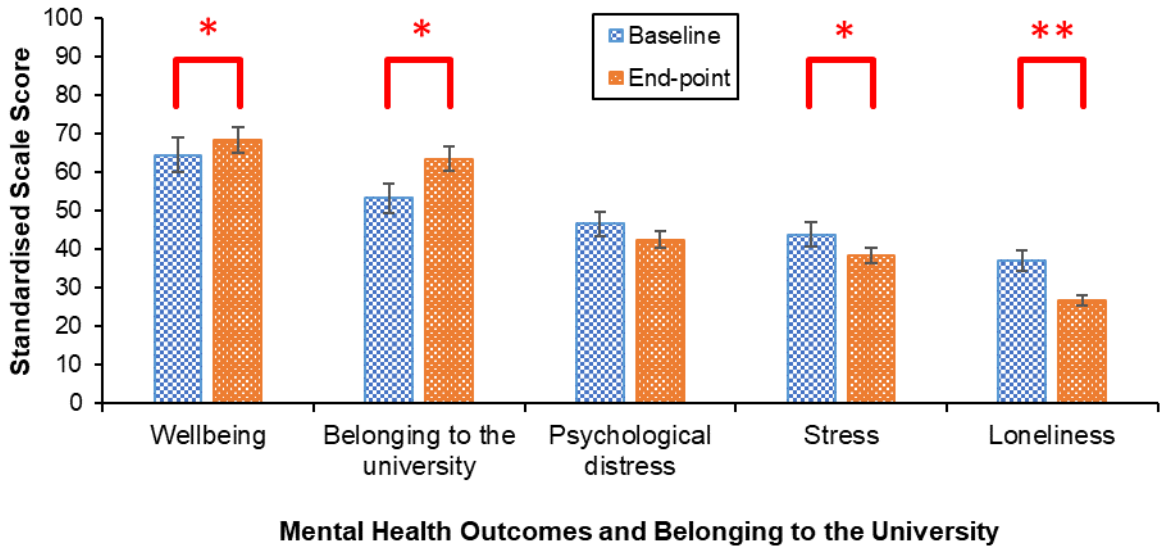


Note. Scale ranges were converted to 0-100 for all scales to enable standardised graph presentation.

Improvements in mental wellbeing [$t(44) = 2.17$, $p = .035$, *Cohen's d* = 4.26, 95% CI (-.62, -.02)] and sense of belonging to the university were observed [$t(44) = 2.59$, $p = .013$, *Cohen's d* = 26.54, 95% CI (-.69, -.08)], alongside decreases in stress [$t(44) = 2.04$, $p = .048$, *Cohen's d* = 2.86, 95% CI (.003, .60)], and loneliness [$t(44) = 3.24$, $p = .002$, *Cohen's d* = 2.53, 95% CI (.17, .79)] from baseline to end-point (Figure 6). Psychological distress did not significantly change [$t(44) = 2.00$, $p = .051$, *Cohen's d* = 6.77, 95% CI (-.002, .60)].

Figure 6

Mean Mental Wellbeing, Belonging to the University, Psychological Distress, Stress and Loneliness Scores at Baseline and End-point

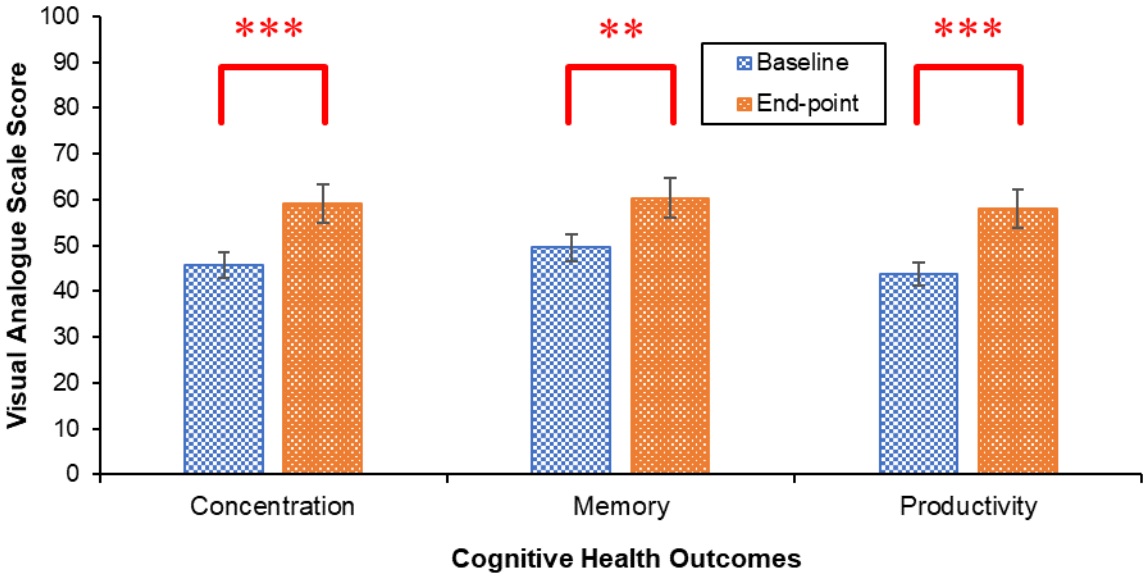


Note. Error bars represent standard error of the mean. Scale sores were standardised by converting the scale range to 0-100 to enable standardised graph presentation. $^{**}p < .01$, $^{*}p < .05$

Improvements in perceived concentration [$t(44) = 4.42$, $p < .001$, *Cohen's d* = 20.29, 95% CI (-.98, -.33)], memory [$t(44) = 3.19$, $p = .003$, *Cohen's d* = 22.86, 95% CI (-.78, -.16)] and productivity [$t(44) = 3.75$, $p < .001$, *Cohen's d* = 25.54, 95% CI (-.87, -.24)] were observed from baseline to end-point (Figure 7).

Figure 7

Mean Concentration, Memory and Productivity Scores at Baseline and End-point



Note. Error bars represent standard error of the mean. ***p < .001, **p < .01

3.3 Implementation outcomes

Participant engagement

As anticipated, engagement in the eight core components of PEAK fluctuated throughout the 12-week program (Table 4). Of the 115 students who enrolled, 108 (94%) engaged in one or more components during week one and 73 (68%) remained engaged in one or more components during week 12. Engagement in the weekly components of the program (i.e., the Moodle content and exercise trackers) progressively declined throughout the program. The number of students who accessed the Moodle content dropped from 71 (62%) during week one to 10 (9%) during week 12. The number of students who completed the exercise tracker also dropped from 69 (60%) during week one to 45 (39%) during week 12.

Table 4

Student Engagement in PEAK

Engagement outcome	No. of participants (% of participants)
"Kick Off" program onboarding	
Total attendance	73(63)
Moodle delivery content	
Week 1	71(62)
Week 2	53(46)
Week 3	39(34)
Week 4	34(30)
Week 5	34(30)
Week 6	29(25)
Week 7	26(23)
Week 8	19(17)
Week 9	18(16)
Week 10	16(14)
Week 11	11(10)
Week 12	10(9)
Weekly average	30(26)
Total	108(94)
Monash Sport Passes	
Weekly average	14(12)
Total	45(39)

"PEAK Packs"	
Opted for "BYO PEAK Pack"	25(22)
Opted for "Fresh PEAK Pack"	14(12)
Total	39(34)
WhatsApp	
Read message	95(83)
Posted	33(29)
Digital trackers	
Exercise tracker	
Week 1	69(60)
Week 2	62(54)
Week 3	54(47)
Week 4	53(46)
Week 5	51(44)
Week 6	42(37)
Week 7	45(39)
Week 8	34(30)
Week 9	35(30)
Week 10	35(30)
Week 11	30(26)
Week 12	45(39)
Weekly average	46(40)
Total	68(59)
Wellbeing tracker	

Week 3	54(47)
Week 6	42(37)
Week 9	35(30)
Tri-weekly average	43(38)
Total	53(46)
"PEAK Points" and rewards	
Exchanged "PEAK Points" for coffee	23(20)
Exchanged "PEAK Points" for personalised small group exercise session	20(17)
Total	36(31)

The number of times each video was viewed varied across video topics, ranging from 58 total views for the video in week one to 10 total views for the video in week 12, with a higher number of views for videos presented earlier in the program (Table 5).

Table 5

Total Number of Educational and Motivational Video Views

Week	Video title	Total no. of views
Baseline	Welcome to PEAK	68
1	Expert tips for CREATING an exercise routine	58
2	Too many assignments to exercise? Exercising your way to PEAK marks	34
3	Overcoming self-consciousness	26
4	But, what if I don't have time to exercise?!	26
5	Too stressed to exercise? Exercising your way to PEAK mood	22

6	Strong Lungs, Strong Brain: the beauty of breathlessness	21
7	Strong Body, Strong Brain: the beauty of strength training	21
8	Connecting with your WHY	19
9	Expert tips for SUSTAINING an exercise routine	16
10	Consistency trumps perfection, habits are the gold	9
11	But, what if I don't feel like exercising?!	10
12	SWOTVAC is coming….Keep moving!	10

Factors influencing engagement, intervention acceptability and appropriateness, and mechanisms of behaviour change

Qualitative interviews revealed several first and second level subthemes relevant to the three implementation outcomes: "factors influencing engagement", "intervention acceptability and appropriateness", and "mechanisms of behaviour change" (see Table 6 for a complete list of themes and exemplar quotes).

Factors influencing engagement

Students described several factors that influenced their engagement in PEAK including fluctuations in university workload, living off-campus, the timing of program components, cultural considerations, and time management.

University workload

Students reported manageable academic demands at the start of PEAK, which coincided with the start of the university semester. As academic pressures intensified, in the

lead up to the examination period (i.e., from week 9), engaging with the program, participating in exercise, and responding to the exercise and wellbeing trackers was deprioritised and more challenging to maintain.

Living off-campus

For some, living off-campus negatively influenced program engagement. Some off-campus students felt disconnected from the program due to the emphasis on on-campus exercise options and rewards and the long commute required for them to access these. While they were aware of the off-campus program exercise options, namely the digital exercise options, these could have been made more prominent and no off-campus program rewards were offered.

Scheduling conflicts

Scheduling conflicts due to lectures or work commitments prevented some students from being able to attend the "Kick Off" PEAK program onboarding session and, as such, they did not receive the same depth of program induction or have the opportunity to meet other PEAK participants in-person before PEAK started. Scheduling conflicts was also a barrier for some students who were not able to use their PEAK points to attend a small group exercise session.

Time-management

Most students with low engagement in PEAK described a persistent struggle with time management throughout the program. Despite being aware of the important role time-management plays in initiating and maintaining an exercise routine, they reported poor time management skills impeded their ability to engage in PEAK and exercise.

Intervention acceptability and appropriateness

Regardless of the degree to which they engaged, all students felt positive about the PEAK program and wanted it to continue in subsequent semesters. Some were enthused that the program symbolised the university genuinely values student mental and cognitive wellbeing, others about it being an exercise-based opportunity, and many by the novel combination of both. All students had suggestions of how to improve to the program for future iterations.

"Kick Off session" program onboarding

Students who attended the onboarding session described it as informative, engaging and clearly conveyed what was involved in participating in PEAK. Learning about the program helped to inform students' expectations about how to embed exercise in their routine from the outset.

Menu of exercise options

The menu of exercise options was generally well-received by the students who found the content relevant, acceptable, and accessible. Some students noted the free passes to access the university gym were particularly important for their program engagement and ability to meet their exercise goals. The exercise starter kit also enabled student to engage in workouts at home if attending the gym was not accessible or appealing. However, some students found some items did not meet their needs or they already owned them. Some students would also seek out their own exercise options if the program's recommendations did not include a specific exercise of interest, or if they found the exercise options too burdensome to access. For instance, some students found it tedious to log into Moodle, select the PEAK program icon, and open the menu of exercise options each day to view the content.

Educational and motivational videos

Perspectives on the videos were mixed. While video viewership across the program cohort was low-moderate (with Moodle-based delivery and the weekly-release format being the biggest barriers to this), some of the students who viewed them described the content as engaging and particularly enjoyed those that reflected authentic student life, used humour, and/or prompted reflection on the reasons why exercising was important to them. Other students, including those who were less engaged in PEAK, did not find the videos acceptable or appropriate. These students either found the videos difficult to access online (i.e., involving too many steps), felt the video style was not engaging or the content was not relevant because they already knew about the benefits of exercise.

PEAK Points reward system

The concept of a points-based reward system was highly acceptable; however, the nature of the rewards and the PEAK points delivery system were felt to be sub-optimal. Students wanted the coffee vouchers to be redeemable at a more popular café than the student union cafeteria. They also wanted to redeem small group exercise sessions earlier in the 12-week program than was made possible by the points allocation system. The process to redeem rewards involved numerous steps: logging exercise sessions to receive points, checking text messages to check point balance, responding to a text message to redeem points, then either receiving a coffee voucher or booking into a small group training session, which students found unnecessarily cumbersome. As such, a sizable subset of students accumulated points without redeeming them.

WhatsApp social support group

The acceptability of the WhatsApp peer-support group varied. For many students, the group fostered a sense of community, and they appreciated the exchange of exercise information, stories, and photographs. However, while all students had access to the group, only a small proportion actively engaged in conversation. Feeling overwhelmed by the volume of communications within the group, shyness, pressure to post a great message, and/or not having met most other members in person contributed to students' reluctance to post a message. Students agreed that more opportunities to meet each other in-person would have increased their engagement in WhatsApp, and the program more broadly. Interestingly, many students who did not post on the WhatsApp feed continued to read it and described value in doing so as it gave them a sense of accountability and solidarity – even in the absence of sharing their own exercise stories.

PEAK Pack exercise groups

Experience of the PEAK Pack exercise groups were mixed as some groups stayed connected while others disbanded soon after forming. For the groups that remained intact, PEAK Pack's provided social accountability to exercise, which increased participation in exercise and helped students overcome common barriers such as feeling tired, busy, or stressed. The success of these groups often hinged on the leadership of one or more members who organised meetups and maintained regular communication, effectively serving as self-appointed "champions". Some students noted that their initial enthusiasm for their PEAK Pack waned as members became less responsive over time. A minority of the students who did not sign up to join a PEAK Pack subsequently felt less integrated into the program when Packs were discussed on WhatsApp.

Exercise and wellbeing trackers

Engagement in the exercise and wellbeing trackers was suboptimal (see Table 4) and all students described engaging in exercise sessions that they did not report via the tracker. Barriers to completing the trackers were doing something else when the text request was received and subsequently forgetting, perceiving the exercise tracker was burdensome, tedious and/or a low priority. This reduced the amount of quantitative data available to evaluate the weekly and tri-weekly behavioural outcomes, including the primary exercise outcome, and means that these behavioural outcomes of the program are likely underestimated. There was also confusion about what duration or type of exercise should be reported in the tracker. For example, students were not sure whether to report multiple short bouts of exercise, dispersed throughout the day, or leisurely walks, which often led to the omission of this exercise from the tracker. Some students also found the exercise tracker demotivating if it highlighted their inactivity, leading to feelings of guilt and inadequacy. Despite variable engagement, many students found receiving a weekly text to track their exercise aided accountability and was a helpful prompt to exercise.

The brevity of the exercise tracker questions were appreciated, and many wanted to see their exercise progress. Conversely, the wellbeing trackers were felt to be too long by many. A minority of students also expressed uncertainty about the interpretation of some items in the wellbeing trackers (e.g., frequency of depressive feelings where students of the threshold that would qualify as depressed), demonstrating the importance of defining such terms.

Program outcome reports

PEAK program outcome reports were well received and the simple visual representations of progress, opportunity to see improvements over time, and the sense of accomplishment these conferred were popular with most students. Knowing that they would

receive a report at the conclusion of PEAK motivated some students to complete the exercise and wellbeing trackers and to maintain their engagement in exercise. However, a significant portion of students were unaware or had forgotten reports would be issue, and this negatively impacted their engagement with the exercise and wellbeing trackers.

Moodle digital delivery platform

The use of Moodle as a digital delivery platform was controversial. Some students found it convenient to have PEAK integrated with their primary university learning system. Others found the platform too formal, disliked PEAK being associated with their academic work, avoided Moodle (and therefore PEAK content) when study stress was high, and/or found access burdensome due to log in requirements and incompatibility with mobile phones.

Cultural considerations

Some international students suggested ways the cultural inclusivity of PEAK could be enhanced, primarily by providing exercise content in multiple languages and via digital platforms commonly used in their cultural groups. For example, an international student from China described using Keep, an exercise app developed in China, instead of the digital exercise options recommended in PEAK because she felt more comfortable using an app that could guide her through exercises in Chinese.

Mechanisms of behaviour change

Psychological Capability

As a result of participation, increases in knowledge were described across the following domains: the long-term benefits of consistently engaging in exercise, how exercise can improve mental, cognitive and brain health, and the variety of types of exercises that can

be incorporated into an exercise regime. Students' especially valued learning from student peers, especially those who were more experienced exercisers, and the PEAK program team, especially the exercise physiologist.

Physical Opportunity

Easy access to a variety of exercise options enabled some students to engage in a wider variety of exercises. Students appreciated the flexibility to engage with the exercise content through on-campus and/or digital formats. The fact all exercise options were free of cost was a major enabler, and the provision of 12 free gym passes was especially useful. Integrating PEAK into the Moodle platform, receiving a reminder text message to complete the exercise tracker, and seeing items from the exercise starter kit in their physical environment served as a helpful prompt and cue to exercise for a minority of students.

Social Opportunity

The social components of PEAK were popular and enhanced accountability and enjoyment of exercise, and for many students, how hard they pushed themselves during sessions. Students valued the opportunity to form a community of student peers, and to form and strengthen friendships, especially for the purpose of exercising together. The inclusive nature of the PEAK community, suited to those with varying levels of exercise experience and fitness, provided a welcoming environment to exercise. This was particularly appreciated by students who were new to exercise, felt too intimidated to exercise, or lacked a pre-existing group of friends to exercise with.

Automatic Motivation

Many students described how they transitioned from viewing exercise as an obligation to a source of enjoyment as a result of taking part in PEAK. They also described the program helped them to establish a consistent exercise routine, which in turn contributed to a sense of accomplishment and wellbeing. Engagement in exercise was reinforced by experiencing the beneficial impacts on their mental, cognitive, and physical health. These included improvements in: improvements in mental clarity, emotion regulation, mood, resilience, energy, ability to cope with stress, particularly in academically demanding periods, concentration, productivity, and physical fitness. For some, the primary motivation to engage in exercise shifted from an extrinsic purpose, such as to lose weight, to an intrinsic purpose, such as enjoying how exercise made them feel.

Reflective Motivation

Motivation to exercise was strengthened by the credibility of the program content and team, and consistent messaging about how exercise can support students' to study well, alongside the mental, cognitive, and brain health benefits of exercise. The PEAK Points reward system incentivised some students to engage in exercise, particularly during the initial stages of the program. Among these students, the appeal of earning points was initially a stronger motivator than the mental and cognitive health benefits of exercise. The goal of exercising three times a week helped some students develop a regular exercise routine. The broad program goals to support students' "mood, mind and marks" also resonated with students' aspirations. Students felt the program content was appropriately tailored to student life and common student barriers and facilitators to exercise.

Table 6

Implementation Evaluation Themes with Exemplar Quotes

Theme	Sub-theme 1	Sub-theme 2	Exemplar quotes
Factors influencing engagement			
Fluctuations in university workload			"From week 1 to week 7, I felt like my course content and the way my lectures and every - my assessments were structured, week 1 to week 7 was actually not that hectic. Then after week 7, things just got very, very hectic. I had so many assignments, so many things to do, and then I would keep procrastinating on exercising. I'd just be like, I'll do it later, I'll do it later, and then never eventually got to it." (P005, female, international student, low engagement) "Then I think, occasionally later on with uni assignments – I guess it's just a matter of maybe I didn't necessarily make it a priority to fill the surveys in" (P099, male, domestic student, moderate engagement)
Living off-campus			"I live a little far from campus. it's like an hour travel, so it's kind of just like I felt a little not engaged with the whole program at times in terms of - because I remember them giving access to 12 gym sessions at the Monash gym, and I didn't use any of them because I live so far away." (P005, female, international student, low engagement)
Scheduling conflicts			"I didn't go [to the Kick Off session] because I work nine til five most days and there was no times that worked." (P072, female, domestic, low engagement) "I didn't attend many of those [personalised small group training] sessions... I think with the timing – so it was a bit hard to always attend some of those training sessions." (P099, male, domestic student, moderate engagement)
Time management			"it's quite honestly about our time management and we don't do that quite well. Even if we know that we don't manage our time quite well, we're still not going to do it next time either." (P113, male, international student, moderate engagement)
Intervention acceptability and appropriateness			
Students perceive it is important for the PEAK program to continue to be offered at the university			"Having a program like this I think shows that there is still a lot of people who do care about the university students themselves and they're not just cash cows for university. I would say definitely this program would have definitely made me see Monash in a more positive light." (P032, male, domestic student, moderate engagement) "I think (PEAK) definitely should be something that's done at Monash and is important…everyone should exercise… it's so important for our health… when I exercise, I'm more productive and less stressed and less hard on myself …I just think there should be more done in the space of getting people to feel like exercises are normal and a fun part of life…." (P072, female, domestic, low engagement)

Theme	Sub-theme 1	Sub-theme 2	Exemplar quotes
The "Kick Off session" PEAK program onboarding was informative, clearly delivered and engaging			"It helped me a bit like, you know, being more engaged; just to understand it better. Because when you have that understanding, then you can kind of have a certain expectation as to how you would design your exercise routine." (P005, female, international student, low engagement)
Menu of exercise options	…were generally relevant, acceptable and/or accessible		"Those [free passes to access the university gym] were instrumental. Without them I don't think I would have gotten three done a week or engaged as much at all." (P001, female, domestic student, high engagement) "Even the exercise starter pack that I got like, it was pretty helpful because there are times I don't really want to go to the gym and just work out in my apartment. It just makes it a lot easier" (P005, female, international student, low engagement)
	… but, did not meet some student's needs or exercise preferences, and/or were difficult to access on the Moodle delivery platform for others		"If you removed [the online exercise options], it would be fine for me because if I wanted to do this specific exercise I would just go online for it, anyways, and it's kind of like the same thing anyways. So, it didn't really make much sense for me to have to come here just [to] find out what videos I should be doing." (P088, male, international student, low engagement) "The starter pack, I only use the calendar and the rest I just put in my drawer… I don't usually use a yoga mat that much. The towel, I don't use towel that much. Like when I sweat, I just use tissue. Other things, it's the water bottle, I already have water bottle." (P115, female, international student, moderate engagement)
Educational and motivational videos	…were informative, engaging, relatable to student life and/or prompted reflection for some		"The "learn a bit" videos, I really enjoyed. I found them engaging and fun. I especially liked the ones where it made me sit and actively think about something like the, what is your why video. The why video was my favourite and then my other favourite was the one when there was cake and Doritos on the bed." (P001, female, domestic student, high engagement)
	…however, were difficult to access from the Moodle delivery platform, not engaging and/or perceived as irrelevant for some		"I found the first few [learn a bit videos] not that engaging for me because I've already experienced the benefits of exercise." (P065, male, international student, moderate engagement) "I don't usually watch this type of video that much because I think everyone knows doing some sport is good for your health, so that's what I think they tell you, or what's the benefits." (P115, female, international student, moderate engagement)
"PEAK Points" reward system	…was an appealing concept for all		"when you gather points, they are accumulating and then you can use them to cash in whatever you like, either with sessions or with coffee. Give yourself some kind of small treat because you work hard" (P115, female, international student, moderate engagement)
	… however, not salient, irrelevant and/or difficult to access for most		"I was thinking that the rewards are kind of not incentivising." (P088, male, international student, low engagement) "I just didn't redeem any of [the points]. I know that if you get eight points you got a coffee but I don't drink coffee. If you get 16 points, you get that gym PT session or something, again, I didn't use it because I live so far away. The points are just sitting there." (P005, female, international student, low engagement)

Theme	Sub-theme 1	Sub-theme 2	Exemplar quotes
			"I thought the PEAK Points were quite good. It was a very easy system to understand, I think. The only thing I would probably prefer is if the point buying system could be improved, because it was a little bit convoluted where you had to text someone and text them what you want and you get a text back with codes and vouchers and then it's very difficult to see which codes you'd used already." (P032, male, domestic student, moderate engagement)
WhatsApp social support group	…helped foster a sense of community and solidarity among peers, and/or accountability to the program and exercise for many		"The PEAK WhatsApp chat was good. I like how everybody like would post pictures or you know, tell about their experience and why they got into PEAK." (P005, female, international student, low engagement)
	…however, overwhelmed with content, too intimidating to engage with, and/or irrelevant for many		"I joined [the whatsapp group] initially, but then I didn't end up having a look at it. I just thought there were too many messages. I think there were quite a few long messages and then I thought I wouldn't be able to keep up with it, so I didn't want to look at it." (P099, male, domestic student, moderate engagement)
"PEAK Packs" exercise groups	…were acceptable, and/or provided social accountability among the groups who remained in tact		"I think [having the option to join a PEAK Pack] is really nice, because its one of the main reasons that I registered [for PEAK] in the first place" (P088, male, international student, low engagement)
	…however, lacked cohesion and group responsiveness for those whose groups disbanded, and/or instilled disconnection from the program for some not involved in a "PEAK Pack"		"it's kind of demoralising because you have the group chat with five people for the PEAK pack, and then initially it was all good because we would ask, hey, do you want to go to the session today? It started out like people would respond, but as time went on they started responding less, or not responding at all. It left people hanging, in a sense. It made it harder, or it made it so that you wouldn't put in the effort to ask them, if that makes sense. You'd ask some people, but not all, sort of thing." (P088, male, international student, low engagement) "I remember reaching out to the specific [PEAK Pack] group and it'll take days for people to reply. So, it might be just that because they're busy or maybe PEAK is just not a priority for them. I don't really know…I was like, I hate this group." (P065, male, international student, moderate engagement) "I felt like if you weren't really in a PEAK Pack, you didn't feel like you belonged to PEAK really, it was more so you were one amongst the many." (P032, male, domestic student, moderate engagement)
Exercise trackers	…were quick and easy to complete, aided accountability and/or served as a reminder to exercise for a minority		"The exercise trackers were short and they were a lot easier to complete." (P005, female, international student, low engagement) "I need to exercise now so I can put it on the exercise tracker, so that motivated me" (P073, female, domestic student, high engagement)
	…however, did not accurately capture the exercise students were engaging in, lacked clarity about what duration or type of exercise could be logged, were easily forgotten, burdensome and/or a low priority for the majority, and		"There's an app called 7 Minutes Fitter, which I use a bit. It's like, is it worth logging that activity or not? Because it usually wants activities that are 10 minutes plus, but if I've done that two times in a day, do I log that? Do I not?" (P032, male, domestic student, moderate engagement)

Theme	Sub-theme 1	Sub-theme 2	Exemplar quotes
	demotivating for some students if it highlighted their inactivity		"I missed the SMS and then I just stopped doing [the weekly exercise tracker]" (P038, female, international student, moderate engagement) "I'd say [the weekly exercise tracker] is a bit demotivating. Because you see all these tracker notifications, like, oh I haven't exercised in the – it, like, makes you feel a bit worse each time it comes up." (P088, male, international student, low engagement)
Wellbeing trackers took too long to complete and questions lacked clarity			"The wellbeing trackers I think were a bit long. Sometimes I wouldn't end up completing them because it clearly said it would take eight to 10 minutes, and I was a bit like, it can be a bit long" (P005, female, international student, low engagement) "It's the questions about how many times you feel depressed last week? Something like that. Because, actually, I don't feel depressed, but sometimes – I don't know the definition of the depressed is, what kind of emotion will be defined as depressed?" (P083, female, international student, low engagement)
Program outcome reports	…were informative, motivating and/or rewarding for most		"I just had a quick flick through the report that you sent out to everyone with the graphs and I loved having that as a final thing that displays how we went. Then I went oh, even though I had some extra bad weeks in there I still came out doing better than I did at the start and that feels really good to look at." (P001, female, domestic student, high engagement) "…the fact I'm going to get a report at the end, that was what motivated me to do [the exercise and wellbeing trackers], and to be consistent. I want to produce good results I'll see how my optimal performance and exercise will change. I want to see that difference." (P073, female, domestic student, high engagement)
	…however, many were not aware that they would receive an outcome report		"I didn't really register that I would get a report at the end." (P014, male, domestic student, high engagement)
Moodle digital delivery platform	…was convenient to access for some		"I had all my uni related things in the same spot and I was used to the Moodle program as well, so that was good to be familiar with the layout of everything, so I liked it" (P073, female, domestic student, high engagement)
	…however, too formal, unappealing, and/or burdensome for most		"[I] feel like I'm learning something, not the things I can enjoy, so maybe it's a formal platform. It's a little bit formal, not like the things I can relax myself." (P083, female, international student, low engagement) "I think maybe – it just felt busy, even though maybe it's quite a quick thing to do, you just have to put effort in or log into Moodle. I feel like if it was an app on the phone – I probably did have enough time to look on Moodle to watch the two-minute videos. That doesn't take too long compared to spending time on social media or messaging on the phone, which you might do quite a bit. So, if it was on the phone and I got a notification I might do it on the way walking or just while commuting, for example. On Moodle you have to do it on your laptop, so it's a bit harder than mobile devices." (P099, male, domestic student, moderate engagement)
Cultural considerations	The cultural inclusivity of the exercise options could be enhanced		"As an international student I feel like - well, you know, I'm fine because I'm a nursing student and I have some knowledge about the terminology, but for the student who has language barriers, probably I think when providing the exercise in the other language. Sometimes they - if they can't understand that it might take some time for them

Theme	Sub-theme 1	Sub-theme 2	Exemplar quotes
			to try to translate or understand in their brain, so that may be a little bit hard to really put themselves into the exercise because they need to be understanding the video." (P058, female, international student, low engagement) "I'm from Chinese background, so there are lots of different kinds of exercise app in my country, I think. So there's one called Keep… it actually uses Chinese to guide you…that's also the reason why I choose a Chinese app. I just want to make myself feel comfortable." (P058, female, international student, low engagement)
Mechanisms of behaviour change			
Psychological Capability	Increased knowledge about the variety of types of exercises that can be incorporated into an exercise regime		"Also, with some of the exercise videos that was - because a lot of these exercises were things that I wouldn't usually do, just having that knowledge like, this is something I can do and incorporate further into my exercise routine, that was also good." (P005, female, international student, low engagement)
	Increased knowledge about how exercise is beneficial	Increased knowledge about how exercise can improve mental, cognitive and brain health	"I remember learning a bit more about the effects that exercise has on a few different things. They talked about memory in the videos and just mood in general. So, I think I just – it strengthened my understanding of how exercise has beyond physical benefits." (P099, male, domestic student, moderate engagement) "I learned about how [exercise] actually helps with the brain, with the brain function and release your dopamine and help your mood, help relieve your stress. Which I didn't think about before, [unclear] exercise or to choose some knowledge about how it actually helps your body, the benefits." (P115, female, international student, moderate engagement)
		Increased knowledge about the long-term benefits of consistently engaging in exercise	"Yes [I learnt something new from PEAK]. Consistency is best and benefits are reaped over time/" (P065, male, international student, moderate engagement)
	Learning from student peers, especially those who were more experienced exercisers, and the PEAK program team, especially the exercise physiologist		"I liked how I could ask any questions [in the whatsapp group] and get some advice from everyone and hearing about everyone's journeys, I found that really interesting." (P073, female, domestic student, high engagement) "In the gym, it's very valuable to be able to talk to people who know much more about gymming and to get their advice on things." (P104, male, domestic student, moderate engagement) "Yes, [I gained new knowledge from PEAK] through [the PEAK exercise physiologist] and the PT session…I asked [the PEAK exercise physiologist] a range of things…He talked about how sit-ups are perhaps not the best form of ab exercise and he gave good advice on that. I asked him about how strength training versus cardio will influence brain – how active you feel and how much energy you have, so he talked a bit about that. That was interesting to hear" (P104, male, domestic student, moderate engagement)
Physical Opportunity	Easy access to a variety of exercise options (online, on-campus and at home) enabled some students to engage in a wider variety of exercises		"Previously I don't exercise, I do yoga and through PEAK I know a new type of exercise we can do, or have a lot of options you can choose, cardio, strength…" (P115, female, international student, moderate engagement)

Theme	Sub-theme 1	Sub-theme 2	Exemplar quotes
			"I like how they had just a range of options. Even within the exercises that they suggested, there were just so many, so many you could choose from. Even how you wanted to do them via video, via an app, it was quite helpful." (P005, female, international student, low engagement)
	Free exercise options, including free passes to the gym, increased the financial accessibility of exercise		"Because I'm not able to afford a gym membership for myself so I found the passes really helpful for me because I could take the opportunity to go to a gym" (P073, female, domestic student, high engagement)
	Prompts and cues via the Moodle platform, reminder text message to complete the exercise tracker, and/or seeing items from the exercise starter kit reminded students to exercise		"I will open Moodle every day, because when I see the home of Moodle, I will see the PEAK program, and maybe I will remind myself to – it's time to do some exercise now." (P083, female, international student, low engagement) "I liked having the tote bag it was kind of a reminder that I need to exercise." (P072, female, domestic, low engagement)
Social Opportunity	Increased opportunities to connect with others	Connecting with peers increased accountability, motivation and enjoyment of exercise	"I used to be the kind of person that's like, I want to [exercise] alone… But through this program, I figured out that exercising with people is actually very fun, and it can help actually help motivate you to go further, above and beyond. Normally I would be tired at this point, but because there's people around me, I'm just going to work a little bit harder. So, yes, it did motivate me to work out socially. (P065, male, international student, moderate engagement)
		Forming and strengthening friendships, especially for the purpose of exercising together	"I want to do exercise and I want to make more friends. Making more friends is an easy thing to do [through] more exercise but I didn't think of how making friends who do exercise contributes to exercise. That's new to me." (P104, male, domestic student, moderate engagement)
		Being part of a likeminded exercise community encourages exercise	"One thing that really helped me go through, besides the tracker and all the sciencey and stuff and all the benefits of exercise, is the community. Having just like-minded people working towards the same goal and knowing that - because usually in university, if you want to join a sports group you have to have a certain fitness level and if not, you're discouraged. Otherwise, if you don't really have a friend group maybe that have similar interests as you and you don't really want to initiate that conversation. But with PEAK because you facilitate everything, it just makes it a lot easier." (P065, male, international student, moderate engagement)
Automatic Motivation	Enjoyment of exercise increased		"…exercise changed from being an obligation to something that I actually enjoy." (P065, male, international student, moderate engagement)
	Ability to establish a consistent exercise routine improved		"I honestly have been putting this PEAK experience up there in the life changing experiences that I've had. The fact that for the first time ever that I remember I am consistently exercising three times a week. I am doing that self-motivated now because the gym pass has run out and I used to be exercising with my housemates, I'm doing that less now, but I am still going out there and I am exercising three times a week. That's never happened before…So just the [exercise] consistency and me knowing that I can commit to consistency makes me feel really good too and PEAK has had a big part of that so it makes me feel really good." (P001, female, domestic student, high engagement)

Theme	Sub-theme 1	Sub-theme 2	Exemplar quotes
	Experiencing the health benefits of exercise was reinforcing	Experiencing the mental health benefits of exercise	"I had quite a stressful semester with both uni and family stuff… once I started exercising and getting a routine it was very clear that I felt much better the days that I did exercise than the days I didn't. That it was providing mental clarity, better emotional regulation and mood, et cetera. So it just made me feel so good that I was motivated to exercise so that I could feel good again." (P001, female, domestic student, high engagement) "The best comparison I can make is between this semester and last semester, because last semester I barely did any exercise at all really… I completely burnt out and couldn't really do anything… main thing that regular exercise has given me [this semester] is resilience to those sorts of times and motivation and energy to not procrastinate as much..." (P014, male, domestic student, high engagement)
		Experiencing the cognitive health benefits of exercise	"whenever I exercised, especially in the morning, I'm able to concentrate on my work better, and I'm able to have a better flow of a day and have something that clears my mind" (P038, female, international student, moderate engagement)
		Experiencing the physical health benefits of exercise	"PEAK was a fantastic opportunity to get points and do this thing with friends and make it so fun and also get fit again." (P001, female, domestic student, high engagement)
	Feeling intrinsically motivated to exercise instead of extrinsically motivated		"…before I would think the purpose of doing exercise is to lose weight… but now I maybe interested for to let me, kind of, enjoy the exercise, and I could actually…feel wellbeing of my mental state, and I will feel quite relaxed after I finished exercise" (P083, female, international student, low engagement)
Reflective Motivation	Motivation to exercise	The credibility of the program content and team was motivating	"Just knowing that the people behind PEAK are such qualified individuals was a very big motivation factor for me and meeting them" (P113, male, international student, moderate engagement)
		Consistent messaging about how exercise can support students to study well, and the mental, cognitive and brain benefits of exercise was motivating	"first semester I was really focused on just study that I completely lost exercise. I have heard that exercise does help but it was not enforced on me… having a program that talks about it regularly really motivated me" (P073, female, domestic student, high engagement)
	Rewards to exercise	Receiving "PEAK Points" and rewards increased motivation to exercise	"I love points. In the first few weeks when I was - before my habits were sticking, I didn't care about the exercise, I didn't care about the mental capacity that I gained or the feelings, I just wanted points." (P001, female, domestic student, high engagement)
	The goal of exercising three times a week was helpful		"I think what PEAK helped was maybe initiate me to exercise because I thought about trying to hit that target of three times a week." (P099, male, domestic student, moderate engagement)
	The program goals and content was appropriately tailored to students aspirations, lifestyle, and their barriers and facilitators to exercise		"I really like this goal of improving mind mood and marks, I find that nice to hear as a student because you want to improve those things especially being full time and all the stress, so I really like that initiative." (P073, female, domestic student, high engagement)

Theme	Sub-theme 1	Sub-theme 2	Exemplar quotes
			“It seems [the program] know where the low points, where's the high points. I think you’ve put the sciencey bit during that part where students are still motivated, so they don't need that much motivation to keep going. Then towards the end of the semester, students are down here, right? So, your videos are more motivational style. That was good. I think it was very relevant.” (P065, male, international student, moderate engagement)

4. DISCUSSION

The PEAK Mood, Mind, and Marks program was developed via consultation with university students, staff and senior leadership, application of the BCW (Brown, Richardson, Halil-Pizzirani, Hughes, et al., 2024) and informed by exercise neuroscience to support university students' engagement in regular exercise for the betterment of their mental and cognitive health. To our knowledge, this program is the first of its kind to embed neuroscience-informed program content and messaging to target students' barriers and facilitators to exercise, including their goals to excel academically. The current study was a pilot evaluation of PEAKs first iteration. Students' engagement in exercise did not shift substantially from the beginning to the end of the program. All aspects of students' mental and cognitive health improved, except psychological distress which remained stable. Overall, students were enthusiastic about an exercise-based program to support their mental and cognitive wellbeing and identified numerous ways to optimise the design and delivery of PEAK to better meet their needs and enhance their engagement.

On average, the exercise tracker data indicated that less than half of students met the program target of exercising three or more times per week, and this proportion decreased from the start to the end of the program. However, engagement with the weekly exercise tracker was low and likely to have led to an underestimation of students' exercise engagement. Students perceived the exercise tracker as tedious and/or often forgot to complete the tracker. The explanation provided to students about what type and level of exercise could be logged was also unclear. Qualitative findings revealed students were often engaging in exercise that was not captured by the exercise tracker. In light of these limitations, it is difficult to discern with certainty the program's impact on the frequency of students' weekly exercise activity. These findings underscore the need for more accurate and

less burdensome data collection procedures to be implemented moving forward. Given the proliferation of smartphones and personal wearable devices, an alternative solution for future evaluations of PEAK is the development of a mobile application that can be linked to a wearable device and incorporates passive activity sensing technology, providing an objective measure of exercise. Adopting such a measure would likely improve the accuracy of the exercise data collected and enhance participant engagement by removing the burden of self-report measures (Brick et al., 2020).

Although the weekly exercise data was unreliable, qualitative finding revealed students did experience ongoing challenges with prioritising exercise, particularly as the semester progressed and academic workload increased. Therefore, while the program may have helped some students initiate an exercise routine, maintaining this routine amidst competing academic priorities remained difficult. Further, students' engagement in PEAK decreased throughout the program, which likely attenuated the program's impact on maintaining students' engagement in exercise at a whole group level. Interestingly students sedentary time decreased and students who identified as "non-exercisers" before PEAK increased their engagement in moderate to vigorous exercise. It is possible reducing sedentary behaviour was a more achievable behavioural goal for students, especially during the exam preparation period. For example, reducing sedentary behaviour can require less effort, time and resources than engaging in exercise (Landais et al., 2022; Park et al., 2020; Tremblay et al., 2011). The increased engagement in moderate to vigorous exercise observed in non-exercises may reflect that these students were not engaged in exercise before participating in PEAK, and, therefore, have a greater scope for improvement compared to students who were already exercising (Gulart et al., 2019; Waters, 2022).

While the impact of PEAK on students' weekly exercise engagement was inconclusive, mental and cognitive health outcomes improved from the beginning to the end

of PEAK, except for psychological distress, which remained stable. Students sense of belonging to the university also improved. Improvements in mental and cognitive health outcomes may have occurred due to an increase in exercise that was not captured by the exercise data collection method. While this would be in keeping with evidence demonstrating regular exercise can positively impact these outcomes (Chovanec & Gröpel, 2020; Hotting & Roder, 2013; Leleikiene et al., 2018; Mandolesi et al., 2018; Pels & Kleinert, 2016), this conclusion is precluded by the absence of an observed increase in exercise activity and challenges with data collection. Alternatively, improvements may have occurred independent of any change in exercise, raising questions about the mechanisms driving these changes. Feeling part of a student peer collective outside of a classroom context may have strengthened many aspects of students' social connectedness, which is a well-established determinant of mental health (Wickramaratne et al., 2022) and supports cognitive functioning (Samtani et al., 2022). Indeed, the largest improvements were observed in loneliness and sense of belonging to the university relative to any other mental health outcomes, suggesting PEAK had a particularly positive impact on social wellbeing. Furthermore, the majority of the students interviewed reported PEAK had pervasive positive impacts on their social connectedness. Specifically, students' felt PEAK help them to feel part of a community and strengthened their social support. These findings demonstrate PEAK had a particularly positive impact on students' social wellbeing, which may have contributed to improvements in their mental and cognitive health.

All students who took part in the qualitative evaluation wanted PEAK to continue being offered at the university, even those with relatively low engagement in exercise and/or the program components. Students' felt such a program could deliver substantial mental, cognitive, and physical health benefits to the student body, address a need to help students incorporate exercise into their daily lives, and demonstrated the university was genuinely

invested in students' mental and cognitive wellbeing. These perspectives are consistent with findings from the PEAK co-design process (Brown, Richardson, Halil-Pizzirani, Hughes, et al., 2024), in which students indicated a strong appetite for proactive exercise-based approaches to support their mental and cognitive health. Prior research has similarly reported that the acceptability of physical activity as a mental health intervention strategy within a university context is high (DeJonge, Omran, Faulkner & Sabiston, 2020), demonstrating that it is valuable to continue to develop these kinds of programs. While the appetite for programs like PEAK was high and students felt positive about the types of interventions delivered in the program (i.e., information about the neuroscientific mental and cognitive health benefits of exercise, identifying with the program goal to support their "mood, mind, and marks", social support, flexible exercise options, credible content, reminders and rewards to exercise, self-monitoring and feedback on exercise engagement and its impacts on mental and cognitive health), they identified numerous opportunities to refine PEAKs content, delivery and design (see Additional File 6 for a summary of program improvements).

Students expressed a desire for more opportunities to connect with each other in-person and to improve the program's cultural inclusivity. International students spoke to the need for digital exercise options to be expanded to include phone applications developed in a variety of cultural contexts. They also suggested to provide online exercise videos in multiple languages. These additions to the program content would enhance the cultural appropriateness of PEAK to better cater to a culturally diverse student population and align with the broader goals of equity and inclusion in public health interventions. Moreover, utilising a multichannel approach comprised of freely available digital channels (e.g., WhatsApp, Moodle, text message) to deliver the program components, while cost effective, did not optimally engage students. This approach was viewed as burdensome and overly complex, which reduced engagement. Students felt overwhelmed by the WhatsApp content

due to the high volume of communications within the WhatsApp group and the different steps involved in accessing the program content via Moodle, responding to text messages to exchange their "PEAK Points" for rewards and/or completing the survey links sent to them via text message were convoluted. Developing PEAK into a single, unified digital delivery tool, such as a mobile application or website, could address this challenge. A single digital platform would streamline program delivery, making it more user friendly, and improve overall engagement and outcomes. Such consolidation could also reduce the staff resources required to support the program, thereby enhancing the scalability and implementation of PEAK within the university setting.

Finally, the multicomponent design could be enhanced by personalising the program content to students' individual needs. As expected, students had varying opinions on whether they liked or disliked the same program component, influenced by their unique needs, priorities, preferences, and expectations. Therefore, students engaged with the program components that suited their needs most, and disengaged with the components that did not. A personalised program design could more effectively cater to the diverse needs of students, including international students. However, creating a personalised program required a level of complexity, resource, and financial input that could not feasibly be accommodated in the first iteration of PEAK. Given advances in technology such as artificial intelligence (AI) is developing rapidly, it is possible the pathway towards program personalisation may become more accessible and feasible. For instance, AI algorithms can be leveraged to analyse participants data, including demographics, fitness levels, and barriers and facilitators to exercise, to develop personalised programs that cater to people's unique exercise needs, goals, and barriers to behaviour change (Zhou, Fukuoka, et al., 2018; Zhou, Mintz, et al., 2018). Using AI in these ways to optimise program personalisation holds substantial potential to improve user acceptability, engagement, and overall impact on health outcomes (An et al.,

2023). However, more research is needed to evaluate the effectiveness of AI-integrated programs in achieving these outcomes, both in a university setting and beyond.

Strengths and Limitations

The current study is the first to evaluate a BCW-informed health behaviour change intervention designed to support university students' mental and cognitive health through exercise. The findings demonstrate clear benefits in conducting small scale pilot studies to optimise and refine behavioural interventions before expending significant resources on large scale clinical trials (Craig et al., 2008; Czajkowski et al., 2015; Michie et al., 2011; Skivington et al., 2021). The use of mixed-methods and a hybrid evaluation of the program's preliminary behavioural and health impacts and implementation provides a comprehensive understanding of its potential effects and user experience. A key strength of the intervention was that it was designed with the intention of maximising its scalability by leveraging digital tools to deliver most of the intervention components.

The study data should be considered in light of several limitations. The evaluation methods were not able to assess the individual impacts of the eight program components and, as such, it is not possible to identify which components are essential to retain in PEAK to maximise program engagement and exercise outcomes. Moreover, standardised measures of students' cognitive health and sense of belonging to the university were not used in the current evaluation, which may have affected corresponding findings. Additionally, the development and evaluation of PEAK focused on an Australian metropolitan tertiary education context. As such it is unclear the extent to which the findings from these studies generalise to universities in regional and remote settings, and tertiary education settings across geographically and culturally diverse countries. Lastly, while single-arm study designs are appropriate for early-stage pilot studies (An et al., 2023; Lancaster & Thabane, 2019), the

lack of a control or comparator group precludes conclusive determination of changes observed in behavioural and health outcomes to students' engagement in PEAK. However, students' strong appetite for programs of this nature coupled with the learnings about the program components provides a solid foundation upon which to optimise the program design and continue its dissemination and iteration.

Conclusion

The current pilot study demonstrated that an exercise-based approach to support students' mental and cognitive health is acceptable. Students were especially receptive to the flexible exercise options, social components of the program, and the program rewards. Moreover, they valued the neuroscience-informed approach to motivational and educational content and that the program's stated outcomes aligned with their academic goals. As is expected for the first pilot of PEAK, the program in its current form requires iteration to strengthen its impact, enhance student engagement, and improve its sustainability and scalability. A streamlined delivery format and personalised program content provide opportunities for optimising PEAK in these ways. Students suggested future iterations should include more opportunities to connect with student peers in-person and culturally inclusive content, demonstrating the potential for program optimisation. Overall, the current findings lay the groundwork for future research and refinement to optimise an impactful, scalable intervention to foster healthy exercise habits in university settings.

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CHAPTER SEVEN: General Discussion

7.1 General Overview and Key Findings

This thesis aimed to identify barriers and facilitators to students' physical activity, map these factors to behaviour change frameworks, and use the BCW process to translate this new knowledge to develop and pilot PEAK, a neuroscience-informed, exercise intervention to support university students' mental and cognitive health. To meet these aims, three studies were undertaken: a systematic review (Study One), an intervention development study (Study Two), and an intervention pilot study (Study Three). These studies went beyond previous knowledge by applying behaviour change frameworks to (i) guide the theoretical synthesis of the factors that influence students' physical activity, and (ii) inform the development and evaluation of a novel neuroscience-informed, exercise-based program for students, incorporating perspectives of multiple key stakeholders. Overall, these studies identified: 56 barriers and facilitators mapping to 12 TDF domains that impact students' participation in physical activity; key intervention functions and BCTs relevant to increase students' engagement in exercise; a clear appetite for an exercise-based intervention to support students' mental and cognitive health; and opportunities to refine PEAK to improve engagement and student outcomes. This final chapter begins with a brief overview of the results of each study, in order of their completion, followed by a discussion of the broader implications of these study findings for supporting students' mental and cognitive health and developing maximally engaging and scalable health behaviour change programs. Key strengths and limitations of the thesis are subsequently discussed, followed by a concluding statement.

7.1.1 Study One. Systematic Review

Study One – Key Influences on University Students' Physical Activity: a Systematic Review Using the Theoretical Domains Framework and the COM-B Model of Human

Behaviour: Study One is the first study to systematically identify and map barriers and facilitators to university students' physical activity to behaviour change theories (i.e., the TDF and COM-B model), and quantify the relative importance of these factors. Twelve theoretical domains were identified as relevant and offer targets for intervention. These domains, in order of relative importance, were: 'environmental context and resources', 'social influences', 'goals', 'intentions', 'reinforcement', 'emotion', 'beliefs about consequences', 'knowledge', 'skills (physical)', 'beliefs about capabilities', 'skills (cognitive and interpersonal)', 'social/professional role and identity', and 'behavioural regulation'. Among these domains, the most common barriers and facilitators were 'lack of time', 'easily accessible exercise options, facilities and equipment', 'exercising with others', and 'prioritisation of physical activity compared to other activities'. By identifying the most important determinants of students' engagement in physical activity, these findings provide a theory-informed roadmap to support the development and implementation of interventions designed to increase university students' physical activity.

7.1.2 Study Two. Intervention Development

Study Two – PEAK Mood, Mind and Marks: Development of an Intervention to Support University Students' Mental and Cognitive Health through Physical Exercise: This study used the BCW to develop PEAK, a behaviour change intervention designed to increase university students' engagement in regular exercise for the benefit of their mental and cognitive health. This process described the steps taken to co-design PEAK with university students, staff, and senior leadership across the three stages of the BCW process: 1) understand the target behaviour, 2) identify intervention options, and 3) identify intervention content and delivery mode. Qualitative focus groups with university students' extended findings from Study One by providing an in-depth context-specific understanding of the barriers and facilitators that impact Australian University students' engagement in exercise. Individual interviews with

senior university staff and leadership offered insights into institutional policies, resources, and strategic priorities relevant for supporting the adoption and sustainability of PEAK. Study Two identified seven intervention types (Education; Modelling; Persuasion; Environmental Restructuring; Incentivisation; Training; and Enablement) and 26 BCTs that are most likely to increase university students' engagement in exercise. The final intervention consisted of eight components targeting students' capability (e.g., increasing knowledge about the mental and cognitive health benefits of exercise), opportunity (e.g., providing a flexible range of accessible exercise options and social support), and motivation to exercise (e.g., increasing the perceived importance of exercise). Specifically, the intervention components included: 1) an in-person "Kick Off session" for program onboarding, 2) a weekly menu of free in-person and digital exercise options and exercise goal, 3) twelve educational and motivational videos, 4) "PEAK Points" reward system, 5) WhatsApp social support group, 6) "PEAK Packs" exercise group, 7) exercise and wellbeing trackers, and 8) program outcome reports. These findings provide a blueprint for other intervention designers to follow when developing a theory-informed behaviour change intervention with key stakeholders.

7.1.3 Study Three. Intervention Pilot

Study Three – PEAK Mood, Mind and Marks: A Pilot Study of an Intervention to Support University Students' Mental and Cognitive Health through Physical Exercise: An assessment of the impact of PEAK on exercise engagement, perceived mental and cognitive health, and implementation outcomes was conducted. Students felt an exercise-based approach to support their mental and cognitive health was acceptable and appropriate and wanted programs like PEAK to continue to be offered at the university. Students' engagement in exercise was variable, and at a whole cohort level did not shift substantially from the beginning to the end of the program. However, it is difficult to discern with certainty the program's impact on the

frequency of students' weekly exercise activity because the method used to measure weekly exercise engagement (i.e., the 'exercise tracker') was suboptimal. Engagement in the exercise tracker was low, especially as the program progressed, and qualitative findings revealed that students were often engaging in exercise sessions they did not record via the exercise tracker, due to the burdensome nature of this data collection method. Perceived mental and cognitive health were stronger at the end of the program across general mental wellbeing, stress, loneliness, concentration, memory, and productivity. Students' sense of belonging to the university also increased. Psychological distress remained stable. Students offered numerous suggestions to improve the program moving forward, such as the use of a single digital delivery platform, more opportunities to connect with peers and to enhance content's cultural inclusivity, highlighting the value in and potential for refining the program content and delivery to optimise an impactful, engaging, scalable intervention to foster healthy exercise habits in a university setting. These findings demonstrate the value in refining the program content and delivery to optimise engagement in, and the impact of PEAK to foster healthy exercise habits in a university setting.

7.2 Implications and Future Directions

7.2.1 Supporting University Students' Mental and Cognitive Health

The findings from this thesis have broader implications for the development of programs to support students' mental and cognitive health. As noted above, perspectives expressed by university students, staff, and senior leaders demonstrated a clear need and strong appetite for programs to support students' mental and cognitive health. This finding is in keeping with evidence demonstrating that mental health difficulties and cognitive health concerns are prevalent among this cohort (Auerbach et al., 2018; Bird et al., 2023). The need to support students' mental health is continuing to be acted upon in the tertiary education sector, evidenced by shifts in institutional priorities alongside a rise in mental health

programs available to students. Within the last ten years a number of universities have formally added student wellbeing as a strategic institutional priority, and have developed policies, frameworks, and handbooks to enhance student wellbeing (Baik et al., 2017; Monash University, 2020; Stallman et al., 2019; The University of Sydney, 2020; Travia et al., 2022). This shift in strategic focus has brought with it an increase in the number of strategies developed to support student mental health and wellbeing, including once-off wellbeing workshops and events, lecture slides routinely directing students to contact mental health helplines and/or medical services, and on-campus student counselling services. However, findings from this thesis indicate that students are broadly dissatisfied with many of these efforts. These initiatives, while well-intentioned, are often difficult to access, deficit-based (i.e., designed to treat "mental illness"), reactive, and/or perceived as tokenistic. Further, students reported that the stigma surrounding mental health discouraged their participation in programs explicitly marketed towards supporting their mental health.

Students' perspectives on the shortcomings of university mental health programs reflect a broader, global dissatisfaction with the mental health system. This dissatisfaction is starkly illustrated in the most recent edition of the World Health Organization's (WHO's) Mental Health Atlas 2020 (WHO, 2020) which provides clear evidence that the increased need for mental health support globally is yet to be met with a scale-up of quality mental health services. Findings from the report, which includes data from 171 countries, showed that most of the mental health targets set in the WHO's Comprehensive Mental Health Action Plan were not close to being achieved in 2020. For instance, only 52% of WHO's 194 Member States met the target related to mental health promotion and prevention programs, falling short of the 80% target. Similarly, less than 50% of people in need received mental health care support. In all countries, the insufficient achievement of WHO's mental health targets and gaps in service coverage are compounded by ongoing stigma associated with mental

health, which deters people from seeking help. In response to the widespread dissatisfaction and stigma associated with the current mental healthcare system, there have been various commissions and calls for reform and new approaches to support mental health (Australian Government, 2023; Australian Psychological Society, 2023; Victorian Government, 2021). These calls for change are echoed in the findings of this thesis, which underscores students desire for alternative mental health programs at universities.

An alternative approach to support mental health is to develop strengths-based programs that are not explicitly advertised as a "mental health" program, yet still confers mental health benefits. For instance, students expressed a desire for empowering programs that emphasise "wellness" as opposed to deficit-based programs or those centred on mental health. These perspectives informed the development of PEAK, which capitalised on the dual mental and cognitive health benefits of exercise. The content and messaging of PEAK purposefully adopted strengths-based, wellness-focused messaging and a novel approach by incorporating the cognitive neuroscience of exercise. This approach resonated positively with students, effectively promoting mental and cognitive health in a way that circumvented the typical stigma associated with mental health. The finding that students are receptive to this approach aligns with a broader perspective that cognition and brain health are perceived more positively and avoid the stigma often associated with mental health (Chapman et al., 2021). For instance, mental health is frequently tied to a medical model that focuses on diagnosing a person based on their deficits, disorder, and disease rather than considering their strengths (Barnes et al., 2022). Conversely, cognition and brain health are terms that leverage the capacity-building, empowering principles of neuroplasticity (Chapman et al., 2021). Consequently, a cognitive and brain health focused intervention offers intervention designers substantial opportunities to implement interventions that mitigates stigma and promotes individual empowerment.

Developing interventions focused on supporting young adults' cognitive and brain health has the potential to deliver long term health benefits. The brain retains plasticity across the life course and is especially pronounced earlier in life (Power & Schlaggar, 2017). This ongoing plasticity means that cognition is modifiable throughout the lifespan and can be positively influenced by interventions at any age (Walhovd et al., 2023), a reality of which most of the public are unaware (Nagel et al., 2021; Van Asbroeck et al., 2021). Despite the potential to promote cognition throughout life course, there is a greater body of evidence and investment in developing cognitive and brain health programs for older adult populations and those at risk of cognitive decline or dementia compared to young adults. Consequently, opportunities for early intervention to promote and maintain cognitive wellbeing across the lifespan and prevent the onset of cognitive difficulties are missed. Indeed, the benefits of promoting cognitive health in early adulthood are increasingly evident. Engaging in brain health-promoting behaviours during young adulthood — such as participating in cognitively stimulating activities, social engagement, physical activity, and maintaining a healthy diet — can promote cognitive health and reduce the risk of cognitive decline and dementia later in life (Dominguez et al., 2021; Farina et al., 2023; Livingston et al., 2020; Puri et al., 2023). Establishing healthy lifestyle habits earlier in life also increases the likelihood these habits will be maintained later in life, thereby promoting the long-term preservation of cognitive health (Hirvensalo & Lintunen, 2011; Waller et al., 2018).

The recognition that cognitive and brain health are important at all stages of life is reflected in a global shift towards prioritising these aspects of health across the life course. For example, in 2022 the WHO released a position paper on the optimisation of brain health to call for the creation of national strategic plans to reduce the burden of neurological disorders and protect the brain (WHO, 2022). These actions have catalysed a broader recognition of brain health as an important aspect of wellbeing across all age groups (Centre

for BrainHealth, 2024; Farina et al., 2023), emphasising the need for tailored strategies in healthcare policy and practice. Given these developments are relatively recent, it is unsurprising that promoting young adults' cognitive health remains under the radar in most sectors, including the university sector. However, the findings from this thesis take the first step towards enabling universities to respond to the WHO's call for action by demonstrating university students and staff are interested in programs to support students' cognitive health. The next step is to educate the university sector about the need, benefits, and opportunities to promote students' cognitive health. Raising this awareness could enable strategic focus to shift towards prioritising students' cognitive wellbeing and inform the development of comprehensive policies and programs targeting cognitive health. In doing so, universities can establish new precedents in higher education and pioneer a global movement towards promoting young adults' holistic wellbeing, including their cognitive, brain and mental health.

7.2.2 Developing Engaging and Scalable Health Behaviour Change Programs

The findings from this thesis illustrate the challenges associated with developing and implementing an engaging and scalable health behaviour change program. Following behavioural intervention design frameworks and co-designing PEAK with university students, staff and senior leaders ensured that the program was theoretically informed, evidence-based and well-received by stakeholders, however, students' engagement in the program pilot remained a challenge. As expected, this challenge was influenced by the substantial heterogeneity in students' needs, preferences, and priorities, which determined which components of PEAK were (or were not) relevant and engaging. These challenges are consistent with ongoing difficulties associated with sustainably engaging students, and the broader population, in health behaviour change programs and highlights the value of personalisation to cater to diverse individual needs.

Personalisation is important for promoting engagement in behavioural interventions (Mayberry et al., 2019; Tong et al., 2021). By tailoring interventions to the specific context of an individual, including their environment, cultural background, socioeconomic status, and personal preferences, personalisation ensures that interventions are relevant to a person's unique needs. Given people's needs change over time and across contexts, personalisation can also adapt to these changes and, therefore, can sustain engagement over time (Ahmad et al., 2019). Personalisation is especially valuable and effective in addressing the needs of people who are from culturally diverse backgrounds, underserved, and equity-deserving (i.e., women, students with a disability, and international students) (Moke, 2022). As demonstrated in the findings from this thesis, these groups experience unique barriers and preferences to health behaviour change that standard public health strategies often do not appropriately address (Aldridge et al., 2018; Campos-Matos et al., 2019). Personalised health interventions can break down barriers such as accessibility issues, cultural differences, and economic constraints, thereby increasing inclusivity, engagement, and contributing to greater equity in health outcomes.

Personalisation offers significant benefits to engage people in behavioural interventions, and in doing so to improve health outcomes and close equity gaps; however, implementing a personalised program requires considerable time, finances, and human resources. While advancements in digital technologies, such as artificial intelligence and machine learning, provide emerging tools to address these challenges by tailoring offerings to meet participants unique wants and needs (Zhou, Fukuoka, et al., 2018; Zhou, Mintz, et al., 2018), these technologies are not readily available to many intervention designers in research contexts. In contexts like this, where technological and financial resources are most often constrained, implementing a personalised program relies on human resources, which requires substantial time and financial investment. These costs cannot often be met by the types of

short-term, small funding grants that are most commonly available in the academic sector. The PEAK program was developed with a two-year grant of $40,000 (funded by the nib foundation Health Smart Grant program, Australia) and exemplifies these challenges. Given the limited resources to enable personalisation in the program design, the first iteration of PEAK focused on cost-effective development and evaluation of the intervention components, with a view to determine which components were worthy of future investment and which could be eliminated. This approach, while resource-efficient, limited the program's ability to maximally engage students due to the absence of personalised program elements. Further, while the initial evaluation of PEAK lays the groundwork for iteration, realising opportunities for program optimisation remains dependent on acquiring additional technological support, sustained funding, and resources that are a continual challenge in the academic sector. Indeed, this scenario is a common predicament in academic research, where opportunities to iterate, implement and scale promising discoveries are often missed due to short term funding duration.

One promising approach to overcome these challenges lies in fostering collaborations between the academic and commercial sectors. In contrast to the academic sector, the commercial sector has access to a substantial amount of sustained funding, resources, expert marketing and advanced technology. For example, more than $9 billion was invested towards digital health companies in 2018, which represented a $2 billion increase from 2017 (Gordon et al., 2020; Mercom Capital, 2018). These resources enable the commercial sector to rapidly develop, implement and market health behaviour change programs, products, and services at scale. There are now over 300,000 healthcare applications available to be downloaded on common digital platforms, and more than 200 applications are added daily (Su et al., 2020). The rapid growth and widespread availability of these applications reaches a global audience swiftly, with an estimated 15.3 million monthly downloads of these applications (ASO,

2023). While developing these applications rapidly means a substantial amount of people can download them quickly, there is considerable variation in their quality (Grundy, 2022) and sustained use is low (Qan'ir et al., 2021). The majority of these products are not evidence-based, theoretically grounded or adhere to public health guidelines (Bondaronek et al., 2018; Mangone et al., 2016; Portenhauser et al., 2021; Tucker et al., 2021; Wasil et al., 2019). Moreover, many lack empirical evidence demonstrating their effectiveness (Alessa et al., 2019; Bondaronek et al., 2018; Lalloo et al., 2017), are not developed in collaboration with experts or end-users (Alessa et al., 2019; Bondaronek et al., 2018; Zhao et al., 2017), and lack adequate assurances around privacy, security, or potential health risks (Alessa et al., 2019; Bondaronek et al., 2018; Mangone et al., 2016; Melcher & Torous, 2020). Beyond the ethical concerns this raises, the perceived credibility of a healthcare product can motivate continued user engagement and the prescription of these applications by clinicians to healthcare service users (Byambasuren et al., 2019). Therefore, the need for scientific rigor in commercial enterprise is an ethical imperative and key for improving the effectiveness of commercial products and building stakeholder trust and engagement.

The mutual benefits of strengthening collaborations between the academic and commercial sector is thus evident. Researchers can bring subject-matter expertise and rigor to the commercial sector, enhancing the impact and safety of products (Lorca-Cabrera et al., 2020), while the commercial sector can provide sustained funding, resources, and technological capabilities to facilitate wider, quicker, and sustained dissemination of evidence-based programs (Kwasnicka et al., 2022). Historically academia and industry have operated in relative silos. However, as the benefits of collaboration between these two sectors continues to be recognised, so does the number of academic and commercial partnerships. For example, data from the Australian Bureau of Statistics confirmed that the percentage of businesses collaborating with universities or other higher education institutions rose steadily

from 4.6% in 2010-11 to 7.6% in 2020-21 (ABS, 2012, 2022), with estimates that these collaborations generate $10.6 billion a year in revenue (Universities Australia, 2019). Beyond the benefits this collaborative model poses for boosting the economy, at an individual level, healthcare users benefit by accessing effective, scientifically credible products quickly and sustainably, including personalised programs to promote a range of health behaviours (examples include EXI for physical activity (EXI Therapeutics, 2023), and Noom for diet (Noom Inc., 2024)). As such, establishing an academic-commercial collaboration offers a potential avenue to develop and disseminate an exercise-based program like PEAK to support university students' mental and cognitive health.

7.3 Strengths and Limitations

The current thesis has a number of methodological strengths. The studies presented in this thesis leveraged gold-standard frameworks for developing behavioural interventions alongside quantitative and qualitative research methods. Following the BCW, which incorporates well-validated models of behaviour (i.e., the TDF and COM-B model), allowed for a theory-informed approach to identify barriers and facilitators to students' physical activity, and intervention components most likely to effectively target these factors. Moreover, specifying the content of PEAK in terms of the BCT taxonomy enabled a detailed description of the intervention content and delivery modes. Being explicit about the intervention content and delivery in this way enables interventions to be replicated with fidelity in other contexts and build towards an evidence base that reveals what types of interventions work, in what contexts, for who, and for which behaviours. Conducting quantitative and qualitative research and triangulating data from the systematic review and the perspectives of multiple key stakeholder groups strengthened the methodology of this thesis. For example, findings from the systematic review established the breadth of student barriers and facilitators to physical activity, and obtaining perspectives from university

students, staff, and leadership was particularly valuable in gaining a deep, contextual understanding of students' barriers and facilitators to exercise, and the anticipated barriers and facilitators to the adoption, implementation, and scalability of PEAK. Further, the qualitative implementation evaluation in Study Three provided insight into the quantitative results from the pilot study.

In addition, to the study specific limitations discussed in each manuscript, this thesis should be considered in light of its overarching limitations. Firstly, the COM-B model is a broad, theoretically derived framework designed to be simplified for its use in applied public health settings to understand a wide range of behaviours. This simplification can be considered a limitation when dealing with specific behaviours such as physical activity because it may lack the detailed constructs necessary to understand the nuanced factors that specifically influence physical activity. Additionally, the development and evaluation of PEAK focused on an Australian metropolitan tertiary education context. As such it is unclear the extent to which the findings from these studies generalise to universities in regional and remote settings, and tertiary education settings across geographically and culturally diverse countries. Generalisability is a common challenge when conducting research with university students, due to the high heterogeneity of the target population with regards to student enrolment status (e.g., domestic vs international), format (e.g., on-campus vs online), workload (e.g., part-time vs full-time), and/or level of degree (e.g., undergraduate vs postgraduate). While efforts were made to seek a diversity of perspectives across students exercise experience and student enrolment status to develop and evaluate PEAK, there is evidence that many contextual factors impact behaviour change and should be considered in future research. Another limitation is that the mental and cognitive health status of students participating in the studies to develop and evaluate PEAK were not considered. Although PEAK was designed to be applicable to all students, regardless of the severity of their mental

and cognitive health challenges, people with significant mental and cognitive health concerns have unique barriers to engaging in exercise (Glowacki et al., 2017; Hobson et al., 2020) which were not considered in the design of PEAK. Furthermore, difference in the severity of students mental and cognitive health difficulties at baseline could have influenced the extent to which PEAK impacted students exercise activity, mental and cognitive health.

7.4 Concluding Statement

University students' mental and cognitive health play an important role in their engagement at university, academic success, and overall quality of life. However, many experience difficulties in these critical aspects of their health. Engaging students in regular exercise is a promising means of supporting their mental and cognitive health, however, behaviour change is notoriously challenging. This thesis takes valuable steps towards providing a theoretical understanding of the key factors influencing students' engagement in physical activity and identifying how to address these using best practice approaches to behavioural intervention development. University students, staff, and senior leadership felt the PEAK provided a proactive, strengths-based approach to authentically support students' mental and cognitive health. While challenges with program delivery were identified, these findings lay the groundwork to inform further research and program development to optimise an effective, engaging, scalable, and sustainable exercise intervention to enhance the mental and cognitive health of university students globally by enabling lifelong healthy exercise habits.

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APPENDICES

Appendix A: Additional Files for Chapter Four: Study One

Additional File 1: Theoretical Domains Framework domains, definitions, and constructs

Additional File 2: PRISMA 2020 checklist

Additional File 3: Search syntax for Ovid MEDLINE

Additional File 4: COM-B/TDF coding manual

Additional File 5: Summary of study characteristics

Additional File 1

The Theoretical Domains Framework (v2)

Theoretical Domain	Definition*	Constructs
Knowledge	An awareness of the existence of something	Knowledge (including knowledge of condition/scientific rationale) Procedural knowledge Knowledge of task environment
Skills	An ability or proficiency acquired through practice	Skills Skills development Competence Ability Interpersonal skills Practice Skill assessment
Social/professional role and identity	A coherent set of behaviours and displayed personal qualities of an individual in a social or work setting	Professional identity Professional role Social identity Identity Professional boundaries Professional confidence Group identity Leadership Organisational commitment
Beliefs about capabilities	Acceptance of the truth, reality or validity about an ability, talent or facility that a person can put to constructive use	Self-confidence Perceived competence Self-efficacy Perceived behavioural control Beliefs Self-esteem Empowerment

Theoretical Domain	Definition*	Constructs
		Professional confidence
Optimism	The confidence that things will happen for the best or that desired goals will be attained	Optimism Pessimism Unrealistic optimism Identity
Beliefs about consequences	Acceptance of the truth, reality, or validity about outcomes of a behaviour in a given situation	Beliefs Outcome expectancies Characteristics of outcome expectancies Anticipated regret Consequents
Reinforcement	Increasing the probability of a response by arranging a dependent relationship, or contingency, between the response and a given stimulus	Rewards (proximal/distal, valued/not valued, probable/improbable) Incentives Punishment Consequents Reinforcement Contingencies Sanctions
Intentions	A conscious decision to perform a behaviour or a resolve to act in a certain way	Stability of intentions Stages of change model Transtheoretical model and stages of change
Goals	Mental representations of outcomes or end states that an individual wants to achieve	Goals (distal/proximal) Goal priority Goal/target setting Goals (autonomous/controlled) Action planning Implementation intention

Theoretical Domain	Definition*	Constructs
Memory, attention and decision processes	The ability to retain information, focus selectively on aspects of the environment and choose between two or more alternatives	Memory Attention Attention control Decision making Cognitive overload/tiredness
Environmental context and resources	Any circumstance of a person's situation or environment that discourages or encourages the development of skills and abilities, independence, social competence and adaptive behaviour	Environmental stressors Resources/material resources Organisational culture/climate Salient events/critical incidents Person × environment interaction Barriers and facilitators
Social influences	Those interpersonal processes that can cause individuals to change their thoughts, feelings, or behaviours	Social pressure Social norms Group conformity Social comparisons Group norms Social support Power Intergroup conflict Alienation Group identity Modelling
Emotion	A complex reaction pattern, involving experiential, behavioural, and physiological elements, by which the individual attempts to deal with a personally significant matter or event	Fear Anxiety Affect Stress Depression Positive/negative affect Burn-out
Behavioural regulation	Anything aimed at managing or changing objectively observed or measured actions	Self-monitoring Breaking habit Action planning

Note. Reprinted by permission from Springer Nature: Implementation Science (Validation of the theoretical domains framework for use in behaviour change and implementation research, by Cane, Connor & Michie), Copyright (2012) *All definitions are based on definitions from the American Psychological Associations' Dictionary of Psychology (Washington: 2007)

Additional File 2

PRISMA 2020 Checklist

Section and Topic	Item #	Checklist item	Location where item is reported
TITLE			
Title	1	Identify the report as a systematic review.	Pg. 1
ABSTRACT			
Abstract	2	See the PRISMA 2020 for Abstracts checklist.	Pg. 2
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	Pg. 4 - 6
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	Pg. 6
METHODS			
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	Pg. 8 - 9
Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	Pg. 7
Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used.	Pg. 7 – 8, Additional File 3
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.	Pg. 9
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process.	Pg. 9 - 10
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which results to collect.	Pg. 9 - 10
	10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.	Pg. 9
Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.	NA
Effect measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results.	NA
Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)).	Pg. 9 - 10
	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.	Pg. 9 - 10

	13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	NA
	13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	Pg. 9 - 10
	13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta-regression).	NA
	13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.	NA
Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).	NA
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	NA
RESULTS			
Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	Pg. 11 - 12
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	Pg. 12
Study characteristics	17	Cite each included study and present its characteristics.	Pg. 11 & Additional file 5
Risk of bias in studies	18	Present assessments of risk of bias for each included study.	NA
Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	Table 3
Results of syntheses	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	Pg. 13 - 20
	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	NA
	20c	Present results of all investigations of possible causes of heterogeneity among study results.	NA
	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	NA
Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.	NA
Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	NA
DISCUSSION			
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	Pg. 20 – 24
	23b	Discuss any limitations of the evidence included in the review.	Pg. 24 - 25
	23c	Discuss any limitations of the review processes used.	Pg. 24 - 25
	23d	Discuss implications of the results for practice, policy, and future research.	Pg. 23 - 25

OTHER INFORMATION			
Registration and protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	Pg. 7
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	Pg. 50
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	NA
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.	Pg. 51
Competing interests	26	Declare any competing interests of review authors.	Pg. 50
Availability of data, code and other materials	27	Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.	Pg. 50

From: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71

For more information, visit: http://www.prisma-statement.org/

Additional File 3

Search syntax for Ovid MEDLINE

1. exercis*.tw.

2. exp Exercise/

3. physical activit*.tw.

4. exp Physical Fitness/

5. exp Sports/

6. inactive.tw.

7. sedentary.tw.

8. 1 or 2 or 3 or 4 or 5 or 6 or 7

9. universit*.tw.

10. colleg*.tw.

11. undergrad*.tw.

12. baccalaureate.tw.

13. tertiary.tw.

14. 9 or 10 or 11 or 12 or 13

15. student*.tw.

16. exp Students/

17. 15 or 16

18. 14 and 17

19. intervention*.tw.

20. (program or programs or programme*).tw.

21. (campaign or campaigns).tw.

22. exp Health Promotion/

23. facilitator*.tw.

24. enabl*.tw.

25. motiv*.tw.

26. promot*.tw.

27. barrier*.tw.

28. inhibit*.tw.

29. (behavio?r chang*).tw.

30. 19 or 20 or 21 or 22 or 23 or 24 or 25 or 26 or 27 or 28 or 29

31. 8 and 18 and 30

32. limit 31 to (english language and yr="2010 -Current")

Additional File 4

COM-B/TDF Coding Manual

Guidelines for all study designs

Can I code b/f across multiple domains of the COM-B/TDF?

1. YES, BUT limit this where possible. Only code across multiple domains if necessary to accurately code b/f.
    - e.g. 'lack of time' = coded to 'environmental contexts and resources' whereas 'lack of time due to having other priorities' = coded across both 'environmental contexts' and resources' and 'goals'.

If there is limited contextual explanation of the b/f (i.e. not enough to know which COM-B/TDF domain it belongs to), do we still extract and code this b/f?

2. NO, BUT highlight this b/f in pink to discuss with the research team whether there is enough information to extract and code the b/f to the COM-B/TDF.

Guidelines for qualitative studies

How much detail do I need in my description of the b/f?

3. Include as much contextual detail as necessary to justify which COM-B/TDF domain the b/f is mapped to.

How should I extract b/fs from the results?

4. Extract b/f from text and/or raw quotes (**not just higher order theme** identified by researchers).
5. ONLY extract b/f if it is a prominent and significant theme (i.e. not if it was only mentioned briefly in one sentence).

Should I extract additional b/fs from the discussion?

6. YES, BUT only if the b/f being discussed is a direct reflection of study data from results. A b/f described in the discussion would NOT be extracted if it was a tangential interpretation made by the researchers and / or related to results of other research studies.

Guidelines for mixed-methods studies

Should I code a b/f from the qualitative data if it has already been mentioned in the quantitative data?

7. NO, only extract additional bs/fs from the qualitative data if it has not been identified in the quantitative data OR if it provides extra contextual information to explain the b/f.

Additional File 5

Summary of study characteristics

Author	Country	Participants	Student enrolment status	Physical activity	Design	Method	Analytical approach
Aljayyousi et al., 2019	Qatar	N = 20 n female = 10 (50%) n male = 10 (50%) Mean age (SD) = N/A	Undergraduates	Mixed physically active and inactive	Qualitative	Semi-structured interviews	Inductive qualitative analyses
Awadalla et al., 2014	Saudi Arabia	N = 1,257 n female = 831 (66.1%) n male = 426 (33.9%) Mean age (SD) = 20.1 (1.40)	N/A	Mixed physically active and inactive	Quantitative	Self-report survey/questionnaire	Response frequency
Bellows-Riecken, Mark & Rhodes, 2013	Canada	N = 126 n female = 81 (70%) n male = 45 (30%) Mean age (SD) = 22.26 (6.04)	Undergraduates	Mixed physically active and inactive	Qualitative	Self-report survey/questionnaire	Content analysis
Brunette et al., 2011	Canada	N = 14 n female = 5 (35.7%) n male = 9 (64.3%) Mean age (SD) = N/A	Undergraduates	Physically active	Qualitative	Semi-structured interview	Interpretative phenomenological analysis
Burton et al., 2021	United Arab Emirates	N = 25 n female = 25 (100%) n male = 0 Mean age	N/A	N/A	Qualitative	Focus groups	Inductive thematic analysis

		(SD) = 20.4 (2.6)					
Chaabna et al., 2022	Qatar	N = 370 n female = 229 (61.8%) n male = 141 (38.2%) Mean age (SD) = 20.1 (3.0)	Mixed undergraduates and postgraduates	Mixed physically active and inactive	Quantitative	Self-report survey/questionnaire	Response frequency
Cooke et al., 2015	United Kingdom	N = 26 (13 control; 13 intervention) n female = 81 (59.6%) n male = 55 (40.4%) Mean age (SD) = 22.2	Undergraduates	N/A	Qualitative (post-intervention)	Focus groups	Thematic analysis
Deliens et al., 2015	Belgium	N = 46 n female = 29 (63%) n male = 17 (37%) Mean age (SD) = 20.7 (1.6)	Undergraduates	Mixed physically active and inactive	Qualitative	Focus groups	Thematic analysis (inductive)
Devine, 2016	USA	N = 16 n female = 9 (56.3%) n male = 7 (43.7%) Mean age (SD) = 20.56 (2.16)	Undergraduates	Mixed physically active and inactive	Qualitative	In-depth open-ended interviews	Grounded theory

Diehl et al., 2018	Germany	*Quantitative* N = 689 n female = 479* (69.5%) n male = 210* (30.5%) Mean age (SD) = 22.69 (2.73) *Qualitative* N = 20 n female = N/A n male = N/A Mean age (SD) = 22.8 (N/A)	Mixed undergraduates and postgraduates	Mixed physically active and inactive	Mixed-methods	*Quantitative* Self-report survey/questionnaire *Qualitative* Semi-structured interviews	*Quantitative* Response frequency *Qualitative* Content analysis
El-Gilany et al., 2011	Egypt	N = 1,708 n female = 856 (50.1%) n male = 852 (49.9%) Mean age (SD) = 19.6 (1.6)	N/A	Mixed physically active and inactive	Quantitative	Self-report survey/questionnaire	Response frequency
Forrest & Bruner, 2017 (Phase II)	Canada	N = 23 n female = N/A n male = N/A Mean age (SD) = N/A	Undergraduates	N/A	Qualitative (post-intervention)	Focus groups	Thematic content analysis
Goldstein et al., 2017	USA	N = 157 n female = 82 (52.2%) n male = 75 (47.8%)	Undergraduates	Mixed physically active and inactive	Quantitative	Self-report survey/questionnaire	Response frequency

		Mean age (SD) = 21.78 (5.17)					
Griffiths et al., 2022	United Kingdom	*Quantitative* N = 729 n female = 481 (66%) n male = 248 (34%) Mean age (SD) = N/A *Qualitative* N = 27 n female = N/A n male = N/A Mean age (SD) = N/A	Undergraduates	Mixed physically active and inactive	Mixed-methods	*Quantitative* Self-report survey/questionnaire *Qualitative* Semi-structured interviews and focus groups	*Quantitative :* Response frequency *Qualitative:* Thematic analysis
Hilger-kolb	Germany	*Quantitative* N = 689 n female = 479 (69.5%) n male = 210 (30.5%) Mean age (SD) = 22.7 (2.7) *Qualitative* N = 20 n female = 13 (65%) n male = 7 (35%) Mean age (SD) = 22.8 (N/A)	Mixed undergraduates and postgraduates	Mixed physically active and inactive	Mixed-methods	*Quantitative* Self-report survey/questionnaire *Qualitative* Semi-structured interviews	*Quantitative* Response frequency *Qualitative* Content analysis
King et al., 2014	USA	N = 480 n female = 318 (66.3%) n male = 162 (33.8%) Mean age	Mixed undergraduates and postgraduates	Mixed physically active and inactive	Quantitative	Self-report survey/questionnaire	Response frequency

		(SD) = 19.68 (1.76)					
Kwan & Faulkner, 2011	Canada	N = 45 n female = 26 (57.7%) n male = 19 (42.3%) Mean age (SD) off-campus students = 18.73 (.89) Mean age (SD) residence students = 18.64 (0.98)	Undergraduates	Mixed physically active and inactive	Qualitative	Focus groups	Thematic analysis (deductive)
LaCaille et al., 2011	USA	N = 49 n female = 32 (65.3%) n male = 17 (34.7) Mean age (SD) = 19.3 (1.2)	Undergraduates	N/A	Qualitative	Focus groups	Thematic analysis
Leinberger-Jabari et., 2023	United Arab Emirates (Abu Dhabi)	N = 35 n female = N/A n male = N/A Mean age (N/A) = N/A	Undergraduates	N/A	Qualitative	Focus groups	Thematic analysis
Lerner, Burns & de Roiste, 2011	Ireland	*Quantitative* *N = 532* n female = 335 (63%) n male = 197 (37%) Mean age male (SD) = 21 (3.20) Mean age female (SD) = 21.2 (4.2) *Qualitative*	Undergraduates	Mixed physically active and inactive	Mixed-methods	*Quantitative* Self-report survey/questionnaire *Qualitative* Semi-structured interviews	*Quantitative* Response frequency *Qualitative* Content analysis

		N = 16 n female = N/A n male = N/A Mean age (SD) = N/A					
Marmo, 2013	USA	N = 56 n female = 31 (55.4%) n male = 25 (44.6%) Mean age (SD) = 23.55	Undergraduates	Mixed physically active and inactive	Qualitative	Focus groups	Thematic analysis
Miyawaki et al., 2019	Japan	N = 499 n female = 92 (18.4%) n male = 407 (81.6%) Mean age (SD) male non-exercise group = 19.1 (1.1) Mean age (SD) male exercise group = 19 (1.0) Mean age (SD) female non-exercise group = 18.8 (0.7) Mean age (SD) female exercise group = 18.9 (0.6)	N/A	Mixed physically active and inactive	Quantitative	Self-report survey/questionnaire	Response frequency
Monforte et al., 2021	Spain	N = 27 n female = 13 (48%) n male = 14 (52%) Mean age (SD) = 40.29 (12.22)	N/A	N/A	Qualitative	Interviews	Thematic analysis

Musaiger et al., 2014	Kuwait	N = 530 n female = 327 (61.7%) n male = 203 (38.3%) Mean age male (SD) = 21.5 (3.5) Mean age female (SD) = 20.6 (2.6)	N/A	N/A	Quantitative	Self-report survey/questionnaire	Response frequency
Nannyonjo et al., 2013	Uganda	*Quantitative* N = 150 n female = 150 (100%) n male = 0 Mean age (SD) = N/A *Qualitative* N = 24 n female = 24 (100%) n male = 0 Mean age (SD) = N/A	Undergraduates	Mixed physically active and inactive	Mixed-methods	*Quantitative* Self-report survey/questionnaire *Qualitative* Focus groups	*Quantitative* Response frequency *Qualitative* Thematic analysis
Nolan, Sandada & Surujlal, 2011	South Africa	N = 462 n female = 268 (58%) n male = 194 (42%) Mean age (SD) = 19.98 (2.25)	Mixed undergraduates and postgraduates	Mixed physically active and inactive	Quantitative	Self-report survey/questionnaire	Response frequency
Othman et al., 2022	Malaysia	N = 26 n female = 26 (100%) n male = N/A Mean age (SD) = 23 (1.17)	Undergraduates	Mixed physically active and inactive	Qualitative	Interviews	Inductive and deductive thematic analysis

Pan & Nigg, 2011	USA	N = 32 n female = 14 (43.8%) n male = 18 (56.2%) Mean age (SD) = 25.3 (6.1)	N/A	N/A	Qualitative	Focus groups and semi-structured interview	N/A
Pellerine et al., 2022	Canada	N = 341 n female = 279 (81%) n male = 62 (19%) Mean age (SD) = 23 (4)	Undergraduates	Mixed physically active and inactive	Quantitative	Self-report survey/questionnaire	Logistic regression model
Quintiliani et al., 2012	USA	N = 14 n female = 6 (42.9%) n male = 8 (57.1%) Mean age (SD) = 25 (N/A)	Undergraduates	N/A	Qualitative	Semi-structured interview	Systematic team-based analysis approach
Ramírez-Vélez et al., 2015	Columbia	N = 5,663 n female = 2,315 (40.9%) n male = 3,348 (59.1%) Mean age (SD) = 20.8 (2.8)	Mixed undergraduates and postgraduates	Mixed physically active and inactive	Quantitative	Self-report survey/questionnaire	Response frequency
Ranasinghe et al., 2016	Sri Lanka	*Quantitative* N = 113 n female = 76 (67.3%) n male = 37 (32.7%) Mean age (SD) = 23.4 (1.0) *Qualitative* N = 87	Undergraduates	Mixed physically active and inactive	Mixed-methods	*Quantitative* Interviewer-administered questionnaire *Qualitative* Focus groups and in-depth interviews	*Quantitative* Response frequency, Chi square and t-tests *Qualitative* Directive content analysis

		n female = 51 n male = 36 Mean age (SD) = 22.8 (1.1)					
Romaguera et al., 2011	Spain	N = 2,051 n female = 1,188 (57.9%) n male = 863 (42.1%) Mean age (SD) = 21.9 (4.8)	Mixed undergraduates and postgraduates	Mixed physically active and inactive	Quantitative	Self-report survey/questionnaire	Response frequency
Silver et al., 2019	Canada	*Quantitative* *N = 477* n female = 317 (66.5%) n male = 160 (33.5%) Mean age (SD) men = 19.9 (2.5) Mean age (SD) women = 19.9 (2.0) *Qualitative* n = 41 n female = 16 (39%) n male = 25 (61%) Mean age (SD) women = N/A	Undergraduates	Mixed physically active and inactive	Mixed-methods	*Quantitative* Self-report survey/questionnaire *Qualitative* Focus groups	*Quantitative* Logistic regression *Qualitative* Thematic analysis
Snyder et al., 2017	USA	N = 24 n female = 16 (66.7%) n male = 8 (33.3%) Mean age (SD) = 21.84 (1.06)	Undergraduates	Physically active	Mixed-methods	*Quantitative* Self-report survey/questionnaire *Qualitative* Interviews	*Quantitative* Response frequency and MANOVA *Qualitative* Interpretive qualitative research analysis

Tong et al., 2018	Australia	N = 55 n female = 28 (51%) n male = 27 (49%) Mean age (SD) = 23.6 (4.6)	N/A	N/A	Qualitative (pre- and post-intervention)	Semi structured, in-depth interviews and focus groups	Thematic analysis (inductive)
von Sommoggy et al., 2020	Germany	N = 46 n female = 28 (60.9%) n male = 18 (39.1%) Mean age students from university 1 (SD) = 23.6 (2.2) Mean age students from university 2 (SD) = 23.8 (2.8)	N/A	Mixed physically active and inactive	Qualitative	Focus groups	Thematic analysis
Walsh, Taylor & Brennick, 2018	Canada	N = 48 n female = 28 (58%)* n male = 21 (43%)* Mean age (SD) = N/A	N/A	N/A	Qualitative	Self-report audio-recording and focus groups	Thematic analysis
Wilson et al., 2019	New Zealand	N = 121 n female = N/A n male = N/A Mean age (SD) = N/A	Undergraduates	N/A	Mixed-methods	Self-report survey/questionnaire	*Quantitative* Response frequency *Qualitative* Thematic analysis (inductive)

*Errata originates from source paper; included for transparency

Appendix B: Additional Files for Chapter Five: Study Two

Additional File 1: The Behaviour Change Wheel intervention functions, definitions and examples

Additional File 2: Student focus group interview schedule

Additional File 3: Staff semi-structured interview schedule

Additional File 4: The APEASE criteria

Additional File 5: University students' perceived barriers and facilitators to exercise and the adoption of PEAK

Additional File 6: University leadership staff's perceived barriers and facilitators to the adoption and scalability of PEAK

Additional File 7: Behaviour Change Techniques selected for the PEAK program, their definitions, and examples

Additional File 8: Educational and Motivational Video Topics and Links

Additional File 1

The Behaviour Change Wheel intervention functions, definitions and examples (reproduced from Michie S., Atkins L., West R. (2014). The Behaviour Change Wheel: A Guide to Designing Interventions. London: Silverback Publishing. www.behaviourchangewheel.com).

Intervention function	**Definition**	***Example of intervention function***
Education	Increasing knowledge or understanding	*Providing information to promote healthy eating*
Persuasion	Using communication to induce positive or negative feelings or stimulate action	*Using imagery to motivate increases in physical activity*
Incentivisation	Creating an expectation of reward	*Using prize draws to induce attempts to stop smoking*
Coercion	Creating an expectation of punishment or cost	*Raising the financial cost to reduce excessive alcohol consumption*
Training	Imparting skills	*Advanced driver training to increase safe driving*
Restriction	Using rules to reduce the opportunity to engage in the target behaviour (or to increase the target behaviour by reducing the opportunity to engage in competing behaviours)	*Prohibiting sales of solvents to people under 18 to reduce use for intoxication*
Environmental restructuring	Changing the physical or social context	*Providing on-screen prompts for GPs to ask about smoking behaviour*
Modelling	Providing an example for people to aspire to or imitate	*Using TV drama scenes involving safe-sex practices to increase condom use*

Intervention function	Definition	*Example of intervention function*
Enablement	Increasing means/reducing barriers to increase capability (beyond education and training) or opportunity (beyond environmental restructuring)	*Behavioural support for smoking cessation, medication for cognitive deficits, surgery to reduce obesity, prostheses to promote physical activity*

Additional File 2

Student focus group interview schedule

Introduction

- Introduce PEAK, work to date, ultimate aims
- Describe purpose of focus groups generally

Mental, cognitive and brain health impact of exercise

- Show students' video created by young adults: "*Exercising smart: how being active can help you perform better in your studies*": https://vimeo.com/ymcavictoria/download/535721809/3ed49f4683

1. What are your reactions to the video that explained some of the mental, cognitive and brain health benefits of physical exercise?
2. To what extent has exercise had an impact on your mental health and cognition?

Appetite for a program to support students' mental and cognitive health

3. How would you describe the mental and cognitive health status of university students?
4. To what extent is there a need for a university program to improve students' mental and cognitive health?

Barriers and facilitators to physical exercise

5. What hinders and helps and helps your engagement with physical exercise?
    a. Prompt: Capability (knowledge / skills)
    b. Prompt: Opportunity (physical / social)
    c. Prompt: Motivation (reflective / automatic)

Co-design

6. If you were to design PEAK, what methods could be used to deliver the program?
7. If you were to design PEAK, what strategies would increase the adoption of the program?
    a. Prompt: What program outcomes are you interested in tracking (i.e. mental, exercise achievement, cognition) and what kind / frequency of feedback would you like?
    b. Prompt: What have/haven't you found engaging in other physical exercise programs?

Conclusion

Are there any other comments you would like to make about PEAK, or topics we have discussed today?

Additional File 3

Staff semi-structured interview schedule

Introduction

- Introduce PEAK, work to date, ultimate aims,
- Describe purpose of interviews generally, and for interviewing them specifically,
- Obtain informed consent.

Document interviewee and department's role

1. Can you briefly tell me about your role at Monash?
    a. What does it involve? How long have you been in the role?

2. Can you tell me what the key role and goals of your department / service are within the university?

Departments perspective and role (if any) in student mental health and cognitive health

3. Is student mental health and cognitive health a focus in your department?
    a. Are there strategies in place to support students' mental and cognitive health? Can you describe them?
    b. What has helped or got in the way of their success?
    (probe department initiation and support + student adoption)

4. How do you think students are doing from mental health and cognitive health perspectives?

Department's perspective on PEAK's worth and scalability

5. Do you think PEAK would be beneficial for i) students and your ii) department?

6. Do you think PEAK could be implemented at Monash, supported by the staff and taken up by the students?
    a. What do you think needs to be in place for that to happen?
        - prompt Capability (knowledge / skills)
        - prompt Opportunity (physical / social)
        - prompt Motivation (reflective / automatic)

7. If the pilot is successful, what chance do you think PEAK has of being scaled up across Monash and to other universities?

b. What do you think would help or get in the way of its scalability?

Department's potential involvement in PEAK

8. Would you, and your department, want to be involved?

9. What things would you need to know, and what would you need to have in place, to make your department's contribution successful?

a. What processes or other factors would get in the way of your involvement?
b. What processes or other factors would help your involvement?

10. In your department, who do we need to win over, in addition to your good self?

Co-design

11. What would you like to see included in the PEAK program?

12. What outcomes would you like to see measured from PEAK, what outcomes would be useful for your department?

a. Do you think measuring these things would help scaling the program up across Monash and to other universities? Why?

Conclusion

And finally, are there any other comments you would like to make about PEAK, your department, or questions I have asked today?

Additional File 4

The APEASE criteria (reproduced from Michie S., Atkins L., West R. (2014). The Behaviour Change Wheel: A Guide to Designing Interventions. London: Silverback Publishing. www.behaviourchangewheel.com).

Criterion	Description
Affordability	Interventions often have an implicit or explicit budget. It does not matter how effective, or even cost-effective it may be if it cannot be afforded. An intervention is affordable if within an acceptable budget it can be delivered to, or accessed by, all those for whom it would be relevant or of benefit.
Practicability	An intervention is practicable to the extent that it can be delivered as designed through the means intended to the target population. For example, an intervention may be effective when delivered by highly selected and trained staff and extensive resources but in routine clinical practice this may not be achievable.
Effectiveness and cost-effectiveness	Effectiveness refers to the effect size of the intervention in relation to the desired objectives in a real world context. It is distinct from efficacy which refers to the effect size of the intervention when delivered under optimal conditions in comparative evaluations. Cost-effectiveness refers to the ratio of effect (in a way that has to be defined, and taking account of differences in timescale between intervention delivery and intervention effect) to cost. If two interventions are equally effective then clearly the most cost-effective should be chosen. If one is more effective but less cost-effective than another, other issues such as affordability, come to the forefront of the decision making process.
Acceptability	Acceptability refers to the extent to which an intervention is judged to be appropriate by relevant stakeholders (public, professional and political). Acceptability may differ for different stakeholders. For example, the general public may favour an intervention that restricts marketing of alcohol or tobacco but politicians considering legislation on this may take a different view. Interventions that appear to limit agency on the part of the target group are often only considered acceptable for more serious problems (Nuffield Council on Bioethics, 2007).
Side-effects/safety	An intervention may be effective and practicable, but have unwanted side-effects or unintended consequences. These need to be considered when deciding whether or not to proceed.
Equity	An important consideration is the extent to which an intervention may reduce or increase the disparities in standard of living, wellbeing or health between different sectors of society.

Additional File 5

University students' perceived barriers and facilitators to exercise and the adoption of PEAK

COM-B category	Theme/ belief statement	Sub-theme/belief statement	Barrier/facilitator/mixed	Example quote(s)
CAPABILITY				
Psy C	My knowledge about exercise and how it is beneficial is variable	Learning how exercise impacts mental, cognitive and brain health is helpful	Facilitator	*"The video [about how exercise impacts mental, cognitive and brain health] was very educative. I didn't actually know - I mean, I knew that exercise is healthy and helpful. But I thought it's okay not to exercise during the exam times, because you don't have time. You're too stressed. You cannot manage everything properly. Yeah, video was really great. Now I know that I have to exercise to help myself, because I didn't know how to relieve my stress during the exam period or other stressful times."* FG 2, Female *"I think this [video] was an eye opener. I need to do something physical, like physical exercise, during exam to help with stress, because I'm the person who will literally do nothing during exams, just study."* FG 2, Female *"I found that the video [about how exercise impacts mental, cognitive and brain health] was very informative as well…when you first just do exercise, oh, I'm just getting stronger or I'm feeling a bit happier, but you don't really think about the overall cumulative effects of it in general."* FG 2, Male

COM-B category	Theme/ belief statement	Sub-theme/belief statement	Barrier/facilitator/mixed	Example quote(s)
		I lack knowledge about how to exercise and use gym equipment	Barrier	*"I don't really know how to use the gym."* FG 4, Female *"When I started going to the gym… I felt like I didn't know what anything did, and I would want to learn everything."* FG 4, Female
		I lack knowledge about how to manage the physical consequences (e.g. muscle soreness) and risks (e.g. injury) of exercise	Barrier	*'"Yeah. I would say something that would hinder exercise engagement, though, would be DOMS [Delayed Onset Muscle Soreness] or nervous system fatigue. When your muscles are very sore…"* FG 2, Male *"Not many people know what soreness is okay to go to the gym or not. Even for me sometimes, I'm scared of snapping my tendons or whatever, right."* FG 2, Male
	I lack time management skills to fit exercise into my daily life		Barrier	*"Time is a big [barrier], being able to manage time."* FG 1, Male *"I mean for me I want to [exercise] I just find it difficult to schedule it into my timetable"* FG 3, Male
	Tracking and receiving feedback on the progress and impact of my exercise is helpful/unhelpful	Tracking and receiving feedback on my exercise progress is helpful	Facilitator	*"I used Apple before, but you have the step count like you said and it's kind of encouraging too. It's a tiny thing like in the notification bar, the amount of steps you've done, but it's also very encouraging to see it next to like oh, this is the number of steps you have remaining to reach your goal. So it's always a very nice format and it's always encouraging to see that, so it helped me to walk more."* FG 1, Female

COM-B category	Theme/ belief statement	Sub-theme/belief statement	Barrier/facilitator/mixed	Example quote(s)
		Tracking and receiving feedback on the impact of exercise on my mental health and cognition is helpful/unhelpful	Mixed	Barrier ***"****I actually don't think [tracking mental health] is a huge factor……because if you do feel well, you feel well right? Whether you track it or not, I mean you'll just intrinsically feel well, so… I don't think that just recording it would increase it or decrease [my exercise], personally for me,"* FG 1, Female *"I feel like logging [mental health change or thinking skill change] would be a bit [over the top] and a bit tedious."* FG 2, Male Facilitator *"I think there's a lot to be said about recognising patterns in how you're feeling and if you recognise it, that'll sort of classically condition you to associate the two. That's just my perspective I guess."* FG 1, Female *"If [students are] seeing the benefits. If they're seeing emotional…benefits that would be probably enough to get them to continue [to exercise once the extrinsic incentive stopped]."* FG 4, Female *"Yeah, [tracking and receiving feedback on thinking skills] would be nice actually. I think with the thinking skills and things, I think that would be really good as like a weekly summary"* FG 1, Male *"Sometimes, especially when you do exercise for a continuous period, you start to notice results, but you forget what you were*

COM-B category	Theme/ belief statement	Sub-theme/belief statement	Barrier/facilitator/mixed	Example quote(s)
				like before, and it's only until you see photos or you have measurements, or you do a certain task, that you're like, hold the phone. Wait, this has actually had a positive impact. I think maybe helping people identify a goal at the start and tracking it, that would definitely incentivise people to - at least me, personally, to keep going." FG 4, Female
Phys C	None identified		-	
OPPORTUNITY				
Phys O	I don't have enough time to exercise		Barrier	***"****Having a big and busy day and you might not find time to get exercise in."* FG 1, Female *"I feel like it's because we're so time poor. There's always something else you can be doing. I feel like with uni you're always behind."* FG 3, Female " I'd feel… too busy that I can't exercise" FG 3, Male
	I need [a range of] accessible exercise options that can flexibly suit my location, the weather, and exercise preferences		Facilitator	*"...making exercise accessible or whatever would be I think – I know that would appeal to me..."* FG 3, Female "*I think [exercise] at home also helps accessibility a lot, because one of the reasons I stopped going to the gym was because I don't drive, and I don't have a car. Going to the gym was like, it would take up my entire morning or afternoon, whenever I did it…It became very inaccessible."* FG 4, Female

COM-B category	Theme/ belief statement	Sub-theme/belief statement	Barrier/facilitator/mixed	Example quote(s)
				"some people have bad home environment, so they can't work out at home. I went through that as well, so going to the gym was the actual place to go to exercise." FG 4, Female *"One other thing might be like the accessibility to be able to do things maybe away from campus as well, so having some sort of online [program]"* FG 1, Male *"Where possible, having outdoor things is great. But then being able to have that back up and use indoor facilities in case of rain"* FG 1, Male *"Having different types of exercise was really beneficial to our motivational levels…Like different types of exercise, so you can do strength based, high impact, just going for a run as a group and yeah, just different types of exercise you can do. Maybe you have yoga as well, just a recovery session with a bunch of other people. "* FG 1, Male *"Yeah, I think… a website system there which provides so much options like time we can choose the time and we can choose the type of the exercise."* FG 3, Male
	Beginners need introductory exercise options to build confidence and learn basic exercise skills		Facilitator	*"…it would be better to have just some introductory classes…like learn how to exercise."* FG 4, Female *"I think it would be a good thing to always wrap the whole, whatever the duration of PEAK is, to always have that one set super-beginner class that's literally just teaching*

COM-B category	Theme/ belief statement	Sub-theme/belief statement	Barrier/facilitator/mixed	Example quote(s)
				the skills. Everyone at least, at one point, would maybe have gone in that class, but then eventually gone to one of the other things that's offered… There should always be a skills and - which is a very basic, maybe for somebody who's never seen exercise before...." FG 4, Female
	I need exercise options that don't need equipment		Facilitator	*"I think also including workouts that are – they use minimal equipment as well, because sometimes people get a little scared by…the amount of things you need to do the workout."* FG 1, Female *"So having a set of workouts that…don't require a lot of things, or just require things at home. That would be good."* FG 1, Female *"I don't really like using gym equipment"* FG 4, Female
	Prompts to exercise are helpful		Facilitator	*"Input all the strategy initially into, say, a PEAK app or whatever it was and then it reminds you at that time, hey, by the way, you said that you wanted to exercise this time... A prompt from the phone that is set by you..."* FG 2, Male *"I've been setting an alarm for every half an hour or an hour or something, and I'll just do 100 star jumps, and it's like a little restart."* FG 4, Female
	I am motivated/demotivated if I must pay money to exercise		Mixed	Barrier *"I think it would be better for PEAK to be free."* FG 4, Female

COM-B category	Theme/ belief statement	Sub-theme/belief statement	Barrier/facilitator/mixed	Example quote(s)
				"For me, I wouldn't pay anything at all [for PEAK]." FG 4, Male Facilitator *"I also find with costs with gym memberships, it's almost like when you pay that's an obligation to attend the gym, so if it's a free program I just don't really – like there's no motivation behind it."* FG 1, Female
	I find it helpful/unhelpful to use existing university digital platforms to deliver the program, i.e. Moodle		Mixed	Barrier *"I doubt people would actively do something on Moodle."* FG 2, Male *"I feel like most of the stuff that goes on with Moodle I ignore it… because on my Moodle I keep my units and I keep the general forum for my faculty and whatever. There are other things like digital wellbeing or stuff like that which I completely ignore…If [the exercise program] were to go up on my Moodle it would have to be really advertised well and designed well."* FG 3, Male Facilitator *"Another way where you could get all the students and - you know on your Moodle page you've got different tiles for units? If you could have a tile...with PEAK and that's - every student could see that, click on it and do whatever."* FG 2, Male *"Yeah, that's why I don't hate the Moodle idea if it was pushed through your faculty*

COM-B category	Theme/ belief statement	Sub-theme/belief statement	Barrier/facilitator/mixed	Example quote(s)
				also kind of advertised maybe through social media. If you saw an advertisement for it if it was done in the right way, I reckon it could be successful through Moodle." FG 3, Female
Soc O	Exercising with others is beneficial	Exercising with others increases motivation	Facilitator	*"having people around to help you out with motivation."* FG 1, Female *"Because when you go to the gym, everyone's actually putting in the work. You feel motivated and stuff. But at home you have to find self-motivation. You have to put it in yourself."* FG 2, Male *"I find with my friends we workout so much better together, so PEAK could have something like - cool, you could have an individual program if you want. But you could also maybe merge two or three of your closest friends to actually work together… I think - if I'm paired with my friends, the people I've been with, we're more likely to push each other..."* FG 2, Male
		Exercising with others helps keep me accountable	Facilitator	*"… if I've made a commitment to say go to the gym on this day, with this person, I can't back out of it."* FG 1, Female *"I think group setting, group accountability [exercising] with other people…."* FG 4, Female
		Exercising with others is enjoyable	Facilitator	*"it's fun [exercising] with friends who you know. I think that's one motivator for me is like just doing it with people is fun..."* FG 1, Female

COM-B category	Theme/ belief statement	Sub-theme/belief statement	Barrier/facilitator/mixed	Example quote(s)
		I enjoy socialising and making new friends through exercise	Facilitator	*"being able to meet new people at group sessions is also great, especially if the program's going to be aimed undergrad students, because we want to meet people around the same age. Because it's so hard to make friends at uni anyway, so yeah."* FG 1, Female *"...if it's more of a comfortable community environment where they like going anyway, and it's also got a social factor to it as well, people don't feel like they're there for exercise, sometimes. It's like, you're just here regular once a week, you're seeing people and you just happen to be exercising. I think that's when the feel good can happen after, because you actually end up feeling good from the socialisation."* FG 4, Female
	Encouragement from others to exercise helps keep me accountable		Facilitator	*"My boyfriend is really good in helping me with [exercise]... he's just like reminding me I should do some exercise today, okay, yeah, I'll do it."* FG 3, Female
	I want options that can flexibly suit my preference to exercise alone or with others		Facilitator	*"Even during the one week, you might decide you're in more of a social mood. Sometimes, I can't stand being in social settings. Sometimes, I'd want to go to the class, when I'm feeling maybe a bit lower, and I'd need that push. But then when I'm in my super introverted kind of mood, I'd happily do a self-workout. If the option is there to do it. It would be bad if we were just forced to just do group classes only, and you're not a group person. Some people thrive working out by themselves. Yeah, that*

COM-B category	Theme/ belief statement	Sub-theme/belief statement	Barrier/facilitator/mixed	Example quote(s)
				would be a big thing, the choice." FG 4, Female
	I respond well to relatable exercise role models and champions to support the program		Facilitator	*"So it's nice to see maybe someone from MSA [Monash Student Association] or something like that who is more actively involved in student… life to talk about PEAK rather than someone higher up, because we never really know them or see them, so yeah."* FG 1, Female *"Sometimes we need to have a role model. Actually we have seen a certain person who has transformed before exercise and after exercise. We may see it or when ourselves do start it and try it and see ourselves some transformation and we will have more aware – more willing to keep it."* FG 3, Male
	Being part of a supportive exercise community is helpful		Facilitator	*"Even though the actual people who were there, these people who were working super hard, they would come up to me on my first one, at the end of the workout, you did really good today. Oh, I love this place. That's why I came back. That's the only reason."* FG 4, Female *"I think that [supportive community] is what really has drawn me into any fitness thing before, is everyone's so friendly and non-judgemental here."* FG 4, Female
MOTIVATION				
Auto M	I feel too tired to exercise		Barrier	*"At the end of the day you might have time [to exercise], but then you're exhausted, or*

COM-B category	Theme/ belief statement	Sub-theme/belief statement	Barrier/facilitator/mixed	Example quote(s)
				you just can't think about that right now. You just want to relax." FG 1, Female *"I genuinely like going to the gym. I like before I go there, and then just halfway through, I'm just like, no, I can't do this. I'm capable, I just can't, my brain just says, no, you're too tired, this is too much, you've just got to go home."* FG 4, Female *"A bit like with maintaining it it would be hard because there are points in the semester where you're like, I'm just so exhausted, I would do anything to just sleep let alone like do exercise."* FG 3, Female
	I don't feel like exercising when I'm experiencing poor mental health		Barrier	*"I think your mental state also would play a big role so if you're sad or depressed as we discussed... If I'm sad, I would not want to exercise. I'm just sad and stuff."* FG 2, Female *"But I'm not used - I don't exercise regularly. I just exercise when I feel like it, because I'm a very emotional person. My mental state, my mood would really determine my abilities of doing anything."* FG 2, Female *"For a mental health situation sometimes our mental health is not good enough and we may just skip the exercise."* FG 3, Male *"Yeah, I feel like because we're so stressed about the exams coming up and we start to neglect about everything else. Because we start to stress more, we don't think about, oh, maybe if we had only about an hour*

COM-B category	Theme/ belief statement	Sub-theme/belief statement	Barrier/facilitator/mixed	Example quote(s)
				exercise, it would actually help us.,." FG 2, Male
	I feel self-conscious exercising in front of others		Barrier	*"…I worked out with some guy friends…I didn't really enjoy it, because they used to comment, oh, your thighs are thicker than mine and stuff like that. I would feel insecure working around with people that I know."* FG 2, Female "*When I started going to the gym, it was really intimidating… you're so scared that you're going to do something, and people are going to be like, what is this girl trying to do?*" FG 4, Female
	I want exercise to be enjoyable		Facilitator	*"...[exercise] needs to be fun as well."* FG 4, Male *"I think, what I remember positively about PE was the fun games that we would play, like dodgeball and stuff like that."* FG 4, Female
	Having a routine helps me exercise	Having an exercise routine is helpful	Facilitator	*"…building up momentum is such an important thing when it comes to exercising I reckon."* FG 1, Female *"If you have an [exercise] routine going, it helps you flow."* FG 2, Male
		Having a healthy sleep routine helps my exercise	Mixed	Barrier *"I think the rest of the time when you have uni, you have a very crazy sleep schedule. I sometimes find myself sleeping at 2am, 3am, which means I wake up really late as well. So it's a late start to the day and it's really hard to find motivation or the energy to do a*

COM-B category	Theme/ belief statement	Sub-theme/belief statement	Barrier/facilitator/mixed	Example quote(s)
				workout, so yeah, that's one of the things I would say." FG 1, Female Facilitator *"…if I had like nine, 10 hours [of sleep]... I'd be like, okay, I need to be active."* FG 2, Female
		Having a healthy diet routine helps my exercise	Facilitator	*"I also find that my eating habits dictate how I feel in terms of going into a workout, so if I've been eating healthily around a certain time, I find the workouts that I do in that time are always more effective and yeah, I don't know. It's almost like the momentum's built into it as well, like if I keep up healthy meals and also exercising it's almost like an ego boost"* FG 1, Female *"Another thing we discussed was diet. Say if you have a routine with diet, you'll be eating healthy, you're more likely to put in the work [to exercise] and stuff."* FG 2, Male 3
	I respond well to incentives to exercise		Facilitator	"*Yeah and then also with a goal, having a reward at the end. That personally [laughs] motivates me, if I know that I've done my exercise for the month or the week or whatever, yeah and done what I planned to do, then I like to reward myself for that."* FG 1, Female *"We love extrinsic motivators [to exercise]"* FG 1, Male "*…You just have to maybe give some reward to students...because we are really motivated*

COM-B category	Theme/ belief statement	Sub-theme/belief statement	Barrier/facilitator/mixed	Example quote(s)
				by rewards. Anything related to...vouchers, money, food, we'll love it" FG 2, Female
Ref M	I don't prioritise exercise (because of my study)		Barrier	*"during assignments and exams, it becomes less of a priority because you're trying to have as much time to do your studies then too…it's really hard to balance it with the amount of assignments we have"* FG 1, Female *"I guess I also find that for uni, the workload is a lot higher compared to high school. So yeah, in a way that kind of hinders me because I feel like I've got to spend more time studying, or working on assignments and that takes away from the time I could be spending on being outside, engaging in physical activities."* FG 1, Female "*But problem with gym was that lack of motivation, because I always prioritise my studies and work over my fitness*." FG 2, Female 3 *"I think I'm a person who stops doing everything during exams. I cancelled my gym membership in the exam month. I put it on hold. I don't go out."* FG 2, Female
	I find it helpful to set exercise goals		Facilitator	*"… if we set a goal, it helps us to do [exercise] and I find that for myself as well. If I set a specific goal, then that's more likely that I'll do it as well, the sense of fulfilment that we would get from that as well helps."* FG 1, Female *"I think setting more achievable goals helps to start [exercise] and maybe even –*

COM-B category	Theme/ belief statement	Sub-theme/belief statement	Barrier/facilitator/mixed	Example quote(s)
				because right now my goal is just like get moving and should really sound like achievable like I can go for a walk and do like 15-minute exercise like that's achievable." FG 3, Female *"I guess the fact that you can change those goals whenever you want, it's very up to you, you don't have to be pressured into, I need to do 30 minutes of exercise. I can do 10 minutes, start small, and then just increase along the way. Then looking back, oh, yes, I started with this, now I can do an hour a day, and that's very rewarding, I think."* FG 4, Female *"For me, what I've noticed is when I have a specific fitness goal that I want to reach, and I've created a plan to help myself reach that goal, that motivates me significantly more than if I'm just kind of like, I don't have a goal to achieve, or I do have a goal, but I don't know how to get there. I think helping people identify what goals they have and how to make a plan to reach that goal, would definitely be a huge help."* FG 4, Female
	Exercise has a positive/negative impact on my mental health and wellbeing	Exercise helps me feel less stressed	Facilitator	"*[Exercise is] a good stress relief*" FG 2, Male *"Less stress [when exercising]"* FG 3, Female *"But then sometimes like in exam week or in the week leading up to exam week when you're so stressed I will find myself going on*

COM-B category	Theme/ belief statement	Sub-theme/belief statement	Barrier/facilitator/mixed	Example quote(s)
				walks or the occasional very infrequent run" FG 3, Female
		Exercise has a positive/negative impact on my mood	Mixed	Facilitator *"[Exercise] makes you happy, like you feel better*" FG 3, Female "*When I do exercise now, I just notice a huge upshoot in how good I feel. It's very, very drastic."* FG 4, Female Mixed *"I find light exercise, in smaller increments, to be quite beneficial in improving my mood, but if I set out to do a real intense, strenuous activity, I find I just feel awful. Just exhausted and gross and sweaty and not happy."* FG 4, Female
		Exercise increases my self-esteem	Facilitator	*"[Exercise] increases your self-esteem"* FG 2, Female
		Exercise helps me to feel a sense of self-achievement	Facilitator	"*The feeling of accomplishing that hardened task would be a good feeling… for let's say team sports and tournaments and the like, when you win as a team or if you're doing for instance resistance training, then at the end of it, after smashing it out, [a very heavy weight or very light even]. It's like I was dead in the middle of it, but at the end I've done it. I feel really happy that I did the goal that I wanted to accomplish."* FG 2, Male *"I get often a sense of achievement [from exercise]"* FG 3, Male

COM-B category	Theme/ belief statement	Sub-theme/belief statement	Barrier/facilitator/mixed	Example quote(s)
	Exercise has a positive/negative impact on my thinking skills	Exercise helps me to stay focused for longer	Facilitator	"*I find I'm able to focus for longer."* FG 1, Female *"I feel…just being able to focus a bit more, rather than drifting the whole time"* FG 4, Female
		Exercise helps me to focus on one task at a time	Facilitator	"*when I have the time to do exercise and stuff…I can focus on one thing"* FG 1, Male *" I can focus more on one thing, instead of jumping between tasks"* FG 1, Female
		It is difficult to think critically, and problem solve directly after engaging in vigorous exercise	Barrier	*"…on these particular days, in the mornings, after my exercise, I just wouldn't be able to think as critically to solve all the problems I needed to deal with… For the few hours after the exercise"* FG 4, Male
	The physical impact of exercise is positive/negative	Exercise has a positive/negative impact on my energy	Mixed	Barrier *"I feel like if I do work out I'm going to expend energy, energy which I might use to study…"* FG 1, Female *"I get really sleepy during my workout, when I get home, I have to nap. I cannot do another task. If you tell me, get home, study, go get some errands, go home - I literally have to allocate time to sleep."* FG 4, Female Facilitator *"Yes, exercise stops you being so lethargic and makes me feel physically healthier"* FG 4, Female

COM-B category	Theme/ belief statement	Sub-theme/belief statement	Barrier/facilitator/mixed	Example quote(s)
				"I notice, as soon as I start doing exercise, I just pretty instantly, just like that, [my energy] shoots way up." FG 4, Female
		Exercise has a positive impact on my strength and fitness	Facilitator	"*That's one reason why I started working out, because I wanted to be fitter"* FG 2, Female
	Exercise has a positive impact on my appearance		Facilitator	"*You look better and you think you look better. Somehow after exercising, I see improvements. My face becomes slimmer right away."* FG 2, Female
				"if you gained weight and you're not happy with your reflection, you're more likely to exercise, not because you like exercising but just because you have to get back in your previous shape just to feel good, to feel yourself again." FG 1, Female

Note. Psy C, psychological capability; Phys C, physical capability; Phys O, physical opportunity; Soc O, social opportunity; Ref M, reflective motivation; Auto M, automatic motivation; FG, focus group

Additional File 6

University leadership staff's perceived barriers and facilitators to the adoption and scalability of PEAK

COM-B category	Theme/ belief statement	Sub-theme/belief statement	Barrier/facilitator/mixed	Example quote(s)
CAPABILITY				
Psy C	None identified			
Phys C	None identified			
OPPORTUNITY				
Phys O	PEAK needs to be affordable for the university and well-resourced		Barrier	*"What would hinder it's [scalability]? Well, there's cost of service delivery for us, so there would need to be some form of - and I'm just thinking out loud here - there would probably need to be some form of recompense, or funding attached to it."* University exercise facilities *"Having [PEAK] well-resourced I think would be an important thing."* (Residential services and colleges) *"with the extra workload for staff to deliver the program if that's how it would be integrated I think that would probably be the biggest problem there is"* Unit co-ordinator
	Integrating the design and delivery of PEAK with pre-existing university services and platforms will reduce operational costs and enhance the universities long-term support of PEAK		Facilitator	*"In terms of the design of it, if you were starting with a blank piece of paper, you'd want to have the integration of the services that are available to the students included. So you'd want to have counselling, you'd want to have the physical activity programs we deliver, you'd want to have*

COM-B category	Theme/ belief statement	Sub-theme/belief statement	Barrier/facilitator/mixed	Example quote(s)
				in person and digital" University exercise facilities
Soc O	Support from others to champion PEAK is important	Local bottom-up student leadership support	Facilitator	*"When it comes from us it's just – it's not authentic enough. We can tell students all day that this is important and you should do this to look after yourself but because we're not in their shoes, we're not in the same position as them, I don't think it is as well received as if it comes from people that are either in their peer group or just one or two steps above them."* Unit co-ordinator
		Organisational top-down leadership support	Facilitator	*"You need all the stakeholders buy-in…a top-down approach is really important."* International student engagement
	Working with partner organisations will enhance the scalability of PEAK		Facilitator	*"…get a larger organisation like NAAUC [National Association of Australian University Colleges] to give it credibility and what not, and then through discussion about what it is et cetera. Then that will just percolate through to the colleges I'd imagine."* Residential services and colleges
MOTIVATION				
Auto M	None identified			
Ref M	The goals of PEAK need to align with organisational priorities, goals, and policies	The university values programs that enhance student wellbeing and academic performance	Facilitator	*"If [PEAK] were framed as a strengths based or skill building program that was linked somehow*

COM-B category	Theme/ belief statement	Sub-theme/belief statement	Barrier/facilitator/mixed	Example quote(s)
				to their academic performance that might be a good way to get some buy in." (Unit co-ordinator)
				"Student engagement [is an important program outcome]. How many students get involved, reductions in isolation or alienation. I guess, just hearing about happy students and what they got out of the program." International student engagement
		The university values programs that enhance students' sense of belonging to university	Facilitator	*"it has started to become really important for the university, in terms of a sense of belonging, for students. Not coming to campus and seeing Monash as just where I go to get to learn the curriculum for my course."* University exercise facilities
		The university values programs that attract talented students to the university	Facilitator	*"I think the ultimate KPI, the ultimate measure is, do talented students want to come to Monash? That's the ultimate. Have we got a university which genuinely cares enough about the students for us to be a university of choice?"* University exercise facilities
		The university values programs that reduce institutional financial costs	Facilitator	*"Well, the university probably looks at anything that's going to reduce costs, so clearly, if this reduces the number of students going to counselling for example…I think that could be a selling point"* Residential services and colleges

Note. Psy C, psychological capability; Phys C, physical capability; Phys O, physical opportunity; Soc O, social opportunity; Ref M, reflective motivation; Auto M, automatic motivation

Additional File 7

Behaviour Change Techniques selected for the PEAK program, their definitions, and examples (adapted from Michie S., Richardson M., Johnston M., Abraham C., Francis J., Hardeman W., Eccles M., Cane J., and Wood C. (2013). The behavior change technique taxonomy (v1) of 93 hierarchically clustered techniques: building an international consensus for the reporting of behavior change interventions. Ann Behav Med, doi: 10.1007/s12160-013-9486-6).

No.	Behaviour Change Technique	Definition	Examples
1.4	Action planning	Prompt detailed planning of performance of the behaviour (must include at least one of context, frequency, duration and intensity). Context may be environmental (physical or social) or internal (physical, emotional or cognitive) (includes 'Implementation Intentions') Note: evidence of action planning does not necessarily imply goal setting, only code latter if sufficient evidence	Encourage a plan to carry condoms when going out socially at weekends Prompt planning the performance of a particular physical activity (e.g. running) at a particular time (e.g. before work) on certain days of the week
12.5	Adding objects to the environment	Add objects to the environment in order to facilitate performance of the behaviour Note: Provision of information (e.g. written, verbal, visual) in a booklet or leaflet is insufficient. If this is accompanied by social support, also code 3.2, Social support (practical); if the environment is changed beyond the addition of objects, also code 12.1, Restructuring the physical environment	Provide free condoms to facilitate safe sex Provide attractive toothbrush to improve tooth brushing technique
8.1	Behavioural practice/rehearsal	Prompt practice or rehearsal of the performance of the behaviour one or more times in a context or at a time when the performance may not be necessary, in order to increase habit and skill Note: if aiming to associate performance with the context, also code 8.3, Habit formation	Prompt asthma patients to practice measuring their peak flow in the nurse's consulting room
9.1	Credible source	Present verbal or visual communication from a credible source in favour of or against the behaviour Note: code this BCT if source generally agreed on as credible e.g., health professionals, celebrities or words used to indicate expertise or leader in field and if the communication has the aim of persuading; if information about health consequences, also code 5.1, Information about health consequences, if about emotional consequences, also code 5.6, Information about emotional consequences; if about social, environmental or unspecified consequences also code 5.3, Information about social and environmental consequences	Present a speech given by a high status professional to emphasise the importance of not exposing patients to unnecessary radiation by ordering x-rays for back pain
6.1	Demonstration of the behaviour	Provide an observable sample of the performance of the behaviour, directly in person or indirectly e.g. via film, pictures, for the person to aspire to or imitate (includes 'Modelling'). Note: if advised to practice, also	Demonstrate to nurses how to raise the issue of excessive drinking with patients via a role-play exercise

		code, 8.1, Behavioural practice and rehearsal; If provided with instructions on how to perform, also code 4.1, Instruction on how to perform the behaviour	
2.2	Feedback on behaviour	Monitor and provide informative or evaluative feedback on performance of the behaviour (e.g. form, frequency, duration, intensity) Note: if Biofeedback, code only 2.6, Biofeedback and not 2.2, Feedback on behaviour; if feedback is on outcome(s) of behaviour, code 2.7, Feedback on outcome(s) of behaviour; if there is no clear evidence that feedback was given, code 2.1, Monitoring of behaviour by others without feedback; if feedback on behaviour is evaluative e.g. praise, also code 10.4, Social reward	Inform the person of how many steps they walked each day (as recorded on a pedometer) or how many calories they ate each day (based on a food consumption questionnaire)
2.7	Feedback on outcome(s) of behaviour	Monitor and provide feedback on the outcome of performance of the behaviour Note: if Biofeedback, code only 2.6, Biofeedback and not 2.7, Feedback on outcome(s) of behaviour; if feedback is on behaviour code 2.2, Feedback on behaviour; if there is no clear evidence that feedback was given code 2.5, Monitoring outcome(s) of behaviour by others without feedback; if feedback on behaviour is evaluative e.g. praise, also code 10.4, Social reward	Inform the person of how much weight they have lost following the implementation of a new exercise regime
13.2	Framing/reframing	Suggest the deliberate adoption of a perspective or new perspective on behaviour (e.g. its purpose) in order to change cognitions or emotions about performing the behaviour (includes 'Cognitive structuring'); If information about consequences then code 5.1, Information about health consequences, 5.6, Information about emotional consequences or 5.3, Information about social and environmental consequences instead of 13.2, Framing/reframing	Suggest that the person might think of the tasks as reducing sedentary behaviour (rather than increasing activity)
1.1	Goal setting (behaviour)	Set or agree on a goal defined in terms of the behaviour to be achieved Note: only code goal-setting if there is sufficient evidence that goal set as part of intervention; if goal unspecified or a behavioral outcome, code 1.3, Goal setting (outcome); if the goal defines a specific context, frequency, duration or intensity for the behaviour, also code 1.4, Action planning	Agree on a daily walking goal (e.g. 3 miles) with the person and reach agreement about the goal Set the goal of eating 5 pieces of fruit per day as specified in public health guidelines
5.6	Information about emotional consequences	Provide information (e.g. written, verbal, visual) about emotional consequences of performing the behaviour Note: consequences can be related to emotional health disorders (e.g. depression, anxiety) and/or states of mind (e.g. low mood, stress); not including 5.5, Anticipated regret; consequences can be for any target, not just the recipient(s) of the intervention; if information about health consequences code 5.1, Information about health consequences; if about social, environmental or unspecified code 5.3,	Explain that quitting smoking increases happiness and life satisfaction

		Information about social and environmental consequences	
5.1	Information about health consequences	Provide information (e.g. written, verbal, visual) about health consequences of performing the behaviour Note: consequences can be for any target, not just the recipient(s) of the intervention; emphasising importance of consequences is not sufficient; if information about emotional consequences, code 5.6, Information about emotional consequences; if about social, environmental or unspecified consequences code 5.3, Information about social and environmental consequences	Explain that not finishing a course of antibiotics can increase susceptibility to future infection Present the likelihood of contracting a sexually transmitted infection following unprotected sexual behaviour
4.1	Instruction on how to perform a behaviour	Advise or agree on how to perform the behaviour (includes 'Skills training') Note: when the person attends classes such as exercise or cookery, code 4.1, Instruction on how to perform the behaviour, 8.1, Behavioral practice/rehearsal and 6.1, Demonstration of the behaviour	Advise the person how to put a condom on a model of a penis correctly
10.1	Material incentive (behaviour)	Inform that money, vouchers or other valued objects will be delivered if and only if there has been effort and/or progress in performing the behaviour (includes 'Positive reinforcement') Note: if incentive is social, code 10.5, Social incentive if unspecified code 10.6, Non-specific incentive, and not 10.1, Material incentive (behaviour); if incentive is for outcome, code 10.8, Incentive (outcome). If reward is delivered also code one of: 10.2, Material reward (behaviour); 10.3, Non-specific reward; 10.4, Social reward, 10.9, Self-reward; 10.10, Reward (outcome)	Inform that a financial payment will be made each month in pregnancy that the woman has not smoked
10.2	Material reward (behaviour)	Arrange for the delivery of money, vouchers or other valued objects if and only if there has been effort and/or progress in performing the behaviour (includes 'Positive reinforcement') Note: If reward is social, code 10.4, Social reward, if unspecified code 10.3, Nonspecific reward, and not 10.1, Material reward (behaviour); if reward is for outcome, code 10.10, Reward (outcome). If informed of reward in advance of rewarded behaviour, also code one of: 10.1, Material incentive (behaviour); 10.5, Social incentive; 10.6, Non-specific incentive; 10.7, Self-incentive; 10.8, Incentive (outcome)	Arrange for the person to receive money that would have been spent on cigarettes if and only if the smoker has not smoked for one month
5.4	Monitoring of emotional consequences	Prompt assessment of feelings after attempts at performing the behaviour	Agree that the person will record how they feel after taking their daily walk
10.6	Non-specific incentive (behaviour)	Inform that a reward will be delivered if and only if there has been effort and/or progress in performing the behaviour (includes 'Positive reinforcement') Note: if incentive is material, code 10.1, Material incentive (behaviour), if social, code 10.5, Social incentive and not 10.6, Non-specific incentive; if incentive is for outcome code 10.8, Incentive (outcome). If reward is delivered also code one of: 10.2,	Identify an activity that the person values and inform them that this will happen if and only if they attend for health screening

		Material reward (behaviour); 10.3, Non-specific reward; 10.4, Social reward, 10.9, Self-reward; 10.10, Reward (outcome)	
10.3	Non-specific reward (behaviour)	Arrange delivery of a reward if and only if there has been effort and/or progress in performing the behaviour (includes 'Positive reinforcement') Note: if reward is material, code 10.2, Material reward (behaviour), if social, code 10.4, Social reward, and not 10.3, Non-specific reward; if reward is for outcome code 10.10, Reward (outcome). If informed of reward in advance of rewarded behaviour, also code one of: 10.1, Material incentive (behaviour); 10.5, Social incentive; 10.6, Non-specific incentive; 10.7, Self-incentive; 10.8, Incentive (outcome)	Identify something (e.g. an activity such as a visit to the cinema) that the person values and arrange for this to be delivered if and only if they attend for health screening
7.1	Prompts/cues	Introduce or define environmental or social stimulus with the purpose of prompting or cueing the behaviour. The prompt or cue would normally occur at the time or place of performance Note: when a stimulus is linked to a specific action in an if-then plan including one or more of frequency, duration or intensity also code 1.4, Action planning	Put a sticker on the bathroom mirror to remind people to brush their teeth
12.1	Restructuring the physical environment	Change, or advise to change the physical environment in order to facilitate performance of the wanted behaviour or create barriers to the unwanted behaviour (other than prompts/cues, rewards and punishments) Note: this may also involve 12.3, Avoidance/reducing exposure to cues for the behaviour; if restructuring of the social environment code 12.2, Restructuring the social environment; if only adding objects to the environment, code 12.5, Adding objects to the environment	Advise to keep biscuits and snacks in a cupboard that is inconvenient to get to Arrange to move vending machine out of the school
12.2	Restructuring the social environment	Change, or advise to change the social environment in order to facilitate performance of the wanted behaviour or create barriers to the unwanted behaviour (other than prompts/cues, rewards and punishments) Note: this may also involve 12.3, Avoidance/reducing exposure to cues for the behaviour; if also restructuring of the physical environment also code 12.1, Restructuring the physical environment	Advise to minimise time spent with friends who drink heavily to reduce alcohol consumption
2.3	Self-monitoring of behaviour	Establish a method for the person to monitor and record their behaviour(s) as part of a behaviour change strategy Note: if monitoring is part of a data collection procedure rather than a strategy aimed at changing behaviour, do not code; if monitoring of outcome of behaviour, code 2.4, Self-monitoring of outcome(s) of behaviour; if monitoring is by someone else (without feedback), code 2.1, Monitoring of behaviour by others without feedback	Ask the person to record daily, in a diary, whether they have brushed their teeth for at least two minutes before going to bed Give patient a pedometer and a form for recording daily total number of steps
2.4	Self-monitoring of outcome(s) of behaviour	Establish a method for the person to monitor and record the outcome(s) of their behaviour as part of a behaviour change strategy Note: if monitoring is part of a data collection procedure rather than a strategy aimed at	Ask the person to weigh themselves at the end of each day, over a two week period, and record their daily weight on a

		changing behaviour, do not code ; if monitoring behaviour, code 2.3, Self-monitoring of behaviour; if monitoring is by someone else (without feedback), code 2.5, Monitoring outcome(s) of behaviour by others without feedback	graph to increase exercise behaviours
15.4	Self-talk	Prompt positive self-talk (aloud or silently) before and during the behaviour	Prompt the person to tell themselves that a walk will be energising
3.1	Social support (unspecified)	Advise on, arrange or provide social support (e.g. from friends, relatives, colleagues,' buddies' or staff) or non-contingent praise or reward for performance of the behaviour. It includes encouragement and counselling, but only when it is directed at the behaviour Note: attending a group class and/or mention of 'follow-up' does not necessarily apply this BCT, support must be explicitly mentioned; if practical, code 3.2, Social support (practical); if emotional, code 3.3, Social support (emotional) (includes 'Motivational interviewing' and 'Cognitive Behavioural Therapy')	Advise the person to call a 'buddy' when they experience an urge to smoke Arrange for a housemate to encourage continuation with the behaviour change programme Give information about a self-help group that offers support for the behaviour
13.4	Valued self-identity	Advise the person to write or complete rating scales about a cherished value or personal strength as a means of affirming the person's identity as part of a behaviour change strategy (includes 'Self-affirmation'	Advise the person to write about their personal strengths before they receive a message advocating the behaviour change
15.1	Verbal persuasion about capability	Tell the person that they can successfully perform the wanted behaviour, arguing against self-doubts and asserting that they can and will succeed	Tell the person that they can successfully increase their physical activity, despite their recent heart attack

Additional File 8

Educational and Motivational Video Topics and Links

Week	Video title and link
Baseline	Welcome to PEAK
1	Expert tips for CREATING an exercise routine
2	Too many assignments to exercise? Exercising your way to PEAK marks
3	Overcoming self-consciousness
4	But, what if I don't have time to exercise?!
5	Too stressed to exercise? Exercising your way to PEAK mood
6	Strong Lungs, Strong Brain: the beauty of breathlessness
7	Strong Body, Strong Brain: the beauty of strength training
8	Connecting with your WHY
9	Expert tips for SUSTAINING an exercise routine
10	Consistency trumps perfection, habits are the gold
11	But, what if I don't feel like exercising?!
12	SWOTVAC is coming….Keep moving!

Appendix C: Additional Files for Chapter Six: Study Three

Additional File 1: The CONSORT Flow Diagram

Additional File 2: The TIDieR (Template for Intervention Description and Replication) Checklist

Additional File 3: Exercise Options

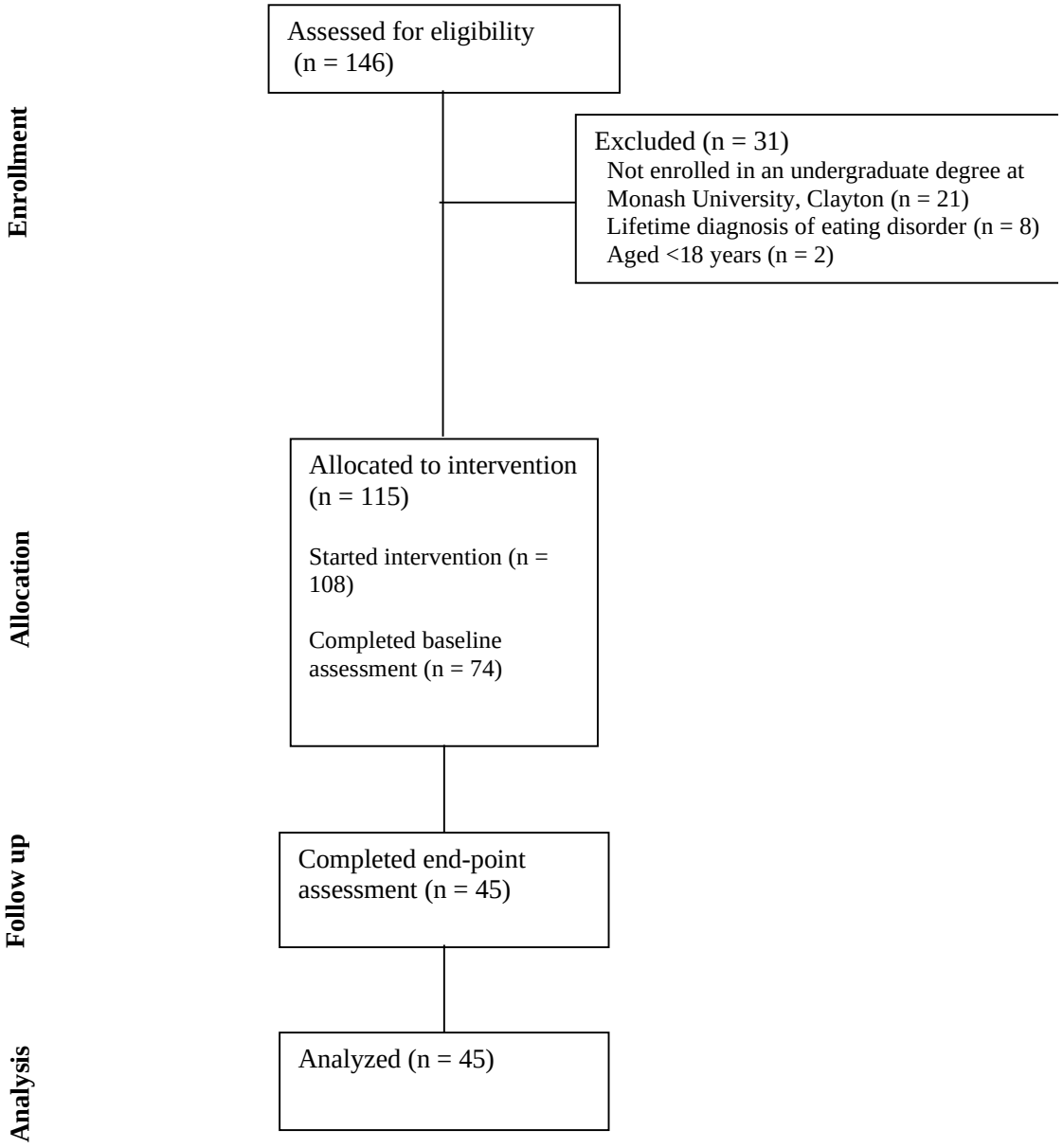
Additional File 4: PEAK Implementation Evaluation Interview Schedule

Additional File 5: Mental and Cognitive Health Outcomes Stratified by Exercise History

Additional File 6: Suggested Improvements for PEAK

Additional File 1

CONSORT flow diagram of the PEAK pilot study



Additional File 2

Table 1

The TIDieR (Template for Intervention Description and Replication) Checklist*:

Information to include when describing an intervention and the location of the information

Item number	Item	Where located **	
		Primary paper (page or appendix number)	Other † (details)
	BRIEF NAME		
1.	Provide the name or a phrase that describes the intervention.	Pg. 7	_____
	WHY		
2.	Describe any rationale, theory, or goal of the elements essential to the intervention.	Pg. 7-9, Table 1	Brown et al., (in review)
	WHAT		
3.	Materials: Describe any physical or informational materials used in the intervention, including those provided to participants or used in intervention delivery or in training of intervention providers. Provide information on where the materials can be accessed (e.g. online appendix, URL).	Pg. 8-9, Table 1	Brown et al., (in review)
4.	Procedures: Describe each of the procedures, activities, and/or processes used in the intervention, including any enabling or support activities.	Pg. 9, Table 1	Brown et al., (in review)
	WHO PROVIDED		

5.	For each category of intervention provider (e.g. psychologist, nursing assistant), describe their expertise, background and any specific training given.	Pg. 9, Table 1	Brown et al., (in review)
	HOW		
6.	Describe the modes of delivery (e.g. face-to-face or by some other mechanism, such as internet or telephone) of the intervention and whether it was provided individually or in a group.	Pg. 9, Table 1	Brown et al., (in review)
	WHERE		
7.	Describe the type(s) of location(s) where the intervention occurred, including any necessary infrastructure or relevant features.	Pg. 9	Brown et al., (in review)
	WHEN and HOW MUCH		
8.	Describe the number of times the intervention was delivered and over what period of time including the number of sessions, their schedule, and their duration, intensity or dose.	Pg. 8-9, Table 1	Brown et al., (in review)
	TAILORING		
9.	If the intervention was planned to be personalised, titrated or adapted, then describe what, why, when, and how.	N/A	N/A
	MODIFICATIONS		
10.‡	If the intervention was modified during the course of the study, describe the changes (what, why, when, and how).	N/A	N/A
	HOW WELL		
11.	Planned: If intervention adherence or fidelity was assessed, describe how and by whom, and if any strategies were used to maintain or improve fidelity, describe them.	Pg. 12	_____
12.‡	Actual: If intervention adherence or fidelity was assessed, describe the extent to which the intervention was delivered as planned.	Pg. 21-26, Table 4 & 5	_____

** **Authors** - use N/A if an item is not applicable for the intervention being described. **Reviewers** – use '?' if information about the element is not reported/not sufficiently reported.

† If the information is not provided in the primary paper, give details of where this information is available. This may include locations such as a published protocol or other published papers (provide citation details) or a website (provide the URL).

ǂ If completing the TIDieR checklist for a protocol, these items are not relevant to the protocol and cannot be described until the study is complete.

* We strongly recommend using this checklist in conjunction with the TIDieR guide (see *BMJ* 2014;348:g1687) which contains an explanation and elaboration for each item.

* The focus of TIDieR is on reporting details of the intervention elements (and where relevant, comparison elements) of a study. Other elements and methodological features of studies are covered by other reporting statements and checklists and have not been duplicated as part of the TIDieR checklist. When a **randomised trial** is being reported, the TIDieR checklist should be used in conjunction with the CONSORT statement (see www.consort-statement.org) as an extension of **Item 5 of the CONSORT 2010 Statement.** When a **clinical trial protocol** is being reported, the TIDieR checklist should be used in conjunction with the SPIRIT statement as an extension of **Item 11 of the SPIRIT 2013 Statement** (see www.spirit-statement.org). For alternate study designs, TIDieR can be used in conjunction with the appropriate checklist for that study design (see www.equator-network.org).

Additional File 3

Table 2

Menu of Exercise Options Offered in PEAK

Mode of delivery	Option	Type	
		Aerobic exercise	Resistance exercise
On-campus	Small group fitness classes	X	X
	Exercise equipment	X	X
	Run club	X	
Digital apps	Nike Run Club	X	
	Nike Training Club	X	X
Digital videos	Fitness blender workouts	X	X
	Team body project workouts	X	X
	YouTube workouts	X	X

Additional File 4

PEAK Implementation Evaluation Interview Schedule

Factors Influencing Engagement and Intervention Acceptability and Appropriateness

"Kick Off" session PEAK program onboarding & exercise starter pack

1. How did you feel about the PEAK Kick Off welcome session?

- Did you attend a PEAK Kick Off welcome session?
  - Why / why not?

Probe for:

i. knowledge + skills;
ii. accessibility + social influences;
iii. attitude + beliefs; habits + emotions

2. How did you feel about the exercise starter pack?

- Did you use the exercise starter pack?
  - Why / why not?

Probe for:

iv. knowledge + skills;
v. accessibility + social influences;
vi. attitude + beliefs; habits + emotions

Moodle delivery platform + content

3. How did you feel about Moodle being the main delivery platform for PEAK?

- Did you engage in the Moodle content?
  - Why / why not?

Probe for:

vii. knowledge + skills;
viii. accessibility + social influences;
ix. attitude + beliefs; habits + emotions

4. How did you feel about the weekly "Learn a Bit" educational videos?

- Did you watch the videos?
  - Why / why not?

Probe for:

x. knowledge + skills;
xi. accessibility + social influences;
xii. attitude + beliefs; habits + emotions

5. How did you feel about the ''Move Some More" exercise options?

- Did you use the weekly “Move Some more” exercises?
    - Why/ why not?

- Did you use any of the free on-campus gym passes?
    - Why / why not?

Probe for:

xiii. knowledge + skills;
xiv. accessibility + social influences;
xv. attitude + beliefs; habits + emotions

WhatsApp group/PEAK Pack exercise groups

6. How did you feel about the PEAK WhatsApp chat?

- Did you read the WhatsApp chat (i.e., look at the chat)?
- Did you post on the WhatsApp chat? (i.e., emoji react to posts or post content)?
    - Why / why not?

Probe for:

xvi. knowledge + skills;
xvii. accessibility + social influences;
xviii. attitude + beliefs; habits + emotions

7. How did you feel about the PEAK Packs?

- Did you sign up for a PEAK Pack?
    a) Why / why not?
- **[If relevant]** How did the PEAK Pack work out for you?

Probe for:

xix. knowledge + skills;
xx. accessibility + social influences;
xxi. attitude + beliefs; habits + emotions

Tracking: exercise tracker + wellbeing tracker

8. How did you feel about the survey trackers (i.e. your exercise tracker survey and wellbeing tracker survey)?

- Did you do any of the trackers?
    - How many?
    - Why / why not?
- Did you do exercise that wasn’t captured in the tracker survey?

- Did receiving a text to track your exercise each week impact how active you were?
    - Why / why not?
- Did knowing you would receive a report of your tracking data at the end of PEAK influence you doing the trackers (or not)?
    - Why / why not?
- How did you feel about the outcome report?

Probe for:

xxii. knowledge + skills;
xxiii. accessibility + social influences;
xxiv. attitude + beliefs; habits + emotions

"PEAK Points" rewards (coffees + personalised exercise sessions with exercise physiologist)

9. How did you feel about the PEAK Points?

- Did you cash in your points for coffee vouchers or personalised exercise sessions?
    - Why / why not?

Probe for:

xxv. knowledge + skills;
xxvi. accessibility + social influences;
xxvii. attitude + beliefs; habits + emotions

<u>Mechanisms of Behaviour Change</u>

11. Do you think you think you got any benefits out of PEAK? (Reflective Motivation)

- What kind?

12. Did you learn anything from PEAK that you didn't know at the start? (Psychological Capability)

13. Did you feel physically able to do the exercise activities? (Physical Capability)

14. Did PEAK impact your motivation to exercise? (Reflective Motivation)

15. Did PEAK impact your enjoyment of exercise? (Automatic Motivation)

16. Did PEAK impact your desire to exercise with others? (Social Opportunity)

17. Did PEAK impact your ability to fit exercise into your daily routine? (Physical Opportunity)

Additional File 5

Table 3

Mental and Cognitive Health Outcomes Stratified by Baseline Exercise History

Outcome	Time-point	Mean (Standard Deviation)		
		Non-exerciser	Sometimes-exerciser	Regular-exerciser
Wellbeing	Baseline	21.55(4.39)	22.11(3.57)	25.57(3.57)
	Week 3	23.20(4.78)	23.80(3.35)	23.33(3.35)
	Week 6	21.13(5.96)	24.29(4.52)	25.83(4.52)
	Week 9	24.50(4.69)	25.56(4.13)	25.25(4.13)
	End-point	22.64(5.09)	24.15(4.61)	24.86(4.61)
Stress	Baseline	8.00(2.41)	6.96(2.12)	5.57(2.12)
	Week 3	6.50(2.72)	6.76(2.13)	5.50(2.13)
	Week 6	9.00(3.46)	5.62(2.96)	6.00(2.96)
	Week 9	7.00(3.51)	5.39(2.80)	5.75(2.79)
	End-point	6.73(2.15)	5.96(3.12)	5.86(3.12)
Loneliness	Baseline	3.82(2.44)	4.85(2.89)	3.86(2.89)
	Week 3	2.60(1.78)	3.32(2.23)	4.67(2.23)
	Week 6	2.13(2.17)	3.29(2.35)	3.33(2.35)
	Week 9	2.38(2.20)	3.94(2.45)	4.75(2.44)
	End-point	3.36(2.46)	3.19(2.34)	3.14(2.34)
Concentration	Baseline	35.00(20.61)	46.70(21.26)	58.71(21.26)
	Week 3	48.50(21.60)	53.08(19.29)	53.00(19.29)
	Week 6	49.13(23.96)	54.29(21.12)	61.00(21.12)
	Week 9	48.88(21.88)	59.00(19.73)	49.00(19.73)
	End-point	56.45(21.30)	60.04(20.40)	59.43(20.40)
Memory	Baseline	42.64(24.82)	48.00(21.30)	66.14(21.30)
	Week 3	51.70(22.44)	57.00(18.76)	60.00(18.76)
	Week 6	53.88(20.99)	58.86(20.21)	64.83(20.21)
	Week 9	55.63(16.22)	65.39(15.87)	42.00(15.87)
	End-point	53.91(24.01)	61.67(18.98)	65.57(18.98)
Productivity	Baseline	30.64(22.34)	45.15(20.94)	58.86(20.94)
	Week 3	53.20(21.80)	52.60(19.21)	57.17(19.21)
	Week 6	49.63(25.40)	54.62(22.63)	62.67(22.63)
	Week 9	57.13(19.57)	59.22(20.61)	39.25(20.61)
	End-point	56.18(24.43)	59.15(23.50)	56.57(23.50)
Belonging to the university	Baseline	41.55(23.58)	53.81(21.71)	69.00(21.71)
	Week 3	66.00(25.35)	60.76(25.43)	68.67(25.43)

Week 6	65.13(18.92)	64.14(23.20)	76.33(23.20)
Week 9	64.25(19.01)	61.28(23.63)	59.00(23.63)
End-point	62.27(27.46)	64.00(25.43)	63.00(25.43)

Additional File 6

Table 4

Suggested Improvements for PEAK

PEAK Program Component	Suggested Improvement/s
Overall program	Provide more opportunities for students to connect with each other in person
	Offer a range of culturally inclusive program content
	Offer personalised program content
Menu of exercise options	Offer digital exercise options developed in a variety of cultural contexts and in multiple languages
Educational and motivational videos	Streamline accessibility of the videos
PEAK Points reward system	Improve the salience, relevance and accessibility of the rewards offered
WhatsApp social support group	Reduce volume of communications on WhatsApp
PEAK Pack exercise groups	Improve group cohesion and responsiveness by appointing a group leader for each PEAK Pack
Exercise and wellbeing trackers	Incorporate passive physical activity tracking, reduce length of wellbeing tracker and improve clarity of wellbeing questions
Program outcome reports	Increase awareness of program outcome reports
Moodle digital delivery platform	Use a single, unified digital tool to deliver the digital components of the intervention