UNIVERSITA' DEGLI STUDI DI VERONA

DEPARTMENT OF

Human Sciences

GRADUATE SCHOOL OF

University of Verona

DOCTORAL PROGRAM IN

Human Sciences - Psychology Curriculum

Cycle / year (1° year of attendance) XXXV / 2019 - 2020

TITLE OF THE DOCTORAL THESIS

Investigating different approaches and analyses of psychological variables to enhance sport and exercise.

IN *CO-TUTELLE DE THÉSE* WITH THE UNIVERSITY OF COPENHAGEN

S.S.D. M-PSI/03

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Investigating different approaches and analyses of psychological variables to enhance sport and exercise

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PhD thesis - University of Verona
Verona, Italy, March 6 2023
ISBN xxx-xx-xxxxx-xx-x

Tesi di Dottorato - Università di Verona
Verona, Italia, 6 Marzo 2023
ISBN xxx-xx-xxxxx-xx-x

Summary

Questa tesi descrive l'acquisizione di diverse nozioni attraverso un percorso logico e progressivo sviluppato nel corso del mio Dottorato. Cinque attività di ricerca sono presentate e accomunate da un focus centrale legato al tema della psicologia dello sport. L'obiettivo finale di questo percorso è stato quello di studiare l'utilizzo della tecnologia digitale, ed in particolare dei wearables (dispositivi indossabili per la misurazione di diversi parametri), per valutare quantitativamente interventi mirati ad incrementare l'attività fisica misurando anche altri parametri, quali lo stress. Il percorso è iniziato con una revisione sistematica della letteratura e meta-analisi delle correlazioni tra variabili psicologiche (quali autoregolazione, autoefficacia, e ansia) e parametri di attività fisica, entrambi misurati tramite questionari validati. Successivamente, l'interesse nell'esplorare variabili psicometriche e la loro validazione nell'ambito dello sport ha portato all'analisi della motivazione sportiva in una coorte di giocatori di rugby italiani. Nel 2020, con l'inizio della pandemia da COVID-19, vi sono state profonde trasformazioni nel modo di svolgere lo sport, sia perchè le attività (agonistiche e non) si sono improvvisamente fermate, sia perchè il modo di misurare i paramentri fisici è cambiato. Queste modifiche sono state evidenzite nel report "Physical activity: Benefits and challenges during the COVID-19 pandemic". In questo nuovo scenario diverse istituzioni pubbliche, strutture accademiche e agenzie private hanno iniziato ad utilizzare tecnologie digitali per promuovere messaggi volti a migliorare il benessere della popolazione e limitare la sedentarietà, soprattutto durante il lock down. Uno degli studi riportati, che include impiegati aziendali, ha dimostrato che interventi che promuovono delle pause "attive" (active breaks) al lavoro, fornite in formato elettronico, possono migliorare il benessere dei dipendenti e ridurne lo stress. L'ultimo studio presentato rappresenta il punto di rientro alle normali attività quotidiane, con un'enfasi particolare posta sul monitoraggio delle propria attività fisica e benessere attaverso l'uso dei wearables, promosso anche dalla stessa pandemia. I risultati hanno raggiunto l'obiettivo di incrementare l'attività fisica e ridurre lo stress, misurato tramite i wearables, grazie alla recezione di specifici messaggi inviati via App. Inoltre, il confronto tra lo stress misurato digitalmente e tramite un questionario validato (e.g., Perceived Stress Scale-10) hanno mostrato una correlazione promettente. Il mio obiettivo è quello di proseguire in questa direzione, per studiare ulteriormente i benefici ed i limiti dell'utilizzo della tecnologia digitale nella psicologia dello sport.

Un riassunto delle attività svolte ed il loro svolgimento nei diversi contesti e nel tempo è riportato nell'introduzione in forma di graphical abstract.

Abstract

This thesis addresses the acquisition of knowledge through a logical step by step process during the PhD course, highlighting five research activities with a main focus on sport and exercise psychology. The ultimate goal for research looked at exploring wearable devices and associated digital technology to deliver interventions aimed to increase exercise while measuring psychological variables such as stress. A foundation was initially set with a systematic review and meta-analysis on correlations between physical activity and key variables such as self-efficacy, self-regulation, and anxiety measured using validated questionnaires. A continued interest in exploring psychometric tools and their validation in sport drove the analysis of a motivation scales and related parameters in a cohort of Italian rugby players. With the beginning of the COVID-19 pandemic, however, community-based sports activities stopped, and the way in which exercise was performed and measured rapidly changed, as I highlighted in the report "Physical activity: Benefits and challenges during the COVID-19 pandemic". In this unexpected scenario, government agencies as well as private entities and academic institutions applied digital technology to deliver health and wellbeing messages. The use of novel tools was beneficial while facing increased sedentarism occurring during restrictions and lock-down periods. The study performed, involving office workers and electronically delivering exercise interventions in the form of active breaks, showed improvement in wellbeing and stress reduction. Finally, the last study presented can be viewed as a marker in time, as people return to normality, exercising and performing their normal routine but with a new emphasis in keeping track of their own health and wellbeing through wearable technology, following the change in measuring physical and psychological variables consolidated during the pandemic. The results met the intended goal to successfully provide a message-based, digitally delivered intervention aimed at increasing exercise and reducing stress among university students, using wearables to measure the outcome. Moreover, the comparison of wearable-associated stress (based on physiological stimuli) with self-reported stress using a validated questionnaire (e.g., Perceived Stress Scale-10) showed a promising connection. I intend to continue in this direction to further explore benefits and limitations of digital technology in sport and exercise psychology.

A graphical abstract of the five research activities and related context is reported in the introduction.

Acknowledgments

I would like to thank my supervisors Margherita Pasini, Stefano De Dominicis, and Glen Nielsen for their outstanding contribution and support during my research activities. I highlight the philosophy expressed to me in my first meeting at Copenhagen University (KU) "*When you are helping others outside yourself then you are making a difference, and this should be expressed through your work*".

A thank you to the administration and governance from both KU and the University of Verona (UNIVR) that have played a key part in the realization of the PhD course and in particular Helle Rudolph Jensen and Catia Cordioli. I would like to thank Manuela Lavelli for her initial governance of the PhD course in Verona and Chiara Sita' for continuation of that coordination within the PhD program in Human Sciences. Equally I would like to thank Marinella Majorano, Elena Trifiletti, Margherita Brondino and Lorenzo Bernini for their work in ensuring yearly progress reports and standards were met, advice on future progress, and interdisciplinary workability. The development and realization of research projects has ultimately defined my progress throughout the PhD course. I would like to thank Massimo Mirandola (Department of Diagnostics and Public Health, UNIVR) and Arnaldo Zelli, Luca Mallia, and Daniela Caporossi (Foro Italico University, Rome, Italy). Equally I would like to thank the Pleaz group in Copenhagen, in particular Matias Welsen Thomasen, Simon Spenter Ifversen, and Ida Vendalo Jorgensen and Valentina Carfora at the Catholic University of Sacred Heart in Milan.

Ultimately, the PhD course is a continuation of academia. I would like to thank my mentors Steven Arthur Baker and Gary Patrick Lennon.

Finally, I would like to thank my family, near and far away, for their support during this PhD journey.

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1. Introduction

This dissertation describes the story of my work at Copenhagen University (KU) and at the University of Verona (UNIVR), showing my learning growth curve and development within the field of academia at a PhD level. Ultimately, I am looking for answers whilst pushing the boundaries within a scientific perspective.

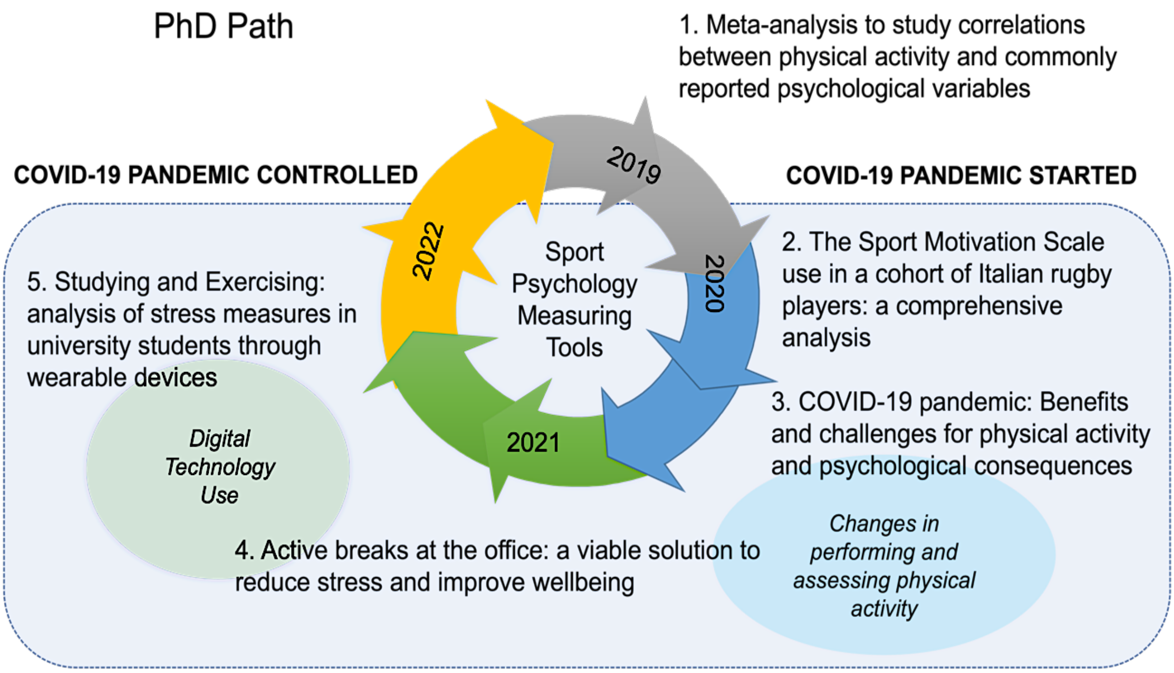
The learning curve is part of a continuum that took me from exploring psychological variables such as self-efficacy, self-regulation, and anxiety to investigating self-determination theory and motivation in a group of amateur rugby players. Furthermore, I gained an understanding of novel applications of digital technology to enhance and measure physical activity in populations at risk for sedentary behaviours such as office workers and university students. The COVID-19 pandemic, that occurred at the beginning of my PhD path, clearly highlighted the need for novel forms of assessing and performing physical activity (Dwyer et al., 2020) and affected, both positively and negatively, my doctorate activities and progression. A summary of the lost and gained opportunities related to the COVID-19 pandemic during my PhD project is reported in Table 1.

Table 1.

Lost and gained opportunities related to the COVID-19 pandemic during the PhD

Lost Opportunities	Gained opportunities
Reduced interactions to develop the study psychometric analysis Face to face social interaction	Increase in digital technology use and remote monitoring for data analysis and communication
Ability to exercise outdoors and in social contexts because of lockdown measurements, increased stress and decreased well being	Initiative and opportunity to look at available resources during times of restrictive measures
Study population: lack of organized sports teams because of COVID-19 restrictions	Initiative, flexibility, collaboration with startups, and opportunity for research while diversifying study populations
Difficulty to collect data due to data collection and access limitations; Limited universities attendances and travel restrictions	Time for reflection on personal learning curve

The path and developments that I have completed during the PhD academic years, from October 2019 until December 2022 are summarised in the graphical abstract below.



Five activities, that are also reported in detail in the dissertation in terms of scope, methods, and results, are reported in the diagram.

During these PhD years I have developed my activities focusing on the wider topic underlying the research work on how psychological variables are measured and linked to physical activity in the wider field of sport and exercise. I specifically followed two different approaches related to the acquisition of knowledge in a more "traditional" way of measuring psychological variables (e.g., correlations between variables and psychometric analyses), for example through validated questionnaires and "self-reported" measures, and a more "modern", objective way of acquiring information through computerised systems and wearable devices.

I planned to perform one or more experimental studies involving participants performing exercise, however this expectation was partially limited by the COVID-19 pandemic. Specifically, my work on the study of psychological variables in rugby players - that I started while working as a sports coach and continued during my studies while at Foro Italico University (Rome, Italy) - could not be continued during 2020-2021 as the rugby championship was suspended for safety reasons. Nevertheless, I was still able to recruit 141 subjects from the beginning of the study until 2020. The results of the study are presented in this dissertation and has been submitted for publication to a peer-reviewed journal.

Thanks to the collaboration with my supervisors, particularly with Prof. Stefano De Dominicis at KU, I was involved in another experimental study, the "Active Breaks Study", in which a Digital Behaviour Change Intervention (DBCIs) was introduced among office workers in the light of an increase in stress levels that they may experience during the COVID-19 pandemic. Engaging in active breaks was correlated to positive outcomes such as reduced stress and improved wellbeing.

The COVID-19 pandemic has had a big impact not only in limiting mobility or subject recruitment during my PhD, but also in reshaping research priorities and in identifying alarming new issues that may lie beside detrimental health consequences, such as increased sedentary behaviours, smart working, reduced sport performance in a social context, etc. Digital technology use has exponentially increased during the pandemic. Awareness pertaining to the use of wearable devices (such as trackers, watches, body mounted sensors, smart clothing, etc.) in sports activities increases people's autonomy in taking care of their active lives and related health.

In October 2021 I was involved in my third PhD experimental study entitled "Studying and Exercising" originated from a collaboration involving KU, UNIVR, and the Catholic University of Milan. In this study, the promotion of physical activity was conveyed through a psychosocial intervention using targeted, "vested" persuasive messages via a phone App (PsyMe) and measuring physical parameters and stress through wearable devices in healthy subjects (university students).

I have also started a collaboration with the Infectious Diseases Unit in Verona during 2020, at the beginning of the COVID-19 pandemic when I wrote the brief report "Physical activity: Benefits and challenges during the COVID-19 pandemic" highlighting the difficulties to guide home-based physical activity without guidelines or monitoring. This short communication, published on the 7th of July 2020 on the Scandinavian Journal of Medicine and Science in Sports (https://doi.org/10.1111/sms.13710), was highly cited (120 times, source Scopus November 2022). This confirmed the high interest that the scientific community has in optimizing the way in which physical activity and psychological variables are recorded and monitored during COVID-19, not only in athletes but also for laypeople or populations with comorbidities who wish, or should, exercise.

Among the non-experimental studies, I have carried out one systematic review and meta-analysis entitled "Correlations between physical activity and commonly reported psychological variables: a meta-analysis" submitted for publication to a peer-reviewed journal. In this review, I investigated the connection between psychological variables and physical activity to identify and implement psychological drivers for the promotion of healthier lifestyles. Thirty-three studies encompassing 19,650 subjects were included in the review and reported Pearson's correlation coefficient. Self-efficacy, social support, anxiety, self-regulation, enjoyment, and outcome expectations were the most commonly studied variables, and only anxiety showed a negative correlation with physical activity. Physical activity had positive correlations with several psychological drivers, particularly self-influence, that represent a key target when promoting interventions in the field of exercise psychology.

The main characteristics and stage of the research projects I carried out during the PhD period are summarised in Table 2.

Table 2.

Main PhD activities and related outcomes

Activity title	Study type	Approach	Outcome	Timeline
1. Correlations between physical activity and commonly reported psychological variables: a meta-analysis	Systematic review and meta-analysis	Own study, reviewed by current supervisor at UNIVR (Prof. M. Pasini)	Publication (submitted to peer-reviewed Journal; first and corresponding author)	Completed
2. The Sport Motivation Scale use in a cohort of Italian rugby players: a comprehensive analysis	Experimental (recruitment of rugby players from 2018 to 2020)	Own study, reviewed by previous and current supervisors	Publication (submitted to peer-reviewed Journal; first and corresponding author)	Completed
3. COVID-19 pandemic: Benefits and challenges for physical activity and psychological consequences	Brief report	Own work, reviewed by current supervisors at KU (Prof. S. De Dominicis) and UNIVR (Prof. M. Pasini)	Published (first author - highly cited article in the Scandinavian Journal of Medicine & Science in Sports)	Completed
4. The use of active breaks for office workers to reduce stress and improve wellbeing	Experimental (office workers from different companies included)	Supervised work at KU (Prof. S. De Dominicis)	Publication (submitted to peer reviewed Journal; coauthor)	Completed
5. “Studying and exercising”: use of wearables in university students	Supervised sub-analysis of a wider study performed in collaboration with UNIVR, the Catholic University in Milan and KU	Independently performed substudy analysis of a supervised project at KU (Prof. S. De Dominicis) and UNIVR (Prof. M. Pasini)	Report, publication will be considered	Data analysis completed

2. Correlations between physical activity and commonly reported psychological variables: a meta-analysis

A summary of the scope, methodology and results of the study are reported in the box below.

Scope. Due to the growing interest in measuring the connection between psychological variables and physical activity (PA) to identify and implement psychological drivers for the promotion of healthier lifestyles, a systematic review and meta-analysis including papers reporting correlations between psychological variables and PA.
Methods. PsycINFO, PsycArticles, SPORTDiscus, Medline, and GoogleScholar were searched between 2005 and 2022. The full study protocol has been published on to the International Prospective Register of Systematic Reviews (PROSPERO, https://www.crd.york.ac.uk/prospero, submission ID# 175424).
Results. Thirty-three studies encompassing 19,650 subjects were included. The percentage of female participants varied from 42% to 100%, and 10 (30%) of studies involved people > 50 years of age. Overall, 44 different questionnaires were retrieved assessing 17 different variables. Twenty studies (60%) assessed self-efficacy, 6 (18%) assessed social support, anxiety, self-regulation, enjoyment, and 4 (12%) outcome expectations. Most studies (85%) were considered of high quality. Random effect meta-analysis showed pooled correlations of -0.16 (95% CI -0.23 - -0.08) for anxiety, 0.19 (95% CI 0.15 - 0.22) for social support, 0.28 (95% CI 0.17 - 0.39) for outcome expectations, 0.31 (95% CI 0.24 - 0.37) for enjoyment and stronger correlations for self-efficacy (0.35, 95% CI 0.31 - 0.40) and self-regulation (0.36, 95% CI 0.22 – 0.48). Gender was a source of heterogeneity by meta-regression for self-regulation and social support (p=0.001).
Conclusions. PA showed correlations with several psychological drivers, particularly self-influence, that represent a key target when promoting interventions in the field of exercise psychology

This work has been submitted for publication and is currently under review. I am first author and corresponding author of the paper.

The primary aim of the study was to identify the most reported psychological variables for which correlations with PA was shown. To overcome the heterogeneity deriving from multiple statistical assessments and to analyse the linear correlations between PA and psychological variables, articles reporting Pearson's correlation coefficients were included in the review. These correlations, although not free from limitations (e.g., not reporting individual-level data, not adjusting for confounders, etc.), represent easy-to-interpret way to report linear relationships between PA and psychological variables and to test the effect of interventions over time.

A random-effect meta-analysis, along with heterogeneity assessment using meta regression, were performed when there were at least four articles available for inclusion. This was possible only for some variables, namely self-efficacy, self-regulation, social support, outcome expectation, enjoyment, and anxiety. For these variables, a review of the types of interventions that may enhance (or reduce, in case of a negative correlation) their effect causing potential benefits for the exerciser population was also performed.
The study inclusion and exclusion criteria are reported in Table 1.

Table 1.

Study inclusion and exclusion criteria

Inclusion criteria (studies had to meet all criteria)	• Studies referred to PA including correlations (e.g., correlation matrices based on Pearson's correlation) with any psychological variable • Studies were published in peer-reviewed journals • Studies were original and published in English language
Exclusion criteria	• Peer-reviewed books or book chapters and dissertations were not considered due to lower peer-evaluation standards • Documents published by institutions with commercial affiliations (e.g., company funding source was retrieved for each article) • Paediatric studies (age < 13 years) • Clinical studies (studies including clinical populations e.g., with chronic disease) • Studies not reporting validated questionnaires or referenced tests, or details for collecting variables to test physical activity or psychological variables were excluded due to potential low reproducibility

2.1 Background

There is high interest in measuring behavioural, cognitive, and emotional outcomes in exercisers, defined as people who engage in PA at various levels, as well as in laypeople. The most relevant outcomes in this field are represented by the identification of beneficial activities in non-clinical groups, including the elderly, and the implementation of psychological drivers for the promotion of greater athletic achievement in professionals and healthier lifestyles in the general population. In recent years there has been a dramatic increase in the number of studies that analyse psychological variables among people who exercise regularly or laypeople adhering to temporary programs to improve fitness levels or to simply achieve healthier lifestyles (Clemente et al., 2019; Bernstein et al., 2019; Zur et al., 2019). The populations involved in these studies, however, are often diverse and may include fragile subjects, such as the elderly, and people with chronic diseases like diabetes or obesity who can benefit from exercise programs (Kosteli et al., 2018; Ku et al., 2018; Matson et al., 2019). Commonly reported variables that are studied among people who engage in PA include those belonging to the social cognitive theory (e.g., self-efficacy and self-regulation) and to the emotional sphere such as anxiety, stress, or depression (Garcia et al., 2012; Kosteli et al., 2018; Ku et al., 2018; Matson et al., 2019; Tonello et al., 2019). Although the relationships between psychological variables and PA are well-documented among exercisers (Levy et al., 2015; Ayotte et al., 2010; Smith et al., 2016; Kosteli et al, 2018; de Oliveria et al., 2019), their assessment often occurs through highly heterogeneous statistical analyses.

2.2 Methods

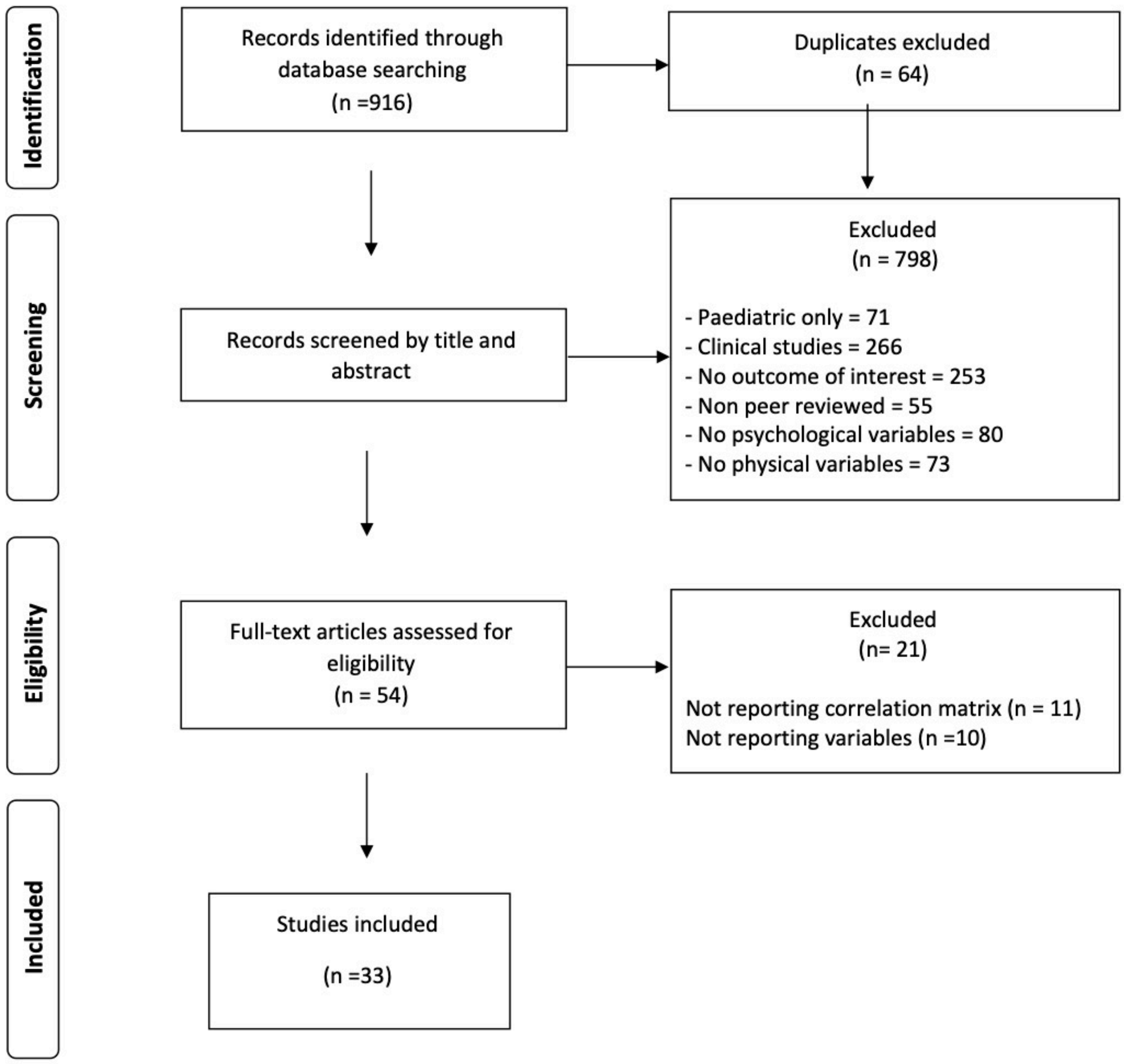
The search strings were prepared together with a qualified librarian and are reported in the box below.

SportDiscus, psycINFO, psycARTCLES
(((“physical activity” OR “sport performer*” OR “exerciser*”) AND (“psychological variables” OR “anxiety” OR “self-efficacy” OR “self efficacy” OR “depression” OR “affect” OR “enjoyment” OR “self-regulation” OR “self regulation” OR “outcome expectation” OR “goal setting” OR “perceived barriers” OR “social support” OR “quality of life” OR “stress” OR “wellbeing” OR “accomplishment” OR “emotion” OR “attitude” OR “autonomy” OR “competence” OR “relatedness”) AND (“correlation matrix”) NOT (“cancer” OR “ischemia” OR “mental disorder*” OR “mental disease” OR “diabetes” OR “obesity” OR “obese” OR “metabolic” OR “articular” OR “rheum* OR “osteoarticular”)))
PubMed
((((physical activity) AND (psychological variable*)) AND correlation matrix)) NOT (diabetes OR obesity OR children OR paediatric OR pediatric pain OR mental OR ischemia OR articular OR osteoarticular OR cancer OR obese OR metabolic OR rheum*)

Databases such as psicINFO, psicARTICLES, sportDISCUS, Medline and GoogleScholar were searched between 2005 and 2022. The PRISMA diagram is reported below.

Figure 1.

PRISMA diagram for study inclusion



Only peer-reviewed papers published in the English language were included. All types of studies, except case reports, were considered. Paediatric studies (age < 13 years), clinical studies (e.g., assessing specific diseases such as osteoarticular disorder, mental health disorders, etc.), and articles focusing on COVID-19-related stressors or PA during the pandemic were excluded to limit potential confounders. Only studies analysing validated PA questionnaire (e.g., International Physical Activity Questionnaire or similar) (Craig et al., 2003) or quantitative assessments (e.g., steps per day) were considered. If multiple assessments or interventions were performed over time, only correlations pertaining to the baseline assessment were included.

A standardized data extraction method was used to record relevant features of each study into an electronic database, including: study characteristics (year of publication, recruitment time period, country, study design), population (age, gender, type, and level of exercise performed), type of psychological variable and related measurement, type of PA assessment (e.g., based on metabolic equivalents, METs), and correlation (r, Pearson's correlation coefficients and its related statistical significance).

People who engage in PA were classified as professional athletes (e.g., remunerated athletes performing services in a professional athletic event and/or playing in higher divisions at a national or international level), semi-professional (e.g., engaging in sports activities but not as a full-time occupation), amateurs (e.g., engaging in PA without remuneration or for recreational purposes) or laypeople (e.g., people that do not regularly engage in PA). Laypeople were reported as elderly (65 years and older), students (if belonging to schools or other academic environment), and general adult population.

The study quality was rated assigning one point for compliance of each item in the two checklists from which group median scores were calculated. Data not reported scored 0 in the checklist. Overall quality was summarized for the RCTs checklist as very poor (score 0-2); poor (score 3-5); moderate (score 6-8); good (score 9-11); very good (score 12-14) and for the observational studies checklist as very poor (score 0-3); poor (score 4-6); moderate (score 7-9); good (score 10-13): very good (score 14-17).

Variables that were reported by 4 or more articles were included in the meta-analysis. Because of the differences that were expected between studies, the results were combined using a random effects model. Fisher's z transformation was used to transform a skewed distribution into a normal distribution and estimate 95% CI.

Pooled incidence risk was reported as unadjusted risk ratio estimates and 95% confidence interval (95% CI). If a study included two different psychological tests, each one was considered as an independent study for the meta-analysis. If longitudinal measures were taken over time, only the first time point was considered for the analysis. A forest plot was generated to show the Pearson's correlation coefficient according to each variable. Heterogeneity between studies was assessed using the I2 tests (0%–40% no heterogeneity, 30%–60% moderate, 50%–90% substantial, and 75%–100% considerable heterogeneity). Meta-regression analysis was implemented to account for potential sources of heterogeneity including gender, age, and year of publication. We did not find studies specifically targeting professional athletes, therefore subgroup analyses was performed according to the type of population reported as elderly, students, adult exercisers and, when applicable, type of sub-variable assessed (e.g., social support from family vs. friends). Publication bias was reported in funnel plots and using the nonparametric "trim-and-fill" analysis method to account for publication bias. The trim-and-fill analysis has the purpose to estimate the studies that may be missing from a meta-analysis because of publication bias. Furthermore, it imputes these studies and computes the overall effect-size estimate using observed and imputed studies.

Stata Statistical Software Release 16 (StataCorp LLC, College Station, TX, USA) was used for data analysis.

2.3 Results

2.3.1 Systematic review

Thirty-three studies were included in the final analysis (Berki et al., 2022; Han et al., 2022; Wang et al., 2020; Erturan et al., 2020; Garn et al., 2020; Kayani et al., 2020; Umstattd et al., 2020; Tonello et al., 2019; Xiao et al., 2019; de Oliveira et al., 2019; Legey et al., 2017; Perchtold-Stefan et al., 2019; Kosteli et al., 2018; Fin et al., 2017; Hwang et al., 2017; Kim et al., 2017; Vance et al., 2017; Orsega-Smith et al., 2017; Smith et al., 2016; Lewis et al., 2016; Siramatr et al., 2016; Zhou et al., 2016; Joseph et al., 2014; Garcia et al., 2014; Garcia et al., 2012; Ayotte et al., 2010; Brunet et al., 2009; Chiu et al., 2009; Yli-Piipari et al., 2009; Morris et al., 2008; Kim et al., 2007; Levy et al., 2005; McAuley et al., 2005). Table 2 summarizes the study characteristics.

Table 2.

Characteristics of the included studies

Author Year	N	Female (%)	Age range (years) Mean, SD	Psychological Variables (Assessment type)	PA Measure	Correlation Coefficient	P value
Berki 2022	249	68.3	14-19 M=16.2 SD=1.22	PACES-H	IPAQ-SF	0.26	< 0.001
Han 2022	1923	50.5	NA	GSES	PARS-3 (METs)	0.25	<0.01
Wang 2020	835	55.2	NA M=20.13 SD=1.06	GSES	PARS-3 (METs)	0.26	< 0.001
Erturan 2020	464	53.4	14-17 M=15.04 SD=0.62	MSLQ SE MSLQ SR	LTPAQ (METs)	0.29 0.13	<0.01 <0.01
Garn 2020	71	45.0	NA M=21.25 SD=1.18	Exercise self-efficacy (EXSE)	GPAQ	0.67	<0.01
Kayani 2020	442	43.0	NA (University students)	SSTAS	Cho's Quest.	-0.24	<0.001
Umstattd 2020	284	77.5	NA M=70.4 SD=9.1	SES SRPA	CHAMPS (METs)	0.47 0.52	< 0.001 < 0.001
Tonello 2019	35	100	26-43 M=34.5 SD=5.1	BDI	MVPA	0.173	NS
Xiao 2019	238	58.4	30-65 M=51.6 SD=5.6	EXSE PSS-10 ESSS QLSB	IPAQ-SF (METs)	0.20 -0.02 0.20 0.17	< 0.01 NS < 0.01 <0.05
de Oliveira 2019	200	78.0	NA	HADS Anxiety HADS Depression	MBQOA (Scale)	-0.19 -0.35	<0.05 <0.05
Legey 2019	140	46.4	NA M=23.6 SD=3.7	STAI – S STAI – T SF-36	BHPAQ (METs)	0.01 0.74 0.003	<0.05 NS <0.05
Perchtold-Stefan 2019	98	55.1	18-33 M=23.06 SD=3.4	PID-5	FQPA (METs)	-0.29	<0.05
Kosteli 2018	312	46.0	50-70 M=59.73 SD=7.73	BSSES IES EPS, EGS OEES	IPAQ (METs)	0.24 0.36 0.22 0.30 0.23	<0.01 <0.01 <0.01 <0.01 <0.01
Fin 2017	615	53.2	12-14 M=13.3 SD=0.79	PACES	PAQ-C	0.24	<0.05
Hwang 2017	401	68.8	NA M=75.2 SD=7.2	EXSE DBSE Social support	GSLTPAQ (METs)	0.40 0.11 0.25	<0.01 <0.05 <0.05
Vance 2017	122	42.6	AR=55-88 M=70.5 SD=7.2	GDS	PAQ	-0.21	<0.05
Orsega-Smith 2017	1900	61.5	NA M=67.7 SD=6.9	PSES PSES SSEB	LTPAQ (METs)	0.24 0.19 0.20	< 0.001 < 0.001 < 0.001
Smith 2016	94	68.1	21-65 M= 42.3 SD = 12.3	BARSE BARSE - Task PACES BPAS EPS EGS PBE SSES Friends SSES Family	Steps/day	0.53 0.38 0.50 0.32 0.53 0.51 −0.30 0.32 0.13	<0.01 <0.01 <0.01 <0.01 <0.01 <0.01 <0.05 <0.01 NS

Lewis 2016	448	87.0	18 - NA M=43 SD=NA	SEFIM PACES	PAR (METs)	0.08 0.08	NS NS
Kim 2016	2414	57.7	44-98 M=75.36 SD=6.07	MPANAS-X Wellbeing (3 item test)	MLTPAQ (METs)	0.28 0.24	<0.01 <0.01
Siramatr 2016	787	69.4	18-22 M=20.79 SD=1.64	MSES OEQ SRQ	GSLTPAQ (METs)	0.50 0.37 0.42	< 0.01 < 0.01 < 0.01
Zhou 2016	249	42.2	17-24 M=19.7 SD=1.6	SR3S	RPAI	0.31	<0.01
Joseph 2014	604	47.7	18-30 M=20.4 SD=1.9	EXSE ABS - Pos ABS - Neg SWLS	GSLTPAQ (METs)	0.26 0.02 0.03 0.10	<0.0001 <0.0001 NS NS
Garcia 2014	280	48.6	NA M=25.6 SD=12.8	ABS - Pos ABS – Neg	Archer-Garcia Ratio	0.24 0.03	<0.01 NS
Garcia 2012	635	58.3	NA M=18.53 SD=5.01	PANAS - Pos PANAS - Neg PWB	BHQ	0.44 -0.18 0.25	<0.001 <0.001 <0.05
Ayotte 2010	232	50.0	50-75 M=58.86 SD=7.16	TRSES BARSE BPAS EPS EGS PSIS	PAQ (METs)	0.40 0.43 0.12 0.31 0.25 0.30	<0.01 <0.01 NS <0.01 <0.01 <0.01
Brunet 2009	381	57.7	17-23 M=18.69 SD=1.15	PNSE Autonomy Competence Relatedness SPAS	GSLTPAQ (METs)	0.27 0.60 0.30 -0.21	<0.05 <0.05 <0.05 <0.05
Chiu 2009	1352	59.2	AR 19-24 M=21.5 SD=NA	PASE	LTPAQ	0.45	<0.01
Yli-Piipari 2009	429	50.3	13-15 M=13.04 SD=0.23	Sport Enjoyment Scale PESAS	MVPA (METs)	0.22 -0.13	<0.001 <0.05
Morris 2008	137	100	NA M=69.6 SD=NA	BARSE	PASE	0.26	<0.05
Kim 2007	2938	44.9	16-19 M=17.7 SD=NA	PASE CASSS	LTEQ	0.46 0.11	<0.05 <0.05
Levy 2005	122	100	22-79 M=45.9 SD=12.8	SEE	GSLTPAQ (METs)	0.17	NS
McAuley 2005	174	72	AR=60-75 M=66.7 SD=5.35	EXSE	PASE	0.28	<0.05

Psychological Tests – abbreviations

GSES = General Self-Efficacy Scale; BSSES = Barriers Specific Self-Efficacy Scale; IES = Interest-Enjoyment Subscale; EPS = Exercise Planning and Scheduling Scale; EGS = Exercise Goal-Setting Scale; CASSS = Social support Family; OEES = Outcome Expectations for Exercise Scale; BARSE =Barrier Self-Efficacy Scale; SRPA = Self-Regulation for Physical Activity Questionnaire; PACES = Physical Activity Enjoyment Scale; BPAS = Benefits of Physical Activity Scale; PBE = Perceived Barriers to Exercise; SSES = Social Support for Exercise Survey; SEE = Self-efficacy for Exercise Questionnaire; EXSE = Exercise Self-efficacy Scale; DBSE = Decisional Balance Scale for Exercise; SSPA = Social Support Scale for Physical Activity; ABS = Bradburn Affect Balance Scale; SWLS = Satisfaction with Life Scale; PSS-10 = Perceived Stress Scale; PNSE = Psychological Need Satisfaction in Exercise; SPAS = Social physique anxiety; ESSS = Exercise Social Support Survey; QLSB = Quality of Life Scale-Brief; SEFIM = Self-efficacy Five-item Measure; PASE = Physical activity self-efficacy Scale; PID-5 = Personality Inventory for DSM-5; TRSES = Task- related self-efficacy Scale; PSIS=Positive Social Influence Scale; SSEB = Social Support for Exercise Behaviours Scale; PSES = Physical Self-efficacy Scale; MSLQ = Motivated Strategies for Learning Questionnaire; HADS = Hospital Anxiety and Depression Scale; STAI – S = State and Trait Anxiety Inventory; SF-36 = Short-Form Health Survey; SES = Sport Enjoyment Scale; PESAS = Physical Education State Anxiety Scale; SSTAS = Spielberg's 6-items State and Trait Anxiety Scale; GDS = Geriatric Depression Scale; PANAS = Positive and Negative Affect Schedule; PWB = Ryff's Short Measurement of Psychological Well-Being; MPANAS-X = Modified Positive and Negative Affect Schedule; MSES = Multidimensional Self-efficacy for Exercise Scale; OEQ = Outcome Expectations Questionnaire; SRQ = Self-Regulation Questionnaire; BDI = Beck's Depression Index; SR3S = Schwarzer and Renner 3 items Scale

Physical Tests – abbreviations

IPAQ = International Physical Activity Questionnaire; IPAQ-SF = International Physical Activity Questionnaire Short Form; Steps/day = Steps per day; GSLTPAQ = Godin-Shephard Leisure-Time Physical Activity Questionnaire; FQPA = Freiburger Questionnaire on Physical Activity; PAR = Physical Activity Recall Interview; PARS-3 = Physical Activity Rating Scale; LTEQ = Leisure Time Exercise Questionnaire; PAQ = Physical Activity Questionnaire; PAQ-C = Physical Activity Questionnaire for Children; LTPAQ = Leisure Time Physical Activity Questionnaire; PASE = Physical Activity Scale for the Elderly; MBQOA = Modified Baecke Questionnaire for Older Adults; BHPAQ = Baecke Habitual Physical Activity Questionnaire; MVPA = Moderate to Vigorous Physical Activity Measure; Cho's questionnaire = Cho's Questionnaire for Assessing the PA level of Individuals; BHQ = Background and Health Questionnaire; MLTPAQ = Modified Leisure-Time Physical Activity Questionnaire; RPAI = Renner Physical Activity Index

Only one randomized controlled trial was retrieved (Lewis et al., 2016). Overall, 19,650 subjects (range, 35 to 2938) were included. Age varied from 13 to 99 years (average 40 years). Three studies included only females while there were no studies performed only in males. The female percentage varied from 42.2 to 100%. Study duration was highly variable, ranging from 7 days to 1 year, with a median duration of 60 days (Q1; Q3, 14 – 180). We did not retrieve any study including professional sports performers or focusing on specific sports or exercise, therefore only studies encompassing laypeople were included. The type of PA analysed included general fitness, exercise participation, or PA for general daily living. For most studies, the authors did not clearly define the type of activity that was performed but rather reported general fitness activities (e.g., mixed PA, leisure, and training sessions ranging from walking to running or performing specific exercise or exercise intensity (e.g., moderate or vigorous activity).

A total of 17 psychological variables were retrieved from correlation matrices, including: self-efficacy, self-regulation, perceived physical ability, outcome expectations, perceived barriers to exercise, social support, goal setting, quality of life, enjoyment, wellbeing, anxiety, stress, positive and negative affect, depression, autonomy, competence, relatedness. Of 33 studies, 20 (60%) assessed self-efficacy, 6 (18%) assessed social support, anxiety, self-regulation, enjoyment, and 4 (12%) outcome expectations and these variables represented the most common ones and were included in the meta-analysis. Overall, 44 different tests were used to assess the 17 psychological variables included. The number of items in the questionnaires varied from 3 to 36. Questionnaires' internal consistency was reported in 29/43 (67%) cases and varied from 0.53 to 0.93. Study quality is summarized in Table 3. Only one randomized controlled trial (Lewis et al., 2016) was retrieved according to the selection criteria, displaying very good quality. For the other studies, the overall quality was good (mean 10.9) and only 3 studies showed moderate quality.

Table 3.

Quality assessment of included studies (n=33)

Author	Total	Score
Berki	10	Good
Han	12	Good
Wang	12	Good
Erturan	12	Good
Garn	12	Good
Kayani	11	Good
Umstattd	11	Good
Tonello	10	Good
Xiao	12	Good
De Oliveira	10	Good
Legey	8	Moderate
Perchtold-Stefan	12	Good
Kosteli	14	Very good
Fin	11	Good
Hwang	10	Good
Vance	9	Moderate
Orsega-Smith	12	Good
Smith	11	Good
Kim	10	Good
Siramatr	10	Moderate
Zhou	10	Good
Joseph	10	Good
Garcia 2012	10	Good
Garcia 2014	10	Good
Ayotte	11	Good
Brunet	10	Good
Chiu	11	Good
Yil-Pipari	14	Very good
Morris	10	Good
Kim	11	Good
Levy	11	Good
McAuley	10	Good
Randomised		
Lewis	12	Good

The main characteristics of the most common retrieved psychological variables are reported as follows:

1. Self-efficacy

Self-efficacy is one of the main concepts within Albert Bandura's social cognitive theory and refers to the ability to execute actions to achieve desired goals (Bandura, 2013). Correlations between self-efficacy and PA indicate predisposition to produce and attain performance outcomes and to control motivation, the environment, and the behaviour that the exercisers exhibit (Bandura, 2013). A low sense of self-efficacy has been associated with stress, depression, anxiety, and a sense of helplessness, while a strong sense of self-efficacy facilitates cognitive processes, performance, and quality of decision making (Zulkosky, 2009). Positive benefits of PA in improving self-efficacy have been well documented and recognized (Downs & Strachan, 2016), and a positive correlation between increased self-efficacy and PA was demonstrated in various sports contexts such as running or cycling (Smith et al., 2016, McAuley et al., 2005; Wang et al., 2020). Participation in PA can influence self-efficacy by acting as one of the principal sources of efficacy information, that is, by providing mastery or performance accomplishment experiences (McAuley et al., 2011). In this study, both acute and chronic PA participation impacted on several measures of self-efficacy for physical performance. Women, who demonstrated significantly lower self-perceptions than men at baseline, made dramatic increases in efficacy during the exercise program, equalling or surpassing men (McAuley et al., 2011). Various subtypes of self-efficacy (e.g., barriers, task, and exercise self-efficacy) have been reported and correlated with PA. Barriers self-efficacy refers to the ability to overcome exercise-related barriers such as pain, discomfort, or events like poor weather or other obstacles to produce successful behavioural performance (Kosteli et al., 2018). Task self-efficacy refers to the exerciser's perception of the ability in accomplishing the task, feel confident in training, and succeed during an exercise test (Ayotte et al., 2010). Exercise self-efficacy, in general, refers to the exerciser's belief that exercise activities can be successfully adopted, performed, and maintained. Exercisers with increased self-efficacy are more likely to show greater interest, participation, exert more effort, and potentially achieve outcomes at higher levels than those with low exercise self-efficacy (Xiao et al., 2019). In this review, self-efficacy was the most studied variable in association with PA and was reported in 20 studies. Of these, 17 studies showed significant positive correlations between self-efficacy and PA (Table 2). Correlation coefficients varied from 0.17 to 0.67. The most frequently reported variables were exercise (n=6), barrier (n=4), and task (n=2) self-efficacy. Nine studies were performed in the US, 7 in the Western Pacific Region, and 4 in the European Region. Eight studies included students and 7 involved the elderly.

2. Self-regulation

Self-regulation refers to the ability to control not only emotions but also behaviours so that positive results and well-being can be obtained (Bandura, 2013; Midgely & Urdan 2001). To achieve these goals, careful planning, goal setting, and creation of strategies may be put in place and can be associated with self-monitoring and reinforcing behaviors to achieve well-being and positive outcomes (Bandura, 2013; Midgely & Urdan, 2001; Zimmerman & Schunk, 2008). From an exercise perspective, self-regulation can be paramount to engaging and sustaining regular PA (Anderson et al., 2006; Ziegelmann et al., 2006; Ayotte et al., 2010). Furthermore, self-regulation can significantly explain and predict PA behavior (Anderson et al., 2006; Ayotte et al., 2010; Umstattd et al., 2008; Kosteli et al., 2018). Higher self-regulation is often associated with increased self-efficacy, and both have may positively impact PA in younger and older adult populations (Dishman et al., 2005; Rovniak et al., 2002; Umstattd et al., 2008 cited in Kosteli et al., 2018). In this review, self-regulation showed positive correlations with PA levels in 6 studies showing significant correlations in all studies and correlation coefficients up to 0.53 (Table 2). Three studies were performed in the American Region, two in Europe and one in South-East Asia (Thailand). Half of the studies involved elderly exercisers.

3. Social support

Social support is based on mutual relationships and the help people receive through contacts, in particular from family and friends (Xiao et al., 2019). Strong social support has been associated to increased quality of life (Xiao et al., 2019). Bandura (1997), cited in Ayotte et al. (2010) suggests that higher levels of social support led to increased self-efficacy which, in turn, increased participation in PA. Anderson et al. (2006) suggest that family support is indirectly associated with increased exercise through self-efficacy and self-regulation. Orsega-Smith et al. (2007) found that social support from friends was significantly related to perceived physical ability and levels of Leisure-Time Physical Activity (LTPA) among older adults. This review also confirmed the correlation between PA and social support, which has been also associated especially with youth athletes' wellbeing (Sheridan et al., 2014; Laird et al., 2018), Social support, either from family or friends, showed a positive significant correlation with PA in 6 studies (all showing significant correlations) with coefficients ranging from 0.11 to 0.32 (Table

2). Three studies were performed in the Western Pacific Region, two in the American Region and one in the European Region. Half of the studies involved the elderly and one included school students from 7 different districts (Kim et al., 2007).

4. Enjoyment

Enjoyment is an intrinsic, affective variable that mediates behaviour via positive experiences and pleasure (Rhodes & Kates 2015). Enjoyment, facilitating positive affective states, may be a predictor of PA behaviour (Wankel, 1993). Various constructs and models, including social cognitive theory, self-determination theory, and the youth PA promotion model support the concept that enjoyment helps determine PA and vice versa (Bandura, 2013; Deci & Ryan, 2000; Welk, 1999). In specific populations, such as young exercisers, enjoyment provides an underlying motivation to engage and maintain both PA and, in the school context, physical education (Yli-Piipari et al., 2009). Enjoyment in sports has been documented also in older adults (Mullen et al., 2011). In this review, enjoyment correlated positively with PA levels in 6 studies (5 showing significant correlations) with correlation coefficients ranging from 0.22 to 0.50 (Table 2). Three studies were performed in the American Region, 2 in the European Region, and one in the Western Pacific Region. One study involved elderly exercisers.

5. Anxiety

Anxiety is characterized by a state of excessive worries about daily life events or activities and can be associated with symptoms such as tachycardia and sleep problems (Siegel, & Dickstein, 2011). Anxiety has been classified as trait anxiety, described as an individual's predisposition, or state anxiety, defined as a transitory emotion with perceived feelings of apprehension and tension (Spielberger 1966). PA has been found to help relieve the symptoms of both state and trait anxiety (Petruzzello et al., 1991; Goldfarb et al., 1990) impacting on biological systems and improving emotional status, especially when exercise provides relief and allows for spending time away from daily worries (Breus & O'Connor 1998). Regular moderate PA has been associated with the reduction of anxiety and depression, thereby showing a global positive effect on the wider field of mental health (Peluso & Guerra de Andrade, 2005). De Oliveira et al., (2019) found a relationship between anxiety and PA levels in a group of 200 elderly divided into a physically active and one inactive group. It was observed that the inactive individuals obtained higher anxiety scores than their active counterparts.

In this review, 6 studies analysing anxiety, including one study carried out in adolescents, showed significantly negative correlations with PA, with values ranging from 0.01 to -0.29 (Table 2). De

Oliveira et al. (2019) showed that PA was a protective factor against anxiety and depression in the elderly. Among the studies included, Legey et al. (2017) found that PA promoted positive psychological effects, decreasing anxiety levels, among physical education students. Three studies focused on state anxiety and one on trait anxiety. Four studies were performed in the American Region, one in the Western Pacific Region, and one in the European Region.

6. Outcome expectations

Outcome expectations in the context of PA refers to the perceived costs, benefits and expectations that will follow a given behaviour, for example the benefits that exercisers expect from their participation in the activities and tasks (Kosteli et al., 2018). Research suggested that outcome expectations may predict exercise behaviour (Schwarzer & Fuchs, 1995). For example, people with higher outcome expectations of PA health-related benefits are more likely to engage in exercise compared with those that do not (Mathews et al., 2010). In this review, outcome expectations correlated positively with PA in 4 studies (3 with significant correlations) with coefficients ranging from 0.12 to 0.37 (Table 2). Two studies were performed in the American Region, one in the European region and one in South-East Asia. Two out of four studies involved elderly exercisers.

7. Other variables

A great number of studies suggest that PA may reduce depressive symptoms in both nonclinical and clinical populations (Dunn et al., 2005; Singh et al., 2005). In a study encompassing 30 moderately depressed men and women who were randomly assigned to an exercise intervention group (e.g., walking up to 40 minutes 3 times per week for 6 weeks), a social support group, or a control group, the results showed that the intervention based on the exercise program was the most effective in reducing depression (McNeil et al., 1991). In this review, De Oliveira et al. (2019) observed that an active group showed higher scores of PA and quality of life. Conversely, the sedentary group revealed higher anxiety and depression. Farren et al. (2018) conducted a study on adolescents showing that sedentary behaviour significantly predicted depression beyond gender and fitness attributes. Other studies on PA engagement in adolescence through emerging adulthood provide evidence that mental health programs may be enhanced by the inclusion of PA (McPhie & Rawana, 2015) while interventions aimed to increase older adults' engagement in PA might help to reduce depressive symptoms (Litwin et al., 2012). A negative significant correlation between depression and PA was reported by 2 studies with correlation coefficients of 0.21 and 0.35 (Table 2) (De Oliveira et al., 2019; Vance et al., 2017). Vance et al. (2017), specifically, suggested that one mechanism by which PA may promote successful cognitive aging is through depression reduction.

Regular PA has been linked to the enhancement of positive affect and a decrease in negative affect (Maher et al., 2021). Positive affect usually refers to the propensity to experience positive emotions and interactions, dealing with life's challenges in a positive way. Conversely, negative affect can be associated with the experience of negative emotions and more negativity in relationships and surroundings. Although the two concepts are often seen as the two ends of a continuum, it is suggested that they should be interpreted as independent of one another (MacLeod & Moore 2000; Garcia et al., 2012). Other variables that can be affected by PA are closely associated with affect. For example, anxiety can be considered as a state of high negative affect, whereas depression may be seen as a mixed state of high negative affect and low positive affect (Clark & Watson 1991). Joseph et al. (2014) suggests that positive and negative affect work as a mediating effect on the relationship between PA and quality of life in a young adult population. We found significant correlations between PA and either positive or negative affect (range 0.02 - 0.44 and -018 - 0.03, respectively) (Table 2), Negative correlation between negative affect and PA was reported by Garcia et al., 2012. Kim et al. (2017) provided significant findings in their study examining the role that participation in PA plays in promoting positive affect and positive emotions and wellbeing among older adults who experience loneliness. In a study on adolescent and adult populations, PA was linked to individuals whose affect profiles were positive and contributed to marked reductions in psychosocial stress and, conversely, to the enhancing of positive affect and wellbeing (Garcia 2014 & Archer 2014).

The relationship between PA and wellbeing may be direct or mediated by other factors (Xiao et al., 2019; Gill et al., 2013; Mailey & McAuley, 2014). Research suggests that engaging in regular PA alleviates stress and improves self-efficacy, which results in greater levels of quality of life (QOL), whereas decreased social support and low self-efficacy result in a lower QOL. Previous research provides positive correlations between PA and QOL through the mediating effects of exercise self-efficacy, self-regulation, physical self-esteem and affect (Elavsky et al 2005 as cited in Joseph et al 2014). We reported a few studies correlating PA and QOL (range, 0.003 to 0.17) (Table 2) (Xiao et al., 2019; Joseph et al., 2014). Understanding the psychosocial factors that can influence PA and QOL could provide benefits for future interventions seeking to prevent stress, improving exercise self-efficacy whilst developing good social relationships (Brett, et al., 2012; Xiao et al., 2019). Increase in wellbeing was also reported in youth athletes in association with PA and social support and enhanced positive affect (Sheridan et al., 2014; Laird et al., 2018; Garcia et al., 2014) as well as among older adults experiencing loneliness (Kim et al., 2016).

Smith et al. (2016), Ayotte et al. (2010), Sas-Nowosielski & Szopa (2015) reported significant positive correlations between PA and goal setting. In various studies, goal setting has been shown to be an important construct for predicting PA. Anderson et al. (2006) and Petosa et al., 2003 underlined that goal setting and planning, both considered as part of self-regulation, are paramount to engage and maintain PA. As previously mentioned, Bandura (1997) also assumed that the ability to self-regulate can represent the fundamental social-cognitive approach to change behaviour. Finally, one study showed a positive correlation between PA and perceived physical ability (Orsega-Smith et al., 2017). This is consistent with findings demonstrating that both perceived physical ability (e.g., the individual's perception of physical condition and exercise ability) and perceived competence are important correlates of PA that can also increase body satisfaction through improvements in physical fitness (Stodden et al., 2008).

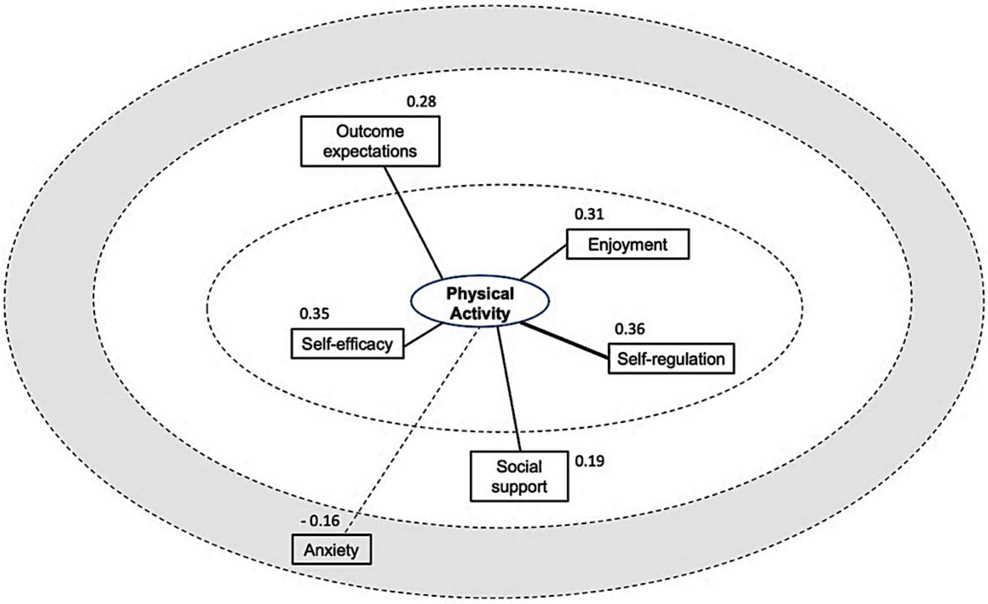
2.3.2 Meta-analysis and meta-regression

Twenty-eight studies including 6 variables (self-efficacy, social support, self-regulation, enjoyment, outcome expectation, and anxiety) could be included in the meta-analysis (Berki et al., 2022; Han et al, 2022; Wang et al., 2020; Erturan et al., 2020; Garn et al., 2020; Kayani et al., 2020; Umstattd et al., 2020; Xiao et al., 2019; de Oliveira et al., 2019; Legey et al., 2017; Perchtold-Stefan et al., 2019; Kosteli et al., 2018; Fin et al., 2017; Hwang et al., 2017; Orsega-Smith et al., 2017; Smith et al., 2016; Lewis et al., 2016; Siramatr et al., 2016; Zhou et al., 2016; Joseph et al., 2014; Ayotte et al., 2010; Yli-Piipari et al., 2009; Brunet et al., 2009; Chiu et al., 2009; Morris et al., 2008; Kim et al., 2007; Levy et al., 2005; McAuley et al., 2005).

Figure 2 summarizes the distribution of psychological variables according to the strength and direction of the pooled correlations reported in the forest plots (random-effects meta-analysis).

Figure 2.

Correlations between physical activity and the most common psychological variables

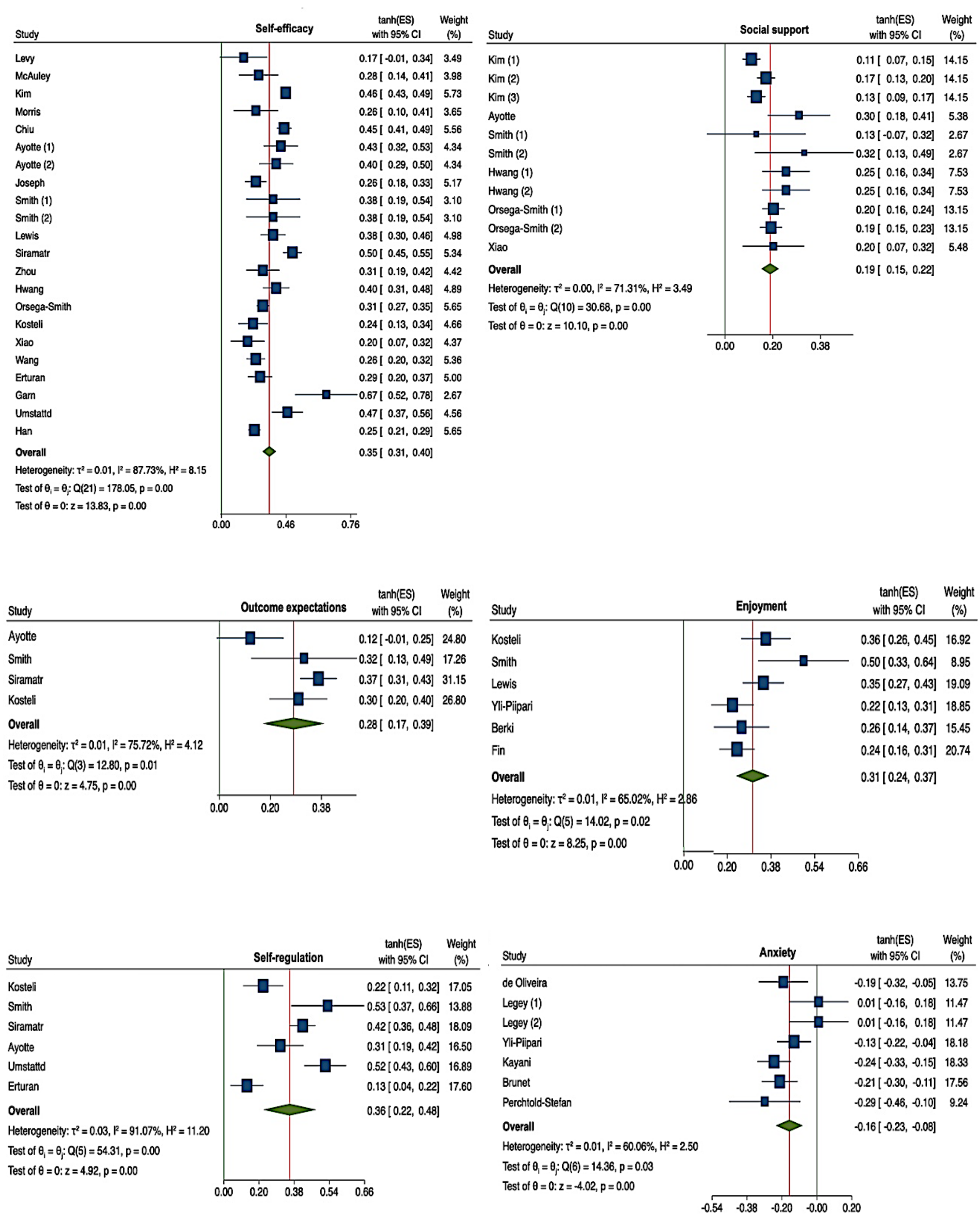


Distribution of psychological variables according to the strength and direction of the correlations as reported in the forest plots. The grey circle includes the negative correlation, the other circles the positive correlations (the closer to the centre, the higher the correlation).

In particular, only anxiety displayed a moderate-to-low negative correlation with PA (-0.12). A positive correlation of low-to-moderate level was shown by social support (0.19) and outcome expectation (0.28), while enjoyment (0.31), self-efficacy (0.35) and self-regulation (0.37) had moderate-to-strong correlations with PA. Self-efficacy displayed the highest number of papers supporting data analysis (Figure 2, thick line). Heterogeneity between studies, assessed using the I2 test, was substantial for enjoyment and anxiety and considerable for the other variables (Figure 3).

Figure 3.

Forest plots showing the correlations for the psychological variables retrieved



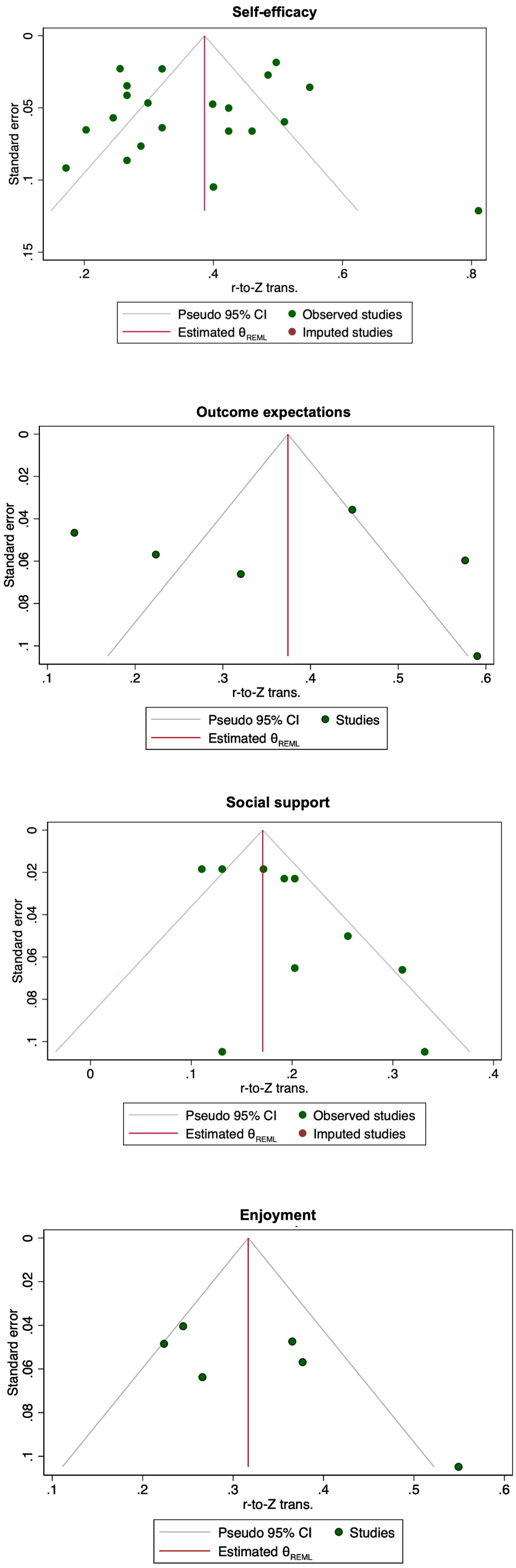
Subgroup analysis was possible only for self-efficacy and social support that included the highest number of studies allowing at least 3 studies per group. For self-efficacy, the correlation coefficients were similar according to the type of population (students: 0.36, 95% CI 0.27 – 0.45; adults: 0.35, 95% CI 0.24 – 0.45; elderly: 0.35, 95% CI 0.29 – 0.41) while for social support the correlation was lower for students compared to other groups (students: 0.14, 95% CI 0.10- 0.17; adults: 0.21, 95% CI 0.12 – 0.30; elderly: 0.21, 95% CI 0.18 – 0.24, $p< 0.001$). Regarding the analysis of variables, correlations with PA were similar for task (0.31, 95% CI 0.27 – 0.34), barriers (0.37, 95% CI 0.26 – 0.47), or exercise (0.38, 95% CI 0.28 – 0.47) self-efficacy and for social support from family (0.19, 95% CI 0.12 – 0.26) and from friends (0.18, 95% CI 0.14 – 0.22).

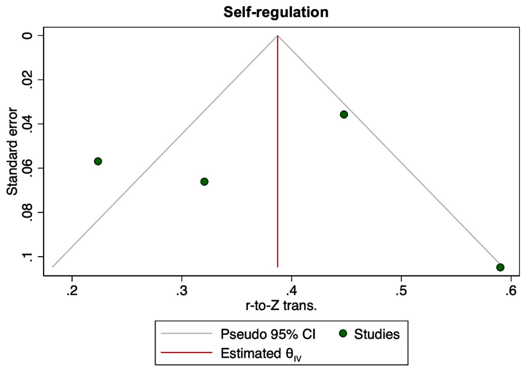
Meta-regression did not show any source of heterogeneity according to age, gender, or year of publication for self-efficacy, enjoyment, outcome expectation, and anxiety. For self-regulation and social support, male gender was negatively associated (-0.012, 95% CI, -0.020 - 0.005, $p=0.001$ and -0.004, 95% CI -0.006 -0.002, $p=0.001$ respectively) while age was positively associated with social support (0.0016, 95% CI 0.0007 - 0.002, $p=0.001$)

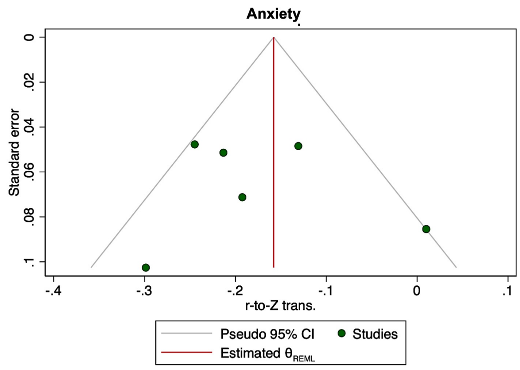
Funnel plots are reported in Figure 4 and reflected the study heterogeneity, however when the missing studies were imputed to search for potential publication bias using the trim-and-fill method, the overall effect size was similar for the observed and imputed studies.

Figure 4.

Funnel plots







2.4 Interventions impacting on psychological variables

Revealing and highlighting interventions to improve health and mental wellbeing is paramount and is one main topic for funded research (European Commission, 2021). Furthermore, adherence to exercise and sport programs is thought to be regulated by psychological variables (Desharnais, 1986). Table 4 summarizes the potential interventions, relevant to cognitive and PA domains, that can have an impact on the six most common psychological variables identified.

Table 4.

Interventions impacting on the most common psychological variables

Interventions for improvement	Comments
Self-efficacy	• Goal setting (physical activity tasks, goal progress, performance, new challenges) • Mastery experiences • Self-monitoring (control to guide cognitions, motivations, behaviours) • Imagery (vicarious experiences, sense of accomplishment) • Performance accomplishment (mastery) • Role modelling (observing others) • Positive talk (verbal persuasion, emotional arousal) • Stress and anxiety reduction • Imaginal experiences
Social support	• Coaches, parent, peers' relation increase • Providing proactive support • Quality of friendship • Individualized interventions
Self-regulation	• Self-report (diaries, self-learning, behaviour driven processes) • Motivational self-statement • Stress and anxiety reduction • Conservation hypothesis (saving energy for additional tasks) • Motivation (new incentive) • Recovery (sleep) • Repeated regulation exercise
Outcome expectations	• Imagery (confidence) • Process focus • Reduce anxiety • Performance objective (no win-loss orientated) • Rotate roles • Anticipate enjoyment • Exercise adherence
Enjoyment	• Reduce pressure • Social support (important people) • Peer interaction • Perception of personal achievement • Engaging in mastery (learning, practicing, improving) • Personal movement experiences (freedom, creativity, feeling athletic) • Perceive competence
Anxiety	• Positive thoughts • Relaxation techniques • Planning (game plan) • Practice (mastery) • Imagery (visualization) • Cognitive behavioural interventions

Although the interventions may not obviously have a direct impact the correlations, improving or controlling certain aspects linked to activity performance or motivation is deeply beneficial for future research and to inform investigators.

Goal setting is an overarching intervention that aims to highlight task features, the behaviours need to undertake these tasks, and the outcomes associated with performing them and the associated behaviours. Goals setting provide focus, task-associated strategies, and the room for reflection on whether these strategies are successful or not, to improve and build on which is likely to increase performance (Bandura, 1988; Schunk, 1989; Koch, 2011, Locke, 1990). Goal setting builds on self-efficacy and perceived outcomes and conveys a belief of improvement and mastery (Elliott & Dweck, 1988). In sport, goals may be beneficial to improve self-efficacy following injuries (Brinkman, 2019) and enhancing self-regulation (Van Yperen, 2021). Role modelling represents another important intervention to enhance performance in sport through the belief that the model knows how to perform tasks and build motivation in the observer (Schunk 1999; Lee, 2021). For athletes, boosting self-efficacy, motivation, and improve performance by observing and copying the behaviour of athletes they admire is common. This can be explained by Bandura's concept of vicarious experience to enhance self-efficacy by observing the actions performed successfully by others. This may reduce anxiety and leads to imitation of successful actions (Bandura, 1997; Schunk, 1989; Fitzsimmons et al., 1991). Mental imagery's role in enhancing self-efficacy is similar, based on the idea that imagery can give people a sense of performance accomplishment and vicarious experience the same way that physically performing and succeeding in the task would (Murphy et al., 2008). In the sports context, imagery has been defined as the state in which individuals imagine themselves having the ability and capability to deal with the upcoming duties or, in general, to improve performance. Imagery has been associated to increased self-efficacy (Mills, 2000), self-regulation (Mills, 2022), and decreased stress (Parnabas, 2011; Lin 2021). Besides vicarious experiences, other factors that can enhance performance acting on self-efficacy and self-regulation include past performance accomplishments and mastery experiences, including the individual experience of success in a previous performance of a challenging task. Perceptions of successful past performance leads to increased self-efficacy beliefs (Bandura, 1997). Performance accomplishments are based on previous mastery experiences. Models predict that when people continually repeat accomplishments, then self-efficacy beliefs will increase (Feltz & Lirgg, 2001). Furthermore, verbal persuasion can be used to enhance self-efficacy beliefs, suggesting that enhancement can be reached if individuals are persuaded of their capability to master a given activity (Bandura, 1994). The optimization of factors such as social support and enjoyment may require tailored interventions. A study investigating the effects of a one-to-one intervention designed to increase social support in professional male golfers showed performance improvement and enhanced self-esteem (Freeman, 2009, Sheridan, 2014). Enjoyment, in particular, has a great importance also in leading motivational climate on positive and negative personal development and reinforcing commitment, especially in nonprofessional context; however, it may be underestimated, less frequently analysed, or reserved to studies in children or youth playing sports. In this report, there was a high heterogeneity in reporting correlations with enjoyment and PA. Mc Donald et al., 2011 investigated the role of enjoyment in 510 young athletes showing that positive experiences in sport were most strongly predicted by affiliation with peers, self-referenced competency, effort expenditure, and orientation towards a task climate. Another report underlined how the creation of a "good feeling" from the coaches to increase players' perception of ability or competence through techniques such as performance profiling that may be relevant also for other psychological variables. Finally, reduction of anxiety to enhance sport performance deserves a specific discussion. As shown by the meta-analysis, anxiety and PA go in opposite direction, and studies have demonstrated that, similar to depression, the association is bidirectional (Da Silva et al., 2012). A 9-year longitudinal study involving over 9,000 participants showed a cross-sectional inverse association between PA and anxiety (OR 0.63 - 0.72). Participants with anxiety and depression at baseline were more likely not to reach the recommended levels of PA at follow-up. In the athlete's context, some studies have promoted relaxation techniques as well as structured psychological interventions, including cognitive behavioural interventions, to minimize anxiety (Gustaffson, 2016; Rowland, 2021; Liang, 2021; Wang et al., 2022; Krane, 1992).

2.5 Discussion

This work showed that most studies displayed a moderate correlation between PA and various psychological variables, including those that are indicative of behavioural performance, such as self-efficacy, or affective variables such as anxiety, stress, and depression. Positive correlations between PA and self-efficacy were shown in 20 studies carried out in laypeople. A negative correlation between depression, anxiety, or negative affect and PA was reported (De Oliveira et al., 2019; Vance et al., 2017; Garcia et al., 2012). Pooled meta-analysis confirmed increased correlation coefficients especially for self-efficacy and self-regulation.

The meta-regression showed that gender was a source of heterogeneity for self-regulation. This may be related to gender differences previously shown for self-regulation, with higher mean levels usually displayed in females (Coyne et al., 2015, Tetering et al., 2020)

Regarding social support, meta-regression showed significant association with gender and age, however only one study (Kim et al., 2016) included young subjects (school age students) with most male subjects (55%) and displayed lower correlations compared to the other studies retrieved, therefore we interpreted these data as not generalizable to the general concept of social support. A systematic review of social support in youth sport included 73 studies concluded that the ways to examine social support have changed, and that coaches are now identified as the key provider of social support in form of practical and emotional support along with parent and peer support, giving the sport experiences both positive (motivation and participation) and negative (drop-out) perspectives (Sheridan et al., 2014)

This review has several limitations. Firstly, there was high heterogeneity in the studies included and, although a clear publication bias was not shown, more studies are needed for several variables (e.g., emotional variables, self-determination theory-related parameters) that we could not include in the meta-analysis because of the limited number of reports available. Although the review included a high overall number of subjects (>19,000), this figure mainly derived from a few large studies, and high variability in the psychological assessments was evident. Secondly, no studies were found involving athletes, this probably reflecting a different method to estimate the relationship between PA and psychological variables as well as the growing interest for sports and wellbeing in laypeople. Finally, although binary correlations are an easy and efficient way to report bidirectional correlations, they only capture generic, noncomplex relationships, therefore the lack of representation of certain variables does not mean they have been studied in more sophisticated ways. We observed an apparent equal representation of female and male populations for the variables studied, and elderly populations were often involved. Single studies tended to assess multiple psychological variables, and multiple questionnaires, often revised to suit a specific context, were used to assess both psychological variables and PA. This may be due to the need of adapting obsolete or complex questionnaires to novel populations, but it may represent a limitation when trying to pool and quantitatively analyse data.

Only one study was retrieved on motivational variables deriving from theories of exercise psychology, such as self-determination theory (e.g., autonomy, relatedness, competence) which represents a well-known field of research. These theories suggest that to support exercisers in growing their motivation, a belief should be built that environments should be created to promote perceptions of autonomy, competence, and relatedness (Texteira et al., 2012). On the other side, but still interconnected, self-efficacy should be reinforced, and social support maintained. A previous systematic review of 66 studies (Texteira et al., 2012) identified very few articles reporting binary correlations between levels of PA and overall autonomy, relatedness, competence but rather analysed intrinsic or extrinsic motivation. A positive relation was observed between more autonomous forms of motivation and PA, and a trend identified intrinsic

motivation as predictive of long-term exercise adherence. Similar to this review, many studies were non-experimental in their design.
Nevertheless, recent evidence is currently challenging (Brand et al., 2019) the solid basis of cognitive-behavioural theories in sport motivation, adding a layer of increased complexity assuming that these theories may be less effective in certain contexts and that alternative approaches may still increase performance and consistency in PA, for example considering also affective and automatic processes.

2.6 Conclusions

The results presented highlighted a growing interest in the study of cognitive and emotional aspects of amateurs and laypeople, including the elderly, performing PA. Despite the high heterogeneity of the type of variables and assessments used, we confirmed the presence of positive correlations between PA and psychological variables that have an impact on people's behaviour in goal achievement and enjoyment in exercise, while negative correlations were observed with negative affect, depression, and anxiety.
Standardization of assessments and measurements for both physical and psychological variables across different studies appears difficult to achieve, although the use of modern technology, including wearables, is becoming common and may help using quantitative measures for PA frequency and intensity.
Moreover, overarching concepts and cross-correlations between different psychological variables were common and emphasized how PA may have a complex and multifaceted effect on psychological constructs, with overall positive and encouraging results and experiences at all ages. This could be important to underpin the positive effects of PA in the present time, especially due to the potential barriers or changes in habits correlated with the SARS-CoV-2 pandemic (Dwyer et al., 2020; Sallis et al., 2021; Wolf et al., 2021).
This paper adds value to a growing amount of research into the benefits of PA and psychological factors that influence exercise. It also highlights the different variety and amount of physical and psychometric tests that measure psychological and physical exercise outcomes.
Comprehensive reviews analysing the correlations between commonly measured psychological and physical variables may be helpful to gather data that may inform targeted interventions in the field of exercise psychology. Specifically, further studies including correlations between measures of wellbeing across different ages and comparing different populations of exercisers using standardized and validated measures are highly encouraged.

Since a comprehensive review analysing qualitatively and quantitatively the correlations between commonly measured psychological variables and PA has not been performed to date, these results could be helpful in choosing the most appropriate variables and in designing potential interventions in the field of exercise psychology.

2.7 References

Anderson, E. S., Wojcik, J. R., Winett, R. A., & Williams, D. M. (2006). Social-cognitive determinants of physical activity: The influence of social support, self-efficacy, outcome expectations, and self-regulation among participants in a church-based health promotion study. *Health Psychology, 25*, 510–520. https://doi.apa.org/doi/10.1037/0278-6133.25.4.510

Ayotte, B. J., Margrett, J. A., & Hicks-Patrick, J. (2010). Physical activity in middle-aged and young-old adults: the roles of self-efficacy, barriers, outcome expectancies, self-regulatory behaviors and social support. *Journal of health psychology, 15*(2), 173–185. https://doi.org/10.1177/1359105309342283

Azevedo Da Silva, M., Singh-Manoux, A., Brunner, E. J., Kaffashian, S., Shipley, M. J., Kivimäki, M., & Nabi, H. (2012). Bidirectional association between physical activity and symptoms of anxiety and depression: the Whitehall II study. *European journal of epidemiology, 27*(7), 537–546. https://doi.org/10.1007/s10654-012-9692-8

Bandura, A. (1988). Self-Efficacy Conception of Anxiety. *Anxiety Research*, 1, 77-98. https://doi.org/10.1080/10615808808248222

Bandura, A. (1994). Social cognitive theory of mass communication. In J. Bryant & D. Zillmann (Eds.), *Media effects: Advances in theory and research* (pp. 61–90). Lawrence Erlbaum Associates, Inc.

Bandura, A. (1997). *Self-efficacy: The exercise of control.* W H Freeman/Times Books/ Henry Holt & Co.

Bandura, A. (2013). *The role of self-efficacy in goal-based motivation.* In E. A. Locke & G. P. Latham (Eds.), *New developments in goal setting and task performance* (p. 147–157). https://doi.org/10.1177%2F0149206315572826

Bernstein, E. E., Curtiss, J. E., Wu, G. W. Y., Barreira, P. J., & McNally, R. J. (2019). Exercise and emotion dynamics: An experience sampling study. *Emotion, 19*(4), 637–644. https://doi.apa.org/doi/10.1037/emo0000462

Berki, T., & Tarjányi, Z. (2022). The Role of Physical Activity, Enjoyment of Physical Activity, and School Performance in Learning Motivation among High School Students in Hungary. *Children (Basel, Switzerland)*, *9*(3), 320. https://doi.org/10.3390/children9030320

Brand, R., & Cheval, B. (2019). Theories to Explain Exercise Motivation and Physical Inactivity: Ways of Expanding Our Current Theoretical Perspective. *Frontiers in psychology*, *10*, 1147. https://doi.org/10.3389/fpsyg.2019.01147

Brett, C. E., Gow, A. J., Corley, J., Pattie, A., Starr, J. M., & Deary, I. J. (2012). Psychosocial factors and health as determinants of quality of life in community-dwelling older adults. *Quality of life research: an international journal of quality of life aspects of treatment, care and rehabilitation*, *21*(3), 505–516. https://doi.org/10.1007/s11136-011-9951-2

Breus, M. J., & O'Connor, P. J. (1998). Exercise-induced anxiolysis: A test of the "time out" hypothesis in high anxious females. *Medicine & Science in Sports & Exercise*, *30*(7), 1107–1112. https://doi.org/10.1097/00005768-199807000-00013

Brinkman C, Baez SE, Genoese F, Hoch JM. Use of Goal Setting to Enhance Self-Efficacy After Sports-Related Injury: A Critically Appraised Topic (2019). *Journal of Sport Rehabilitation*, *29* (4), 498 – 502. https://doi.org/10.1123/jsr.2019-0032

Brunet, J., & Sabiston, C. M. (2009). Social physique anxiety and physical activity: A self-determination theory perspective. *Psychology of Sport and Exercise*, *10*(3), 329–335. https://doi.org/10.1016/j.psychsport.2008.11.002

Coyne, M.A., Vaske, J.C., Boisvert, D.L. (2015). Sex Differences in the Stability of Self-Regulation Across Childhood. *J Dev Life Course Criminology* 1, 4–20.

Chiu, L.K. (2009). University students' attitude, self-efficacy and motivation regarding leisure time physical participation. *Jurnal Pendidik Dan Pendidikan*, *24*, 1-15.

Clark, L. A., & Watson, D. (1991). Tripartite model of anxiety and depression: psychometric evidence and taxonomic implications. *Journal of abnormal psychology*, *100*(3), 316–336. https://doi.org/10.1037//0021-843x.100.3.316

Clemente, F. M., Owen, A., Serra-Olivares, J., Nikolaidis, P. T., van der Linden, C., & Mendes, B. (2019). Characterization of the Weekly External Load Profile of Professional Soccer Teams from Portugal and the Netherlands. *Journal of human kinetics*, *66*, 155–164. https://doi.org/10.2478/hukin-2018-0054

Craig, C. L., Marshall, A. L., Sjöström, M., Bauman, A. E., Booth, M. L., Ainsworth, B. E., Pratt, M., Ekelund, U., Yngve, A., Sallis, J. F., & Oja, P. (2003). International physical activity questionnaire: 12-country reliability and validity. *Medicine and science in sports and exercise*, *35*(8), 1381–1395. https://doi.org/10.1249/01.MSS.0000078924.61453.FB

Deci, E. L., & Ryan, R. M. (2000). The "what" and "why" of goal pursuits: Human needs and the self-determination of behavior. *Psychological Inquiry, 11*(4), 227–268. https://doi.org/10.1207/S15327965PLI1104_01

de Oliveira, L., Souza, E. C., Rodrigues, R., Fett, C. A., & Piva, A. B. (2019). The effects of physical activity on anxiety, depression, and quality of life in elderly people living in the community. *Trends in psychiatry and psychotherapy*, *41*(1), 36–42. https://doi.org/10.1590/2237-6089-2017-0129

Desharnais, R., Bouillon, J., & Godin, G. (1986). Self-Efficacy and Outcome Expectations as Determinants of Exercise Adherence. *Psychological Reports*, *59*(3), 1155–1159. https://doi.org/10.2466/pr0.1986.59.3.1155

Dishman, R.K., Motl, R.W., Sallis, J.F., Dunn, A.L., Birnbaum, A.S., Welk, G.J., Jobe, J.B. (2005). Self-management strategies mediate self-ef!cacy and PA. *American Journal of Preventive Medicine*, *29*, 10–18. https://doi.org/10.1016/j.amepre.2005.03.012

Downs, M., & Strachan, L (2016). High School Sport Participation: Does It Have an Impact on the Physical Activity Self-efficacy of Adolescent Males? *International Journal of Human Movement and Sports Sciences*, *4*(1), 6 - 11. DOI: 10.13189/saj.2016.040102.

Dunn, A. L., Trivedi, M. H., Kampert, J. B., Clark, C. G., & Chambliss, H. O. (2005). Exercise treatment for depression: efficacy and dose response. *American journal of preventive medicine, 28*(1), 1–8. https://doi.org/10.1016/j.amepre.2004.09.003

Dwyer, M. J., Pasini, M., De Dominicis, S., & Righi, E. (2020). Physical activity: Benefits and challenges during the COVID-19 pandemic. *Scandinavian Journal of Medicine & Science in Sports*, *30*(7), 1291-1294. https://doi.org/10.1111/sms.13710

Erturan, G., McBride, R., & Agbuga, B. (2020). Self-regulation and self-efficacy as mediators of achievement goals and leisure time physical activity: a proposed model. *Pedagogy of Physical Culture and Sports*. http://dx.doi.org/10.15561/18189172.2020.0102

Elavsky, S., McAuley, E., Motl, R. W., Konopack, J. F., Marquez, D. X., Hu, L., Jerome, G. J., & Diener, E. (2005). Physical activity enhances long-term quality of life in older adults: efficacy, esteem, and affective influences. *Annals of behavioral medicine: a publication of the Society of Behavioral Medicine*, *30*(2), 138–145. https://doi.org/10.1207/s15324796abm3002_6

Elliott, E. S., & Dweck, C. S. (1988). Goals: An approach to motivation and achievement. *Journal of Personality and Social Psychology, 54*(1), 5–12. https://doi.org/10.1037/0022-3514.54.1.5

European Commission, Horizon Research 2022. https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/topic-details/horizon-hlth-2022-stayhlth-01-01-two-stage

Farren, G. L., Zhang, T., Gu, X., & Thomas, K. T. (2018). Sedentary behavior and physical activity predicting depressive symptoms in adolescents beyond attributes of health-related physical fitness. *Journal of sport and health science*, *7*(4), 489–496. https://doi.org/10.1016/j.jshs.2017.03.008

Feltz, D. L., & Lirgg, C. D. (2001). Self-efficacy beliefs of athletes, teams, and coaches. In R. N. Singer, H. A. Hausenblas, & C. M. Janelle (Eds.), Handbook of sport psychology, (2nd ed., pp. 340-361). New York: John Wiley & Sons.

Fin, G., Baretta, E., Moreno-Murcia, J. A., & Nodari Júnior, R. J. (2017). Autonomy support, motivation, satisfaction and physical activity level in physical education class. *Universitas Psychologica, 16*(4), 1–12. http://dx.doi.org/10.11144/Javeriana.upsy16-4.asms

Fitzsimmons, P. A., Landers, D. M., Thomas, J. R., & van der Mars, H. (1991). Does self-efficacy predict performance in experienced weightlifters? *Research quarterly for exercise and sport*, 62(4), 424–431. https://doi.org/10.1080/02701367.1991.10607544

Freeman, P., Rees, T., & Hardy, L. (2009). An Intervention to Increase Social Support and Improve Performance. *Journal of Applied Sport Psychology, 21*, 186 - 200. DOI: 10.1080/10413200902785829

Garcia, D., Archer, T., Moradi, S., & Andersson-Arntén, A.-C. (2012). Exercise frequency, high activation positive affect, and psychological well-being: Beyond age, gender, and occupation. *Psychology*, *3*(4), 328–336. https://psycnet.apa.org/doi/10.4236/psych.2012.34047

Garcia, D., & Archer, T. (2014). Positive affect and age as predictors of exercise compliance. *PeerJ,* 2, e694. https://doi.org/10.7717/peerj.694

Garn, A. C., & Simonton, K. L. (2020). Young Adults' Short-Term Trajectories of Moderate Physical Activity: Relations With Self-Evaluation Processes. *Frontiers in psychology*, *11*, 2079. https://doi.org/10.3389/fpsyg.2020.02079

Gill, D. L., Hammond, C. C., Reifsteck, E. J., Jehu, C. M., Williams, R. A., Adams, M. M., Lange, E. H., Becofsky, K., Rodriguez, E., & Shang, Y. T. (2013). Physical activity and quality of life. *Journal of preventive medicine and public health = Yebang Uihakhoe chi, 46 Suppl 1*(Suppl 1), S28–S34. https://doi.org/10.3961/jpmph.2013.46.S.S28

Goldfarb, A. H., Hatfield, B. D., Armstrong, D., & Potts, J. (1990). Plasma beta-endorphin concentration: response to intensity and duration of exercise. *Medicine and science in sports and exercise*, *22*(2), 241–244. https://doi.org/10.1055/s-2007-1024678

Gustafsson, H., Lundqvist, C., Tod, D., (2016), Cognitive behavioral intervention in sport psychology: A case illustration of the exposure method with an elite athlete, *Journal of Sport Psychology in Action*, *8*(3), 152-162.

Han, S. S., Li, B., Wang, G. X., Ke, Y. Z., Meng, S. Q., Li, Y. X., Cui, Z. L., & Tong, W. X. (2022). Physical Fitness, Exercise Behaviors, and Sense of Self-Efficacy Among College Students: A Descriptive Correlational Study. *Frontiers in psychology*, *13*, 932014. https://doi.org/10.3389/fpsyg.2022.932014

Hwang, J., & Kim, Y. (2017). Psychological, Social Environmental, and Physical Environmental Variables in Explaining Physical Activity in Korean Older Adults. *Revista de Psicología del Deporte*. *26*. 83-91. Corpus ID: 56428258

Joseph, R. P., Royse, K. E., Benitez, T. J., & Pekmezi, D. W. (2014). Physical activity and quality of life among university students: exploring self-efficacy, self-esteem, and affect as potential mediators. *Quality of life research: an international journal of quality-of-life aspects of treatment, care and rehabilitation*, *23*(2), 659–667. https://doi.org/10.1007/s11136-013-0492-8

Kayani, S., Kiyani, T., Kayani, S., Morris, T., Biasutti, M., & Wang, J. (2020). Physical Activity and Anxiety of Chinese University Students: Mediation of Self-System. *International journal of environmental research and public health*, *18*(9), 4468. https://doi.org/10.3390/ijerph18094468

Kim, D., Kang, I., & Lee, S. (2007). Social Support, Self-concept and Self-efficacy as Correlates of Adolescents' Physical Activity and Eating Habits. *Korean Journal of Family Medicine, 28*(4), 292-301.

Kim, J., Lee, S., Chun, S., Han, A., & Heo, J. (2017). The effects of leisure-time physical activity for optimism, life satisfaction, psychological well-being, and positive affect among older adults with loneliness. *Annals of Leisure Research*, *20*(4), 406-415. https://doi.org/10.1080/11745398.2016.1238308

Koch A, Nafziger J. Self-regulation through Goal Setting (2011). *The Scandinavian Journal of Economics* 113(1), 212-227. https://doi.org/10.1111/j.1467-9442.2010.01641.x

Kosteli, M.-C., Cumming, J., & Williams, S. E. (2018). Self-regulatory imagery and physical activity in middle-aged and older adults: A social-cognitive perspective. *Journal of Aging and Physical Activity*, *26*(1), 14–24. https://doi.org/10.1177/0276236618767083

Krane, V. (1992). Minimizing anxiety in the competitive environment. Coaching Volleyball, 28-29.

Ku, P. W., Steptoe, A., Liao, Y., Sun, W. J., & Chen, L. J. (2018). Prospective relationship between objectively measured light physical activity and depressive symptoms in later life. *International Journal of Geriatric Psychiatry*, *33*(1), 58-65. https://doi.org/10.1002/gps.4672

Lee, S., Kwon, S., & Ahn, J. (2021). The Effect of Modeling on Self-Efficacy and Flow State of Adolescent Athletes Through Role Models. *Frontiers in psychology*, *12*, 661557. https://doi.org/10.3389/fpsyg.2021.661557

Laird, Y., Fawkner, S., & Niven, A. (2018). A grounded theory of how social support influences physical activity in adolescent girls. *International journal of qualitative studies on health and well-being*, *13*(1), 1435099. https://doi.org/10.1080/17482631.2018.1435099

Legey, S., Aquino, F., Lamego, M. K., Paes, F., Nardi, A. E., Neto, G. M., Mura, G., Sancassiani, F., Rocha, N., Murillo-Rodriguez, E., & Machado, S. (2017). Relationship Among Physical Activity Level, Mood and Anxiety States and Quality of Life in Physical Education Students. *Clinical practice and epidemiology in mental health: CP & EMH, 13*, 82–91. https://doi.org/10.2174/1745017901713010082

Lewis, B. A., Williams, D. M., Frayeh, A., & Marcus, B. H. (2016). Self-efficacy versus perceived enjoyment as predictors of physical activity behaviour. *Psychology & health,* 31(4), 456–469. https://doi.org/10.1080/08870446.2015.1111372

Levy, S., & Ebbeck, V. (2005). The exercise and self-esteem model in adult women: the inclusion of physical acceptance. *Psychology of Sport and Exercise*, *6*, 571-584. https://doi.org/10.1016/j.psychsport.2004.09.003

Liang, D., Chen, S., Zhang, W., Xu, K., Li, Y., Li, D., Cheng, H., Xiao, J., Wan, L., & Liu, C. (2021). Investigation of a Progressive Relaxation Training Intervention on Precompetition Anxiety and Sports Performance Among Collegiate Student Athletes. *Frontiers in psychology*, *11,* 617541. https://doi.org/10.3389/fpsyg.2020.617541

Lin, H. H., Lin, T. Y., Ling, Y., & Lo, C. C. (2021). Influence of Imagery Training on Adjusting the Pressure of Fin Swimmers, Improving Sports Performance and Stabilizing Psychological Quality. *International journal of environmental research and public health*, 18(22), 11767. https://doi.org/10.3390/ijerph182211767

Litwin H. (2012). Physical activity, social network type, and depressive symptoms in late life: an analysis of data from the National Social Life, Health and Aging Project. *Aging & mental health*, *16*(5), 608–616. https://doi.org/10.1080/13607863.2011.644264

Locke, E. A. and Latham, G. P. (1990). *A theory of goal setting and task performance*. Englewood Cliffs, NJ: Prentice Hall.

MacDonald, D. J., Côté, J., Eys, M., & Deakin, J. (2011). The role of enjoyment and motivational climate in relation to the personal development of team sport athletes. *The Sport Psychologist, 25*(1), 32–46.

MacLeod, C., & Moore, R. (2000). Positive thinking revisited: Positive cognitions, well-being and mental health. *Clinical Psychology and Psychotherapy*, *7*, 1-10. https://doi.org/10.1002/(SICI)1099-0879(200002)7:1%3C1::AID-CPP228%3E3.0.CO;2-S

Maher, J. P., Hevel, D. J., Reifsteck, E. J., & Drollette, E. S. (2021). Physical activity is positively associated with college students' positive affect regardless of stressful life events during the COVID-19 pandemic. *Psychology of sport and exercise*, *52*, 101826. https://doi.org/10.1016/j.psychsport.2020.101826

Mailey, E. L., & McAuley, E. (2014). Physical activity intervention effects on perceived stress in working mothers: the role of self-efficacy. *Women & health*, *54*(6), 552–568. https://doi.org/10.1080/03630242.2014.899542

Mathews, A.E., Laditka, S.B., Laditka, J.N., Wilcox, S., Corwin, S.J., Liu, R., . . . & Logsdon, R.G. (2010). Older adults' perceived physical activity enablers and barriers: A multicultural perspective. *Journal of Aging and Physical Activity*, *18*, 119–40. https://doi.org/10.1123/japa.18.2.119

Matson, T. E., Anderson, M. L., Renz, A. D., Greenwood-Hickman, M. A., McClure, J. B., & Rosenberg, D. E. (2019). Changes in Self-Reported Health and Psychosocial Outcomes in Older Adults Enrolled in Sedentary Behavior Intervention Study. *American journal of health promotion: AJHP, 33*(7), 1053–1057. https://doi.org/10.1177/0890117119841405

McAuley, E., Elavsky, S., Motl, R. W., Konopack, J. F., Hu, L., & Marquez, D. X. (2005). Physical activity, self-efficacy, and self-esteem: longitudinal relationships in older adults. *The journals of gerontology. Series B, Psychological sciences and social sciences, 60*(5), P268–P275. https://doi.org/10.1093/geronb/60.5.p268

McAuley, E., Szabo, A., Gothe, N., & Olson, E. A. (2011). Self-efficacy: Implications for Physical Activity, Function, and Functional Limitations in Older Adults. *American journal of lifestyle medicine, 5*(4), 10.1177/1559827610392704. https://doi.org/10.1177/1559827610392704

McPhie, M. L., & Rawana, J. S. (2015). The effect of physical activity on depression in adolescence and emerging adulthood: a growth-curve analysis. *Journal of adolescence, 40*, 83–92. https://doi.org/10.1016/j.adolescence.2015.01.008

McNeil, J. K., LeBlanc, E. M., & Joyner, M. (1991). The effect of exercise on depressive symptoms in the moderately depressed elderly. *Psychology and aging, 6*(3), 487–488. https://doi.org/10.1037//0882-7974.6.3.487

Midgley, C., & Urdan, T. (2001). Academic self-handicapping and achievement goals: A further examination. *Contemporary Educational Psychology, 26*(1), 61–75. https://doi.org/10.1006/ceps.2000.1041

Mills, K. D., Munroe, K. J., & Hall, C. R. (2000). The Relationship between Imagery and Self-Efficacy in Competitive Athletes. *Imagination, Cognition and Personality, 20*(1), 33–39. https://doi.org/10.2190/FC65-AP4T-E94J-5W7P

Morris, K.S., McAuley, E. & Motl, R.W. (2008). Neighborhood satisfaction, functional limitations, and self-efficacy influences on physical activity in older women. *International Journal of Behavioral Nutrition and Physical Activity 5*, 13 https://doi.org/10.1186/1479-5868-5-13

Mullen, S. P., Olson, E. A., Phillips, S. M., Szabo, A. N., Wójcicki, T. R., Mailey, E. L., Gothe, N. P., Fanning, J. T., Kramer, A. F., & McAuley, E. (2011). Measuring enjoyment of physical activity in older adults: invariance of the physical activity enjoyment scale (paces) across groups and time. *The International Journal of Behavioral Nutrition and Physical Activity, 8*, 103. https://doi.org/10.1186/1479-5868-8-103

Murphy, S., Nordin, S., & Cumming, J. (2008). Imagery in sport, exercise, and dance. In T. S. Horn (Ed.), *Advances in sport psychology* (pp. 297–324,463–467). Human Kinetics.

Orsega-Smith, E., Payne, L., Mowen, A., Ho, C., & Godbey, G. (2007). The Role of Social Support and Self-Efficacy in Shaping the Leisure Time Physical Activity of Older Adults. *Journal of Leisure Research, 39*, 705 - 727. https://doi.org/10.1080/00222216.2007.11950129

Parnabas, V.A., & Mahamood, Y. (2011). Anxiety and imagery of green space among athletes. *2011 3rd International Symposium & Exhibition in Sustainable Energy & Environment (ISESEE)*, 165-167. https://doi.org/10.1109/ISESEE.2011.5977126

Perchtold-Stefan, C. M., Fink, A., Rominger, C., Weiss, E. M., & Papousek, I. (2020). More habitual physical activity is linked to the use of specific, more adaptive cognitive reappraisal strategies in dealing with stressful events. Stress and health: *Journal of the International Society for the Investigation of Stress, 36*(3), 274–286. https://doi.org/10.1002/smi.2929

Peluso, M. A., & Guerra de Andrade, L. H. (2005). Physical activity and mental health: the association between exercise and mood. *Clinics (Sao Paulo, Brazil), 60*(1), 61–70. https://doi.org/10.1590/s1807-59322005000100012

Petosa, R. L., Suminski, R., Hortz, B. (2003). Predicting vigorous physical activity using social cognitive theory. *American Journal of Health Behaviors, 27*, 301–310.
https://doi.org/10.5993/AJHB.27.4.2

Petruzzello, S. J., Landers, D. M., Hatfield, B. D., Kubitz, K. A., & Salazar, W. (1991). A meta-analysis on the anxiety-reducing effects of acute and chronic exercise. Outcomes and mechanisms. *Sports medicine (Auckland, N.Z.), 11*(3), 143–182. https://doi.org/10.2165/00007256-199111030-00002

Rhodes, R. E., & Kates, A. (2015). Can the Affective Response to Exercise Predict Future Motives and Physical Activity Behavior? A Systematic Review of Published Evidence. *Annals of behavioral medicine : a publication of the Society of Behavioral Medicine, 49*(5), 715–731. https://doi.org/10.1007/s12160-015-9704-5

Rovniak, L.S., Anderson, E.S., Winett, R.A., & Stephens, R.S. (2002). Social cognitive determinants of physical activity in young adults: A prospective structural equation analysis. *Annals of Behavioral Medicine, 24*, 149–156. https://doi.org/10.1207/S15324796ABM2402_12

Rowland DL, Moyle G, Cooper SE. Remediation Strategies for Performance Anxiety across Sex, Sport and Stage: Identifying Common Approaches and a Unified Cognitive Model. *International Journal of Environmental Research and Public Health*. 2021; 18(19):10160. https://doi.org/10.3390/ijerph181910160

Sallis, R., Young, D. R., Tartof, S. Y., Sallis, J. F., Sall, J., Li, Q., Smith, G. N., & Cohen, D. A. (2021). Physical inactivity is associated with a higher risk for severe COVID-19 outcomes: a study in 48 440 adult patients. *British journal of sports medicine, 55*(19), 1099–1105. https://doi.org/10.1136/bjsports-2021-104080

Sas-Nowosielski, K., & Szopa, S. (2015). Self-regulation strategies used by men and women attending to fitness clubs. *Baltic Journal of Health Physical Activity 7*(3), 23-28. https://doi.org/10.29359/BJHPA.07.3.03

Schunk, D. H. (1989). Self-efficacy and achievement behaviors. *Educational Psychology Review, 1*, 173-208.

Schunk, D. H. (1999). Social-self interaction and achievement behavior. *Educational Psychologist, 34*, 219-227.

Schwarzer, R., & Fuchs, R. (1995). Changing risk behaviors and adopting health behaviors: The role of self-efficacy beliefs. Self-efficacy in Changing Societies, 259–288. doi:10.1017/cbo9780511527692.011

Sheridan, D., Coffee, P., & Lavallee, D. (2014) A systematic review of social support in youth sport, *International Review of Sport and Exercise Psychology, 7*:1, 198-228, https://doi.org/10.1080/1750984X.2014.931999

SIGN checklist, available at: https://www.sign.ac.uk/checklists-and-notes.html. Accessed on January 31st, 2020.

Siegel, R. S., & Dickstein, D. P. (2011). Anxiety in adolescents: Update on its diagnosis and treatment for primary care providers. *Adolescent health, medicine and therapeutics, 3*, 1–16. https://doi.org/10.2147/AHMT.S7597

Singh, N. A., Stavrinos, T. M., Scarbek, Y., Galambos, G., Liber, C., & Fiatarone Singh, M. A. (2005). A randomized controlled trial of high versus low intensity weight training versus general practitioner care for clinical depression in older adults. The journals of gerontology. *Series A, Biological sciences and medical sciences, 60*(6), 768–776. https://doi.org/10.1093/gerona/60.6.768

Sriramatr, S., Silalertdeskul, S., & Wachirathanin, P. (2016). Social Cognitive Theory Associated with Physical Activity in Undergraduate Students: A Cross-sectional Study. *Pacific Rim international journal of nursing research, 20*, 95-105. https://he02.tci-thaijo.org/index.php/PRIJNR/article/view/41039

Smith, G., Williams, L., O'donnell, C., & McKechnie, J. (2016). The influence of social-cognitive constructs and personality traits on physical activity in healthy adults. *International Journal of Sport and Exercise Psychology*, 1-16. https://doi.org/10.1080/1612197X.2016.1142459

Spielberger, C.D. (Ed.). (1966). Anxiety and behavior. Academic Press.

Stodden DF, Goodway JD, Langendorfer SJ, Roberton MA, Rudisill ME, et al. (2008) A developmental perspective on the role of motor skill competence in physical activity: an emergent relationship. *Quest 60*: 290–306

Teixeira, P. J., Carraça, E. V., Markland, D., Silva, M. N., & Ryan, R. M. (2012). Exercise, physical activity, and self-determination theory: a systematic review. *The international journal of behavioral nutrition and physical activity, 9*, 78. https://doi.org/10.1186/1479-5868-9-78

Tetering, M., Laan, A., Kogel, C. H., Groot, R., & Jolles, J. (2020). Sex differences in self-regulation in early, middle and late adolescence: A large-scale cross-sectional study. *PloS one, 15*(1), e0227607. https://doi.org/10.1371/journal.pone.0227607

Tonello, L., Oliveira-Silva, I., Medeiros, A. R., Donato, A., Schuch, F. B., Donath, L., & Boullosa, D. (2019). Prediction of Depression Scores From Aerobic Fitness, Body Fatness, Physical Activity, and Vagal Indices in Non-exercising, Female Workers. *Frontiers in psychiatry, 10*, 192. https://doi.org/10.3389/fpsyt.2019.00192

Umstattd, M.R., Wilcox, S., Saunders, R., Watkins, K., & Dowda, M. (2008). Self-regulation and PA: The relationship in older adults. *American Journal of Health Behavior, 32*, 115–124. https://doi.org/10.5993/AJHB.32.2.1

Van Yperen, N. W. (2021). Achievement goals and self-regulation in the sport context. In P. A. M. Van Lange, E. T. Higgins, & A. W. Kruglanski (Eds.), *Social psychology: Handbook of basic principles* (pp. 589–606). The Guilford Press.

Vance, D. E., Marson, D. C., Triebel, K. L., Ball, K. K., Wadley, V. G., & Cody, S. L. (2016). Physical Activity and Cognitive Function in Older Adults: The Mediating Effect of Depressive Symptoms. *The Journal of neuroscience nursing: journal of the American Association of Neuroscience Nurses, 48*(4), E2–E12. https://doi.org/10.1097/JNN.0000000000000197

Wang, K., Yang, Y., Zhang, T., Ouyang, Y., Liu, B., & Luo, J. (2020). The Relationship Between Physical Activity and Emotional Intelligence in College Students: The Mediating Role of Self-Efficacy. *Frontiers in psychology, 11*, 967. https://doi.org/10.3389/fpsyg.2020.00967

Wang, L., Li, S., Wei, L., Ren, B., & Zhao, M. (2022). The Effects of Exercise Interventions on Mental Health in Chinese Older Adults. *Journal of environmental and public health, 2022*, 7265718. https://doi.org/10.1155/2022/7265718

Wankel, L.M. (1993). The importance of enjoyment to adherence and psychological benefits from physical activity. *International Journal of Sport Psychology, 24*, 151–169.

Welk, G. J. (1999). The youth physical activity promotion model: A conceptual bridge between theory and practice. *Quest, 51*, 5-23. https://doi.org/10.1080/00336297.1999.10484297

Wolf, S., Seiffer, B., Zeibig, J. M., Welkerling, J., Brokmeier, L., Atrott, B., Ehring, T., & Schuch, F. B. (2021). Is Physical Activity Associated with Less Depression and Anxiety During the COVID-19 Pandemic? A Rapid Systematic Review. *Sports medicine (Auckland, N.Z.), 51*(8), 1771–1783. https://doi.org/10.1007/s40279-021-01468-z

Xiao, Y., Wang, H., Zhang, T., & Ren, X. (2019). Psychosocial predictors of physical activity and health-related quality of life among Shanghai working adults. *Health and quality of life outcomes, 17*(1), 72. https://doi.org/10.1186/s12955-019-1145-6

Yli-Piipari, S., Watt, A., Jaakkola, T., Liukkonen, J., & Nurmi, J. E. (2009). Relationships between physical education students' motivational profiles, enjoyment, state anxiety, and self-reported physical activity. *Journal of sports science & medicine, 8*(3), 327–336.

Zhou, G., Wang, D., Knoll, N., & Schwarzer, R. (2016). Planning Mediates Between Self-Efficacy and Physical Activity Among Motivated Young Adults. *Journal of physical activity & health, 13*(1), 87–93. https://doi.org/10.1123/jpah.2014-0555

Ziegelmann, J. P., Lippke, S., & Schwarzer, R. (2006). Adoption and maintenance of physical activity: Planning interventions in young, middle-aged, and older adults. *Psychology & Health, 21*, 145–163. https://doi.org/10.1080/14768320500188891

Zimmerman, B. J., & Schunk, D. H. (2008). Motivation: An essential dimension of self-regulated learning. In D. H. Schunk & B. J. Zimmerman (Eds.), *Motivation and self-regulated learning: Theory, research, and applications* (pp. 1–30). Lawrence Erlbaum Associates Publishers.

Zulkosky, K. (2009), Self-Efficacy: A Concept Analysis. *Nursing Forum, 44*: 93-102. https://doi.org/10.1111/j.1744-6198.2009.00132.x

Zur, I., Cooke, A., Woodman, T., Neil, R., & Udewitz, R. (2019) Don't Make Me Angry! A Psychophysiological Examination of the Anger–Performance Relationship in Intermediate and Elite Fencers, *Journal of Applied Sport Psychology, 31*:3, 285-302. https://doi.org/10.1080/10413200.2018.1464079

3. The Sport Motivation Scale use in a cohort of Italian rugby players: a comprehensive analysis

A summary of the research scope, findings, and conclusions are reported in the box below.

Scope. The Sport Motivation Scale (SMS) is a widely used instrument that assesses motivational processes in different sport environments. In this study, we reproduced confirmatory factor analysis and investigate SMS reliability, temporal stability, and construct validity in a sample of 141 Italian semi-professional and amateur male rugby players from four different teams across the Country.
Findings. The seven-factor original SMS subscales did not optimally fit with the original validation but showed adequate internal consistencies (from 0.63 to 0.88). Results of correlational analysis among the SMS subscales and between the SMS and the overall types of motivation further supported the validity of the scale. Temporal stability measured with Lin's concordance and Pearson's correlation coefficients was satisfactory. There were no significant observed differences in SMS subscales according to rugby-specific parameters (type of role played, time spent in the same team, hours of training per week) except for increased external regulation and decreased introjected regulation in players with longer compared with shorter rugby experience. Finally, a structural equation model was built showing significant paths consistent with previous literature on self-determination theory and SMS.
Conclusions. The results reinforce the utility of the SMS in different groups of exercisers, including rugby players, and suggest performing further studies to investigate factors and interventions that can positively impact long-term sport motivation in rugby.

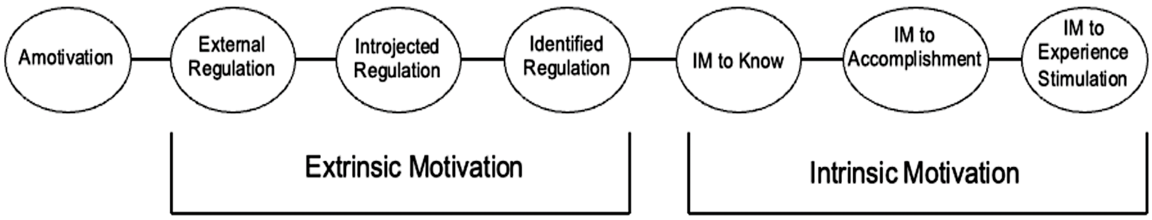
This work has been submitted for publication and is currently under review. I am first author and corresponding author of the paper.

3.1 Background

In sport, motivation represents a key construct that can facilitate beneficial and successful experiences (Duda, 2007; Vallerand, 2007). It has been suggested that motivation is the foundation of all athletic efforts and accomplishment (Adeyeye et al., 2013). Deci & Ryan self-determination theory (SDT) defines three broad types of motivation, namely intrinsic, extrinsic, and amotivated behaviours (Deci & Ryan, 1985; Ryan & Deci, 2004; Vallerand & Losier, 1999). Intrinsic motivation (IM) can be described as the driver to perform an activity because it is perceived as naturally enjoyable and gratifying. Extrinsic motivation (EM) is based on the gain of independent outcomes such as prizes, awards or - conversely - punishment, while amotivation (AM) stands out as the lack of intrinsic and extrinsic motivation. Vallerand et al. have further divided IM and EM into sub-motives (Vallerand et al., 1992). IM for engaging in activities can be differentiated into three different types, specifically IM to know (pleasure of learning or understanding), IM toward accomplishment (satisfaction of surpass oneself), and IM to experience stimulation (practice exciting experiences). In parallel, EM can be subclassified as external regulation (controlled by external sources such as rewards), introjected regulation (regulated by internal pressures to attain a reward) and identified regulation (accepting the action when it is personally important). These subgroups have been ordered along the self-determination continuum starting from IM (e.g., IM to experience stimulation, IM toward accomplishment, and IM to know) to EM (e.g., identified regulation, introjected regulation, external regulation) until AM (Deci & Ryan, 1985, 1991; Ryan & Deci, 2000), as reported in Figure 1.

Figure 1.

Constructs from the sport motivation scale according to the self-determination continuum



The different types of motivation were first assessed in a scale by Briere et al. (1995) and translated into English by Pelletier et al. (Pelletier et al., 1995) generating the Sport Motivation Scale (SMS). The SMS is widely used worldwide to measure motivation according to SDT in sports. The SMS includes 28 items and seven subscales, each composed by four items or types of motivation representing IM, EM, and AM. Chatzisarantis et al. performed a meta-analysis of perceived locus of causality in sport supporting the self-determination continuum from external regulation to introjection and identification with simplex-like correlation matrices (Chatzisarantis et al., 2003). SMS was also further validated in several studies, including both individual and team sports, showing adequate internal consistency as well as acceptable validity and temporal stability. English and French validations appeared useful to contribute to SMS structure, reliability, and the construct validity in populations with differences in age, geographic origin, or cultural background (Alexandris et al., 2002; Doganis, 2000; Goergiadis et al., 2001; Hamer et al., 2002; Jackson et al., 1998; Ntoumanis, 2001). In Italy, Candela et al. validated the SMS in an Italian sport context using transcultural procedures (e.g., translation and back-translation by bilingual individuals followed by revisions by sport psychology experts) (Candela et al., 2013).

This study has been performed involving male rugby union players in Italy. In Italy, rugby is not usually part of school sports activities or extracurricular activities, and it is frequently outclassed by soccer or basketball. Nevertheless, as of 2017 there are over 82,000 male and female registered rugby players in Italy, who are predominantly amateurs or semi-professional in nature, gaining little or no external rewards or income that are usually assigned to a small percentage of elite players (Topic: Rugby in Italy, 2022). Although the SMS scale has been previously used in rugby, in this context a validation process has not been clearly reproduced. Various factors, however, have been studied in the game of rugby in association with different forms of motivation. Burnout, for example, showed positive association with AM and negative association with IM (Cresswell et al., 2005). In this study, a burnout questionnaire was used in 199 professional rugby players who trained on average for 15 hours per week during the rugby season and had mean rugby experience of 4.12 years (SD = 2.69). The same authors performed a similar study involving 392 top amateur male rugby players with mean age 25.3 years (SD 4.3), rugby experience of 11.2 years (SD 6.6), and training on average 7.8 hours per week during the rugby season. The authors compared their sample with that of Pelletier et al., showing higher AM (2.28 vs. 1.75), external regulation (3.64 vs. 2.89), IM stimulation (5.09 vs. 3.69) and IM to accomplishment (4.87 vs. 3.69), however statistical significance between the two groups was not reported. Motivation to play rugby can vary across environments and cultures and includes passion for the game, involvement in sport, maintaining a healthy lifestyle, and gaining self-esteem (Cheng et al., 2016; Heazlewood et al., 2019). Conversely, reasons for demotivation leading to dropout in the elite setting include rigid development pathways with selection of players for representative sides very early in adolescence, lack of a long-term development with main emphasis on early success, overtraining or specialised training that focuses on aspects such as a perfect technique rather than exploring the players' own skill set (Rothwell et al., 2020).

The motivation can be challenged in rugby also in the transition from the amateur to the elite environment, where enjoyment can be lower with higher physical challenge (Rumbold et al., 2018). This is in line with research showing that experienced sport performers who remain engaged in their sport for prolonged periods advocate a developmental philosophy, which is based on a delayed specialisation while keeping a dedicated focus on personal development (Fraser-Thomas et al., 2008). Although there are studies focusing on motivation in rugby, elements that may specifically characterise non-elite rugby players, such as the years of experience in rugby, engagement in playing in the same team, the type of role played (e.g., backs vs. forwards), and basic abilities (such as passing skills) have not been investigated in relation to the different types of motivation using SMS.

3.2 Scope

The study aimed at validating the use of SMS in a non-probabilistic sample of Italian rugby players and investigating the relations between the motivation subscales and the three broad types of motivation (intrinsic motivation, extrinsic motivation, and amotivation). Firstly, we reproduced the validation process for SMS to examine the factor structure. Secondly, kurtosis, skewness, internal consistency, and correlations among subscales were investigated. The reproducibility of the SMS was retested after eight weeks in a subgroup of players. Thirdly, we evaluated the differences in the subscale means according to rugby-specific parameters. Finally, a structural equation model based on SDT was generated to explore SMS subscale correlation and their influence on the three broader types of motivation.

3.3 Methods

A total of 141 union rugby players (M age = 24.84, SD = 4.45, Min 18 – Max 41) were included between 2017 and 2020. The players were recruited from 4 different rugby clubs in Northern and Central Italy. The sample included amateurs and semi-professional players with mean rugby experience of over 10 years (M =12.49, SD = 5.56, Min 0.5 – Max 27). Participants' age and rugby-related parameters (e.g., experience, time spent in the current team, role in the team, and amount of weekly training) were collected. Passing ability was recorded based on a score assigned by the teams' coaches using (e.g., scoring for each player one, for lower ability, up to five, for higher ability, for both right and left-handed passes and calculating the proportion out of ten). A summary of the cohort's characteristics is reported in Table 1.

Table 1.
Characteristics of the included rugby players

Characteristics	Participants (n=141)
Age (years)	24.84 ± 4.40
Rugby experience (years ± SD)	12.40 ± 5.63
Years in same team (years ± SD)	5.23 ± 4.49
Training hours per week ± SD	9.74 ± 3.78
% Passing skills ± SD	55.31 ± 12.06
Role in the team (%)	
Forwards	67 (48)
Backs	74 (52)

3.3.1 Sport Motivation Scale (SMS)

We used the original SMS by Pelettier et al. (Pelletier et al., 1995) according to the Italian validated version described by Candela et al. (Candela et al., 2013) and adapted for rugby players. In the validation process by Candela et al. the scale was administered to 228 athletes with similar mean age compared with the present cohort (M age= 25, SD= 13). The SMS consisted of 28 items, 7 subscales (identified regulation, introjected regulation, external regulation, IM to experience stimulation, IM toward accomplishment and IM to know), and 3 broad motivation types (AM, EM-combined, and IM-combined). The overall structure was the same of the original scale (Pelletier et al., 1995) with questions referring to the game of rugby rather than sport in general (for example, in the AM subscale the question "*I used to have good reasons for doing sports, but now I am asking myself if I should continue doing it*" was posed as "*I used to have good reasons for playing rugby, but now I am asking myself if I should continue doing it*"). Each question was answered using a Likert scale ranging from 1 (does not apply at all) to 7 (applies exactly). Mean (M) and standard deviation (SD) were calculated according to previous reports (Pelletier et al., 1995). When we performed comparisons with other reports, e.g., Cresswell et al., only the available SMS subscales were included, and we used the same calculation for the average values (e.g., Likert scale average) to be consistent with the other paper's analysis.

3.3.2 Distribution and confirmatory factor analysis (CFA)

The distributions of skewness and kurtosis were investigated for each SMS subscale and for the three motivation types. A CFA to verify the construction validity of the subscales was conducted as previously described by other authors (Candela et al., 2013; Doganis, 2000; Filho et al., 2010;

Nunez et al., 2006; Pelletier et al., 1995) using a maximum likelihood method of estimation. The CFA model was built according to the results obtained by previous validations considering the relationships between the 7 subscales and the wider groups of AM, EM, and IM (Doganis, 2000; Nunez et al., 2006; Pelletier et al., 1995). Specifically, as shown in Table 3, amotivation did not show to correlate with other items except for external regulation, the least autonomous type of extrinsic motivation, while strong correlations were found between all forms of IM (Pelletier et al., 1995; Candela et al., 2013; Komarc et al. 2020).

CFA fitting was calculated using Chi-Square Test (model vs. saturated and baseline vs. saturated), Comparative Fit Indices (CFI), Tucker-Lewis Index (TLI) and Root Mean Square Error of Approximation (RMSEA) values.

3.3.3 SMS correlations and internal consistency

Pearson’s correlations were performed between the seven SMS subscales and between the subscales and the types of motivation (AM, EM, IM). Cronbach’s alpha was used to assess the internal consistency, both at baseline and in the subgroup assessment at eight weeks.

3.3.4 Temporal stability

SMS temporal stability has been previously shown by Nunez et al. in a sample of 275 athletes performing various sports but not including rugby (Nunez et al, 2006), with test-retest r values ranging from 0.69 to 0.74. In this study, SMS was retested after eight weeks in a sample of 47 players assuming there were no major changes or interventions during the study period. Test stability and concordance were measures using Pearson’s correlation coefficient and Lin's concordance correlation coefficient (CCC), respectively, for each subscale and type of motivation.

3.3.5 Group analysis according to rugby-specific parameters

Rugby parameters were grouped according to age (above or below 25 years old), time spent in participating in organized rugby (above or below 10 years), years of experience in the current team (above or below 5 years), role played (backs or forwards), hours of training per week (above or below 10 hours), and players’ passing skills (above or below 50%) and compared for each SMS subscale.

3.3.6 Structural Equation Model (SEM)

The modelling was based on SDT and structured to confirm the subscale structural validity in this sample and, specifically, showing the relationships between the subscales and AM, EM, IM. Compared with Cresswell et al., who performed SMS in a male group of nonprofessional rugby players in New Zealand with similar mean age, this sample included players who had longer experience as rugby players and were playing in the same team for longer. Based on these premises and on the abovementioned reports, we hypothesised that amotivation would have hardly correlated with IM and could only influence the less autonomous forms of EM such as external regulation that is consistent with motivators as external rewards (e.g., being amotivated may trigger the stimulus for tangible external rewards). Secondly, we hypothesised that EM would have mostly affected more autonomous forms such as introjected and identified regulation. Regarding IM, we expected to find an impact driven mainly by IM to know and to accomplishment, and potentially less affected by experience stimulation that can be mitigated by the long rugby experience.

3.3.7 Statistical analysis

For continuous variables, mean and standard deviation were calculated. For nominal variables, count and percentages were used. The association between categorical variables was assessed using Fisher's test. T-test was used to assess the difference of continuous variables. (D'Agostino, Belanger & D'Agostino, 1990) with the adjustment made by Royston (1991). The joint test for normality based both on skewness and kurtosis was used (Gould 1991). A factor confirmatory analysis was performed using Stata. A postestimation goodness of fit was assessed using Chi-Square Test, CFI, TLI, and RMSEA values. Pearson's correlation coefficient was used to test the correlations between SMS subscales and test-retest over time. Concordance was measured by Lin's concordance correlation coefficient (CCC). P values < 0.05 were considered significant. All analyses were carried out using Stata Version 17.0 (College Station, TX: StataCorp LP).

3.4 Results

A total of 141 male rugby players were included in the study and recruited within the first two months of the rugby season. Mean experience in playing rugby was 13 years, with average experience in playing in the current team of 5 years. The amount of time spent playing rugby, including training and matches, was around 10 hours per week. The players were evenly distributed between backs and forwards. The average passing ability was 55%. The players' characteristics are reported in Table 1.

Compared to a similar cohort of male union rugby players described by Cresswell et al, this group had comparable mean age (25.28 years, 95% CI 34.86 - 25.70 vs. 24.84, 95% CI 24.11 - 25.57, P=0.31) but significantly longer experience as rugby players (11.2 years, 95% CI 11.46 – 13.34 vs. 12.40, 95% CI 11.46 – 13.34, P=0.04) and an increased number hours of training per week (9.74 hours, 95% CI 9.11 – 10.37, P<0.001) although we included in the calculation also the amount of hours engaging in weekend matches (Cresswell et al., 2004).

3.4.1 Scale distribution and confirmatory factor analysis (CFA)

Skewness and kurtosis levels are reported in Table 2. We observed significant degrees of skewness and kurtosis for AM (P< 0.001), external regulation (P= 0.05), and IM to experience stimulation (P=0.04) with AM showing the most relevant differences. Conversely, optimal distributions were shown for IM-combined, EM-combined, IM to know, IM to accomplishment and forms of EM such as identified regulation and external regulation. The CFA model is reported in Figure 2.

Table 2.

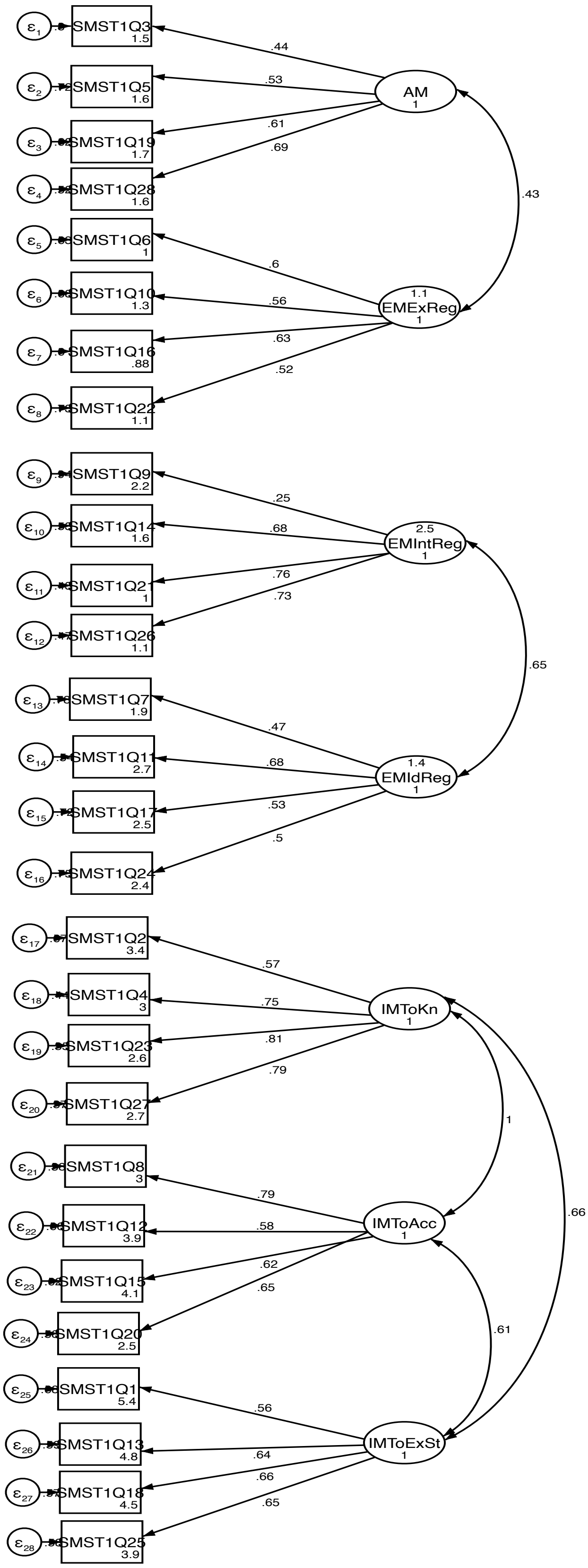
Descriptive statistics and internal consistency

Measure	M	SD	Skewness	Kurtosis	P	alpha
1. IM to know	17.957	4.991	-0.298	2.615	0.211	0.823
2. IM to accomplishment	19.014	4.421	-0.473	3.248	0.055	0.757
3. IM experience stimulation	22.404	3.611	-0.523	3.184	**0.039**	0.720
4. EM identified regulation	18.447	4.098	-0.266	2.898	0.406	0.630
5. EM introjected regulation	19.043	4.580	-0.355	2.755	0.189	0.675
6. EM external regulation	11.085	4.523	0.506	3.191	**0.045**	0.668
7. Amotivation	7.986	3.653	1.000	3.557	**0.0002**	0.652
8. IM-combined	59.376	11.235	-0.364	2.897	0.192	0.884
9. EM-combined	48.574	4.991	-0.298	2.615	0.575	0.766

Refers to 141 subjects. Abbreviations: EM= extrinsic motivation, IM= intrinsic motivation, M= mean, SD= standard deviation. Significant P values (joint test) in bold

Figure 2.

CFA model



Similar to what was reported in the original validation (Pelletier et al., 1995) and subsequently - and more soundly - confirmed by other authors attempting SMS validation, the model fit was not optimal according to the chi-square statistic (Nunez et al., 2006, Martens, 2002), showing in this case: $\chi 2$ model vs. saturated (345) = 817.083, $p < .001$, $\chi 2$ baseline vs. saturated (378) = 1814.559, $p < .001$, CFI = .67, TLI = .64, RMSEA = .09.
Three items, in particular, showed moderate or low values in three different subscales pertaining to non-autonomous motivation, namely AM (0.44, corresponding to the question “I used to have good reasons for playing rugby, but now I am asking myself if I should continue doing it”), introjected regulation (0.25, “because it is absolutely necessary to do sports, such as participating in rugby, if one wants to be in shape”), and identified regulation (0.47, “because, in my opinion, it is one of the best ways to meet people”).

3.4.2 Correlations within SMS subscales

Mean values by subscale are reported along with SD, skewness, kurtosis and alpha values in Table 2. Internal validity was similar to the one reported by Candela et al. (Candela et al., 2013) with values ranging from 0.65 for AM to 0.82 for IM to know. Compared to Cresswell et al., mean values for AM and external regulation in this sample were significantly lower (2.28, 95% CI 2.17 – 2.39 vs. 1.99, 95% CI 1.83 – 2.15, P< 0.001 for AM and 2.77, 95% CI 2.58 – 2.96 vs. 3.64, 95% CI 3.52 – 3.76, P< 0.001 for external regulation), IM to stimulation was significantly higher (5.09, 95% CI 5.00 – 5.18 vs. 5.6, 95% CI 5.45 – 5.75, P< 0.001), and IM to accomplishment was similar (4.87, 95% CI 4.76 – 4.98 vs. 4.75, 95% CI 4.57 – 4.93, P= 0.27) (Cresswell et al., 2004).
The correlations within SMS subscales are shown in Table 3 and were comparable to those highlighted by other reports and by articles validating SMS in different sports contexts (Doganis, 2000; Filho et al., 2010; Nunez et al., 2006; Pelletier et al.,1995; Cresswell et al., 2004).

Table 3.

Bivariate correlations

Measure	1	2	3	4	5	6	7	8	9
1. IM to know	1	0.781**	0.526**	0.554**	0.473**	0.407**	-0.125	0.920**	0.614**
2. IM to accomplishment		1	0.480**	0.582**	0.525**	0.368**	-0.028	0.895**	0.667**
3. IM experience stimulation			1	0.444**	0.587**	0.291**	-0.125	0.744**	0.501**
4. EM identified regulation				1	0.503**	0.262**	-0.042	0.618**	0.777**
5. EM introjected regulation					1	0.262**	-0.007	0.606**	0.788**
6. EM external regulation						1	0.223**	0.357**	0.696**
7. Amotivation							1	-0.053	0.081
8. IM-combined								1	0.697**
9. EM-combined									1

Cresswell et al. showed a significantly positive correlation between AM and external regulation (0.52 compared to 0.22 in this sample) and between IM-combined and external regulation (0.30 compared to 0.36 for this sample), while AM and IM-combined were not significantly correlated (-0.14 and -0.05 in our sample). No significant correlations were shown for AM except for external regulation. We observed high correlations between identified regulation and IM to know and between introjected and identified regulation. As expected, we observed high correlations within all IM subscales with values close or above 0.50 therefore confirming similar, but not identical, constructs for the IM components.

3.4.3 Scale stability over time

SMS temporal stability was shown in a subgroup of 47 players reassessed at 8 weeks (Figure 2). As shown in Table 4, chronback alpha was comparable or even higher at reassessment compared to baseline except for AM that decreased. Lin's test and Pearson's retest correlation showed significant correlations (Figure 3) over time especially for IM-combined (0.722), EM-combined (0.705) and IM to know (0.771) (Table 4).

Figure 3

Correlations between SMS repeated over time

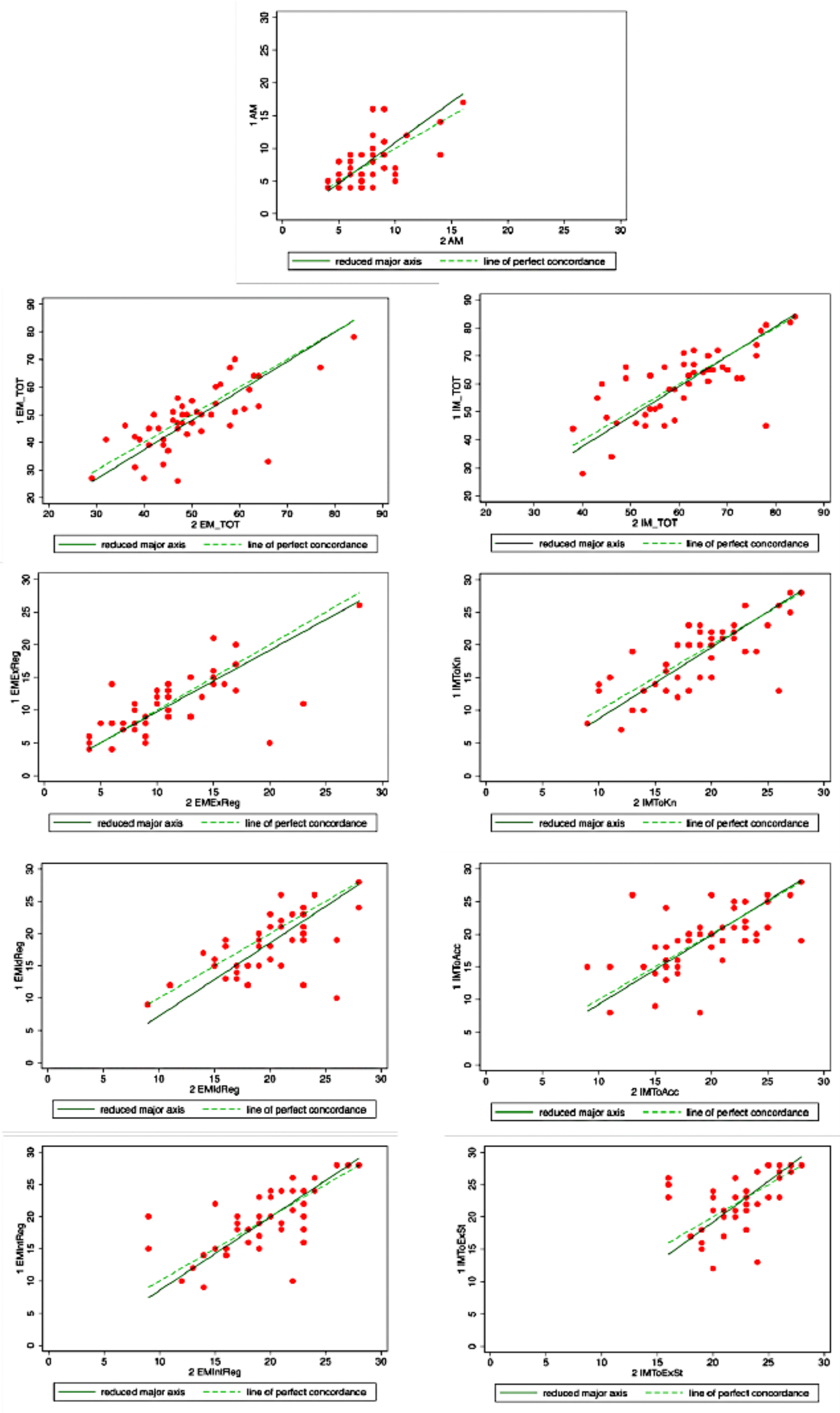


Table 4.

SMS temporal stability and internal consistency

Measure	alpha1	alpha2	CCC	P	r	P
IM-combined	0.883	0.904	0.722	<0.001	0.725	<0.001
EM-combined	0.766	0.841	0.705	<0.001	0.718	<0.001
IM to know	0.823	0.854	0.771	<0.001	0.777	<0.001
IM to accomplishment	0.757	0.748	0.599	<0.001	0.601	<0.001
IM experience stimulation	0.720	0.777	0.520	<0.001	0.564	<0.001
EM identified regulation	0.630	0.761	0.573	<0.001	0.611	<0.001
EM introjected regulation	0.675	0.722	0.666	<0.001	0.672	<0.001
EM external regulation	0.668	0.762	0.692	<0.001	0.695	<0.001
Amotivation	0.653	0.437	0.656	<0.001	0.673	<0.001

Alpha1 and alpha2 indicate internal consistency at time point 1 and 2. EM= extrinsic motivation, IM= intrinsic motivation. CCC= concordance correlation coefficient

3.4.4 Group analysis according to rugby-specific factors

Differences according to rugby-related factors in SMS subscales M and SD are reported in Table 5.

Table 5.

Bivariate correlations

Motivation subscales	Age < 24 years	Age ≥ 25	P
IM to know	17.849	18.074	0.658
IM to accomplishment	19.137	18.882	0.731
IM experience stimulation	22.397	22.412	0.824
EM identified regulation	18.014	18.912	0.167
EM introjected regulation	18.603	19.515	0.384
EM external regulation	11.278	10.882	0.517
Amotivation	8	7.971	0.852
	Rugby experience ≤ 10 years	**Rugby experience > 10 years**	
IM to know	18.288	17.603	0.277
IM to accomplishment	19.164	18.853	0.859

IM experience stimulation	22.041	22.794	0.268
EM identified regulation	18.397	18.500	0.988
EM introjected regulation	18.068	20.088	**0.005**
EM external regulation	12.096	10.000	**0.008**
Amotivation	7.781	8.206	0.904
	Years in current team < 5	**Years in current team ≥ 5**	
IM to know	18.211	17.662	0.659
IM to accomplishment	19.211	18.785	0.831
IM experience stimulation	22.171	22.677	0.458
EM identified regulation	18.250	18.677	0.538
EM introjected regulation	18.789	19.338	0.515
EM external regulation	11.382	10.738	0.578
Amotivation	8.132	7.815	0.625
	Forwards	**Backs**	
IM to know	17.716	18.176	0.741
IM to accomplishment	18.672	19.324	0.327
IM experience stimulation	22.328	22.473	0.672
EM identified regulation	18.955	17.986	0.165
EM introjected regulation	19.209	18.892	0.802
External	11.269	10.919	0.997
	7.552	8.378	0.250
	Training time ≤ 10 hours / week	**Training time > 10 hours / week**	
IM to know	18.630	17.050	0.08
IM to accomplishment	19.420	18.467	0.192
IM experience stimulation	22.284	22.567	0.565
EM identified regulation	18.988	17.717	0.143
EM introjected regulation	19.086	18.983	0.894
EM external regulation	11.420	10.633	0.267
Amotivation	8.025	7.933	0.496
	Passing ≤ 50%	**Passing > 50%**	
IM to know	18.141	17.771	0.705
IM to accomplishment	19.296	18.729	0.450
IM experience stimulation	23.183	21.614	**0.002**
EM identified regulation	18.887	18.000	0.212
EM introjected regulation	19.634	18.443	0.090
EM external regulation	10.817	11.357	0.280
Amotivation	7.789	8.186	0.469

N=141. EM= extrinsic motivation, IM= intrinsic motivation. Significant P values in bold.

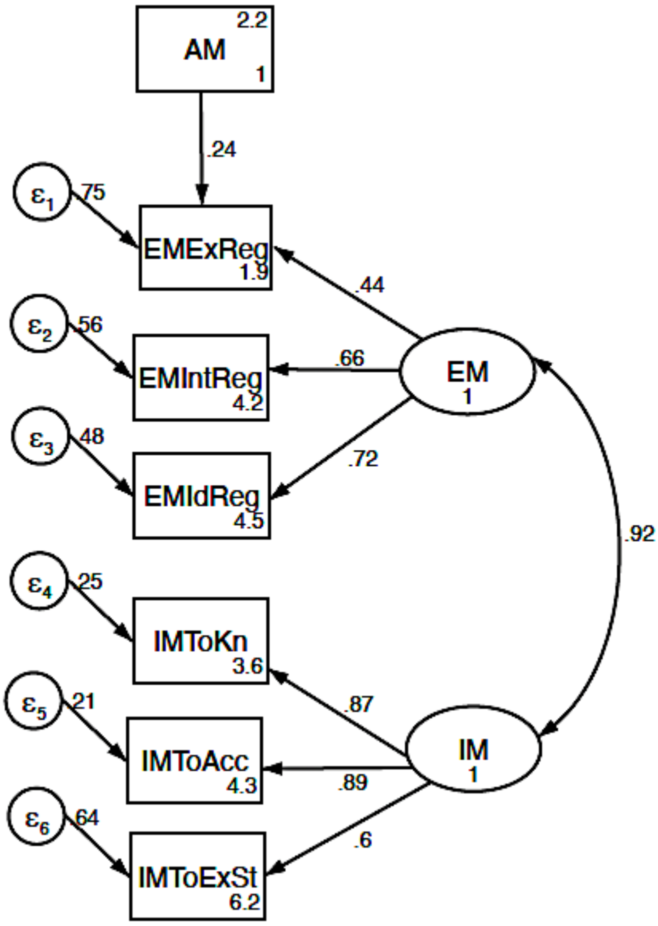
We did not observe major differences according to age, number of years of experience in playing rugby, training time per week, team role, or passing ability. One exception was represented by rugby experience for external regulation (increased in players with shorter compared with longer rugby experience) and for introjected regulation (increased in players with longer compared with shorter rugby experience). Moreover, we observed that intrinsic motivation to experience stimulation was increased in players with lower compared to higher passing skills.

3.4.5 SEM

According to the previous literature, we expected EM and IM to correlate within them, and AM to influence only extrinsic motivation. We expected high influence of EM on extrinsic motivation and external regulation and high impact of IM on all subscales, particularly IM to know and to accomplishment. As shown if Figure 4, the model showed all hypothesized paths.

Figure 4.

Structural Equation Model (SEM) based on self-determination theory.



We observed an overall good fit to the data: $\chi2$ model vs. saturated (13) = 36.01, p < .001, $\chi2$ baseline vs. saturated (21) = 377.54, p < .001, CFI = .94, TLI = .90, RMSEA = .11. Regarding the strength of the correlations, lower strength (<0.5) was noted for amotivation and external regulation and between external regulation and EM.

3.5 Discussion

We investigated SMS structure, validity, temporal stability, and correlations between subscales in a group of amateurs and semi-professional rugby players in Italy. Although only male players were included, our sample appeared representative of the Italian rugby population, as amateurs and semi-professional players from different teams and geographic areas were included.

Although we based our CFA on the information obtained by previous SMS, the overall fitting was suboptimal showing low TLI. While this result may be partially explained by the limited sample size and by a selected population (male rugby players), low TLI were previously reported by other authors performing CFA and including different sport performers (Nunez et al., 2006, Martens 2002). Despite an overall agreement about the validity of the scale, and especially about its usefulness, some studies have criticized the SMS arguing that specific items do not load adequately on their hypothesized factors and questioning about the validity of the instrument (Mallet et al., 2007; Martens & Webber, 2002; Reimer et al., 2002). For this reason, Mallet et al. (2007) proposed a revised SMS that includes most of the SMS original items, some new items and a new integrated regulation subscale. Despite these criticisms and the further SMS revisions, Pelletier et al. (2007) concluded that the revisions were not clearly warranted based on the SDT principles and that the literature (Alexandris et al., 2002; Doganis, 2000; Goergiadis et al., 2001; Hamer et al., 2002; Jackson et al., 1998; Ntoumanis, 2001; Pelletier et al., 2007) supports the overall validity of the scale original motivational constructs as measured by their indicators. Nevertheless, our results showed acceptable internal validity and temporal stability, with solid correlations within subscales that informed and fit very well our hypotheses for the SEM. Certain subscales and related items, however, showed non-normal distribution and lower reproducibility over time and may highlight some specificities in assessing motivation in the non-professional environment and for rugby players. Similar to what has been previously reported, our model showed that AM influences external regulation with limited impact on more autonomous forms of motivation. Situation such as these highlight SDT's concept of internalization of externally regulated motivators that may take place within an experienced cohort of rugby players when they value the integration of certain mundane activities that provide for external regulated motivators to reach a valued outcome. Within groups of rugby players mundane training drills maybe such seen as such an example where punishment for mistakes may take the form of re rehearsal until the drill is undertaken correctly and to an adequate level of performance. This would be consistent with Organismic Integration Theory (OIT), a sub-theory of SDT that suggests EM can vary and is dependent on the amount of autonomy and how one values and perceives an activity (Ryan & Deci, 2000). In the SEM we observed a high impact on being intrinsically motivated caused by all forms of IM. Rugby is an extremely physical and mentally demanding game that requires commitment to training and game day with the potential of serious injury to muscles, joints, or concussions. This whilst balancing school, work, and family commitments in amateurs. The environment (e.g., coaches, team feeling) can play a pivotal role providing a favourable "microsystem" that, for experienced players with prolonged experience in the same team, may built on a sense of belonging where elements such as trust and confidence are consistently placed in the players by the staff and other players (Rothwell et al., 2020). Therefore, it is highly beneficial for rugby players and the continuation of the sport that people who play rugby have self-determined forms of motivation to favour behaviour persistence (Sarrazin et al., 2007; Guzman et al., 2012). Compared to a larger cohort of male nonprofessional rugby players, with comparable mean age, we observed lower AM and EM while IM to experience was higher. Our sample included subjects with prolonged rugby experience, often playing long-term in the same team, and performing consistent weekly training (Cresswell et al., 2004). It is possible that these characteristics, that have been linked to persistent participation behaviour in other sports (Rottensteiner et al., 2015; Guillet et al., 2002), strongly favoured self-determined forms of motivation and less AM and extrinsic motivation. In our study, the type of motivation did not significantly differ according to the role played (e.g., backs or forwards), the overall training time, and the time spent in the current team, supporting the fact that our sample was quite homogeneous. Rugby experience (e.g., participating in rugby for > 10 years), however, appeared as an interesting parameter to investigate in future work and may have a selective impact on EM. In general, EM underlies engagements regulated by the pursuit of some outcomes separate from involvement in the activity itself (Vallerand, et al., 1992). Teixeira et al. found negative associations between external regulation and exercise behaviour in 16 independent samples (Texteira et al., 2012). This may suggest that when players mature in experience and especially at an armature level that they become more aware and less keen in accepting rewards or coercive external motivations to reach certain goals. A significant relationship was found between high experience and increased introjected regulation. Introjected regulation describes engaging in activity based on the approval of others or on social comparisons. While this type of behaviour is internally driven, it has an external perceived locus of control (EPLOC) (Deci and Ryan, 1995). Since the causality of the behaviour is believed to be external, the behaviour is considered non-self-determined (Ryan & Deci, 2000). This correlation maybe explained in that rugby players with higher years of experience are practicing and playing rugby because they feel social pressure to look good, be part of a social group and be in good shape and they feel embarrassed when they feel they are not looking at their best in comparison to player with less experience. (Pelletier et al., 1995). Furthermore, it maybe that these ideals are valued within this group so that they are accepted as personally important and maybe perceived as steps towards an ideal and development as a person (Pelletier et al., 1995).

IM to experience was significantly higher among players with lower passing ability based on the coaches' perception (in comparison with players with higher perceived passing ability. IM to experience refers to motivation to experience stimulating sensations (e.g., excitement, thrills) resulting from participation to a certain activity (Pelletier et al., 1995; Vallerand & Losier, 1999). This correlation maybe explained by reasoning that rugby players experience stimulation when they are passing during practice and in rugby games. This can be further hypothesized that this group of players find passing a rugby ball more exciting and dynamic, they can see themselves improving, attaining proficiency, and as a result, passing a rugby ball provides positive, stimulating experiences, including fun and enjoyment than higher perceived passing ability players (Banack et al., 2011). These elements may help in providing a further insight into psychological dimensions that support the reasons why some rugby players choose to continue to play and why others decide to quit (Vallerand & Losier, 1999; Vallerand & Rousseau, 2001).

In conclusion, we observed reproducible results in terms of SMS internal consistency, correlations within subscales, and temporal stability compared with previous studies (Nunez et al., 2006; Cresswell et al., 2005; Komarc et al., 2020). An understanding of the SMS applications and the psychological processes that underpin athlete motivation is of pivotal importance for coaches, administrators and policy makers when looking to interpret and enhance an athlete's motivation both in the short- and especially long-term (Vallerand & Losier, 1999; Vallerand & Rousseau, 2001). Further studies are needed to investigate factors and interventions that impact motivation in rugby, including male and female players and adapting the study to the group characteristics. These results can encourage stakeholders to formulate strategies to provide motivational interventions that are conducive to and fulfils the needs of athletes so that they are inspired, strive to learn, extend themselves, master new skills, and apply their talents responsibly (Reinboth & Duda, 2006).

My future plans include the study of other variables that are relevant in rugby players, such as ego and task orientations as well as the study of psychological needs such as autonomy, competence, and relatedness.

3.6 References

Adeyeye, M. F., Vipene, J.B., & Asak, A. D. (2013). The Impact of Motivation on athletic achievement. A case study of the 18th national sports festival, Lagos, Nigeria. Academic Research International. 4. 378-383.

Alexandris, K., Tsorbatzoudis, C., & Grouios, G. (2002). Perceived constraints on recreational sport participation: Investigating their relationship with intrinsic motivation, extrinsic motivation and amotivation. J Leisure Res, 34(3), pp.233-252

Brière, N.M., Vallerand, R.J., Blais, M.R., & Pelletier, L.G. (1995). Devéloppement et validation d'une mesure de motivation intrinsèque, extrinsèque et d'amotivation en context sportif: l'Echelle de Motivation dans les Sports (EMS). Int J Sport Psychol, 26(4), pp.465-489

Candela F, Zucchetti G, Villosio C. Preliminary validation of the Italian version of the original sport motivation scale. J Human Sport Exercise 2014;9:136-147

Cheng, E.; Hui, P.; Pegg, S.; Stebbins, R. Old Bodies, Young Hearts: A Qualitative Exploration of the Engagement of Older Male Amateur Rugby Union Players in Taiwan. Leis. Stud. 2016, 35, 549–563

Chatzisarantis, N.L.D., Hagger, M.S., Biddle, S.J.H., Smith, B., & Wang, J. (2003). A meta-analysis of perceived locus of causality in exercise, sport, and physical education contexts. J Sport Exercise Psy, 25(3), pp.284-306

Cresswell SL, Eklund RC. Motivation and burnout among top amateur rugby players. Med Sci Sports Exerc. 2005 Mar;37(3):469-77.

D'Agostino, R. B., A. J. Belanger, and R. B. D'Agostino, Jr. 1990. A suggestion for using powerful and informative tests of normality. American Statistician 44: 316–321.

Deci, E. L., & Ryan, R. M. (1980). The empirical exploration of intrinsic motivational processes. In L. Berkowitz (Ed.), Advances in experimental social psychology (Vol. 13, pp. 39–80). New York: Academic.

Deci, E.L., & Ryan, R.M. (1985) Intrinsic motivation and self-determination in human behavior. New York: Plenum, 1985.

Deci, E. L., & Ryan, R. M. (1985b). Intrinsic motivation and self-determination in human behavior. New York: Plenum.

Deci, E. L. & Ryan, R. M. (1991). A motivational approach to self: Integration in personality. In

R. Dienstbier (Ed.), Nebraska Symposium on Motivation: Perspectives on motivation (pp. 237-288). Lincoln: University of Nebraska Press.

Doganis, G. (2000). Development of a Greek version of the Sport Motivation Scale. Percept Motor Skill, 90(2), pp.505-512

Duda, J.L., & Balaguer, I. (2007). Coach-created motivational climate. In S. Jowett & D. Lavalle (Eds.), Social psychology in sport (pp. 117–130). Champaign, IL: Human Kinetics

Filho M.B., Andrade, D., Miranda, R., Nunez, J.L, Martin-Albo, J., & Ribas, P.R. (2010). Preliminary validation of a brazilian version of the sport motivation scale. Univ Psychol, 10(2), pp.557-566

Fraser-Thomas, J., Côté, J., & Deakin, J. (2008a). Examining adolescent sport dropout and prolonged engagement from a developmental perspective. Journal of Applied Sport Psychology, 20, 318–333. doi:10.1080/10413200802163549

Goergiadis, M.M., Biddle, S.J.H., & Chatzisarantis, N.L.D. (2001). The mediating role of self determination in the relationship between goal orientations and physical worth in Greek exercisers. Eur J Sport Sci, 1(5), pp.1-9

Gould, W. W. 1991. sg3: Skewness and kurtosis tests of normality. Stata Technical Bulletin 1: 20–21. Reprinted in Stata Technical Bulletin Reprints, vol. 1, pp. 99–101. College Station, TX: Stata Press.

Guillet, E., Sarrazin, P., Carpenter, P. J., Trouilloud, D., and Cury, F. (2002). Predicting persistence or withdrawal in female handballers with social exchange theory. Int. J. Psychol. 37, 92–104. doi: 10.1080/00207590143000243

Guzmán, J. F., & Kingston K. (2012) Prospective study of sport dropout: A motivational analysis as a function of age and gender, European Journal of Sport Science, 12:5, 431-442, DOI: 10.1080/17461391.2011.573002

Hamer, M., Karageorghis, C.I., & Vlachopoulos, S.P. (2002). Motives for exercise participation as predictors of exercise dependence among endurance athletes. J Sports Med Phys Fit, 42(2), pp.233-238

Heazlewood, T.; Walsh, J.; Climstein, M. Participant Motivation of Male Master's Rugby Players Participating in Golden Oldies World Rugby Festival. In Proceedings of the World Congress on Science & Football, Melbourne, Australia, 4–7 June 2019

Jackson, S.A., Kimiecik, J.C., Ford, S.K., & Marsh, L.W. (1998). Psychological correlates of flow in sport. J Sport Exercise Psy, 20(4), pp.358-378

Komarc M, Harbichová I, Scheier LM. Psychometric validation of Czech version of the Sport Motivation Scale. PLoS One. 2020 Jan 2;15(1):e0227277.

Mallett, C. (2005). Self-determination Theory: A case study of evidence-based coaching. The Sport Psychologist, 19, 417-429.

Martens, M.P., & Webber, S.N. (2002). Psychometric properties of the sport motivation scale: An evaluation with college varsity athletes from the US. J Sport Exercise Psy, 24(3), 254-270.

Ntoumanis, N. (2001). Empirical links between achievement goal theory and self-determination theory in sport. J Sport Sci, 19(6), pp.397-409 Italian

Nunez, J.L., Martin-Albo, J., Navarro, J.G., & Gonzales, V.M. (2006). Preliminary validation of a Spanish version of the Sport Motivation Scale. Percept Motor Skill, 102(3), pp.919-930

Pelletier, L. G., Fortier, M. S., Vallerand, R. J., Tuson, K. M., et al. (1995). Toward a new measure of intrinsic motivation, extrinsic motivation, and amotivation in sports: The Sport Motivation Scale (SMS). *Journal of Sport & Exercise Psychology, 17(1), 35–53.*

Rottensteiner, C., Konttinen, N., and Laakso, L. (2015). Sustained participation in youth sports related to coach-athlete relationship and coach-created motivational climate. Int. Sport Coach. J. 2, 29–38. doi: 10.1123/iscj.2014-0060

Royston, P. 1991 1991c. sg3.5: Comment on sg3.4 and an improved D'Agostino test. Stata Technical Bulletin 3: 23–24. Reprinted in Stata Technical Bulletin Reprints, vol. 1, pp. 110–112. College Station, TX: Stata Press.

Rumbold, J. L., Fletcher, D., & Daniels, K. (2018). Using a mixed method audit to inform organizational stress management interventions in sport. Psychology of Sport & Exercise, 35, 27–38. doi:10.1016/j.psychsport.2017.10.010

Ryan, R. M., & Deci, E. L. (2000). Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. American Psychologist, 55(1), 68–78. https://doi.org/10.1037/0003-066X.55.1.68

Ryan, R. M., & Deci, E. L. (2004). Autonomy is no illusion: Self-determination theory and the empirical study of authenticity, awareness, and will. In J. Greenberg, S. L. Koole, & T.

Pyszczynski (Eds.), Handbook of experimental existential psychology (pp. 449–479). New York: The Guilford Press.

Rothwell, M., Rumbold, J. L., & Stone, J. A. (2020). Exploring British adolescent rugby league players' experiences of professional academies and dropout. International Journal of Sport and Exercise Psychology, 18(4), 485–501.

Sarrazin, P., Boiché, J., & Pelletier, L. (2007). A self-determination theory approach to dropout in athlete. In M. Hagger & N. Chatzisarantis (Eds.), Intrinsic motivation and Self-Determination in exercise and sport (pp. 229-241). Champaign, Illinois: Human Kinetics Publisher.

Statista. 2022. Topic: Rugby in Italy. [online] Available at: <https://www.statista.com/topics/6375/rugby-in-italy/#dossierKeyfigures)> [Accessed 12 September 2022].

Teixeira, P.J., Carraça, E.V., Markland, D. et al. Exercise, physical activity, and self-determination theory: A systematic review. Int J Behav Nutr Phys Act 9, 78 (2012). https://doi.org/10.1186/1479-5868-9-78

Vallerand, R.J. (1997). Toward a hierarchical model of intrinsic and extrinsic motivation. In M. P. Zanna (Ed.), Advances in experimental social psychology (Vol. 29, pp. 271-360). New York: Academic Press.

Vallerand, R.J., & Losier, G.F. (1999). An integrative analysis of intrinsic and extrinsic motivation in sport. J Appl Sport Psychol, 11(1), pp.142-169

Vallerand, R. J. (2007). Intrinsic and extrinsic motivation in sport and physical activity. A review and a look at the future. In G. C. Tenenbaum & R. Eklund (Eds.), Handbook of sport psychology (3rd ed.) (pp. 59-83). New York, USA: John Wiley.

Vallerand, R.J., Blais, M.R., Brière, N.M., & Pelletier, L.G. (1989). Construction et validation de l'Echelle de Motivation en Education (EME). Can J Behav Sci, 21(3), pp.323-349

Vallerand, R.J., Pelletier, L.G., Blais, M.R., Brière, N.M., Senecal, C.B., & Vallieres, E.F. (1992). The academic motivation scale: A measure of intrinsic, extrinsic, and amotivation in education. Educ Psychol Meas, 52, pp.1003-1017

4. Physical activity: Benefits and challenges during the COVID-19 pandemic

I acknowledge that this paper has been already published as a free access publication and the data are reported here according to the indications provided by the publisher (Wiley).

The first instances of the coronavirus (COVID-19) pandemic were reported in Wuhan, China, in December 2019 (Dong et al., 2020). Using a spike protein that connects to the angiotensin-converting enzyme 2 (ACE2) receptors expressed on a variety of human cells, including the lung epithelial cells, COVID-19 infects the host's cells similarly to other coronaviruses (Remuzzi & Remuzzi, 2020). When this article was written at the beginning of the pandemic (May 2020) globally 3 665 912 patients had tested positive and 257 337 of these passed away (Dong et al., 2020). The study of the ACE2 receptors and their characteristics appeared important to understand viral entry and pathogenic factors. Smoking or taking specific anti-hypertensive drugs were two examples of putative triggers that may encourage the development of ACE2 receptors; however, there was a lack of strong data to support these theories. It is well established, however, that vulnerable groups are more susceptible to severe COVID-19, including the elderly, immunosuppressed individuals, and patients with several concomitant conditions.
In Italy, during the first pandemic wave in 2020, adults between 80 and 89 years old had a case fatality rate that was 4.47 times greater than that of those between the ages of 60 and 69 (Wan et al., 2020). Among COVID-19 patients who needed hospitalization, diabetes, hypertension, and cardiovascular illnesses were reported as the most common comorbidities (Chen et al., 2020).
The link between physical activity and COVID-19 severity appears to favour exercise as a protective factor, although anecdotical cases of healthy physically fit young subject developing sever COVID-19 have been reported, potentially linked to the type of viral variant or high viral load. As a general principle, by lowering both systolic and diastolic blood pressure and reshaping left ventricular hypertrophy, physical activity helps to minimize overall cardiovascular risks (Hegde & Solomon 2015). Additionally, PA is proven to improve insulin sensitivity and the metabolic syndrome (Ahmed et al., 2012). Therefore, it stands to reason that active individuals should have better control of high-risk comorbidities that enhance vulnerability to severe COVID-19 than sedentary individuals. However, in this brief report unanswered issues between PA and COVID-19 predisposition were discussed. Specifically, while moderate-intensity exercise is good for the immune system, some studies have shown that single bouts of prolonged

exercise can cause immune suppression (such as a derangement in type I and II cytokine balance) in the hours and days after exercise, which may increase the risk of infection (Simpson et al., 2015). Other authors have disputed these ideas, arguing that exercise - including high-intensity training - might actually be advantageous and doesn't cause immune suppression or, at least, clinically significant consequences that may have an impact on infection predisposition (Nieman & Wentz, 2019; Campbell & Turner, 2018). Moreover, the impact of PA on ACE2 receptor modulation has been documented, particularly in animal research; nevertheless, clinical effects on angiotensin-related pathways in humans are largely unknown (Motta-Santos et al., 2016; Nunes-Silva et al., 2017).

In general, and during the COVID-19 pandemic associated restrictions, it was widely agreed that if people are healthy, they should strive to exercise as much as they can, even at home, without changing their exercise regimen (Chen et al., 2020).

Even with the COVID-19 growing globally and driving politicians, institutions, and experts to give people answers and guidance, there were still significant exercise prescription concerns to be made. Fitness centres shut down, and contests and training for athletes at all levels were suspended in numerous nations. Long-term (i.e., more than two weeks) self-quarantine made it difficult to be physically active and may have lowered people's quality of life. There have been reports of elevated stress following social estrangement during earlier coronavirus outbreaks (Hawryluck et al., 2004). I underline that exercise at home should be encouraged; moreover, home exercise is not a new concept, and numerous clinical populations have reported on the positive effects of home exercise on both physical and psychological characteristics (Kawagoshi et al., 2015; Karapolat et al., 2008). The type and quantity of PA that is advised for home training during the COVID-19 pandemic, however, was initially not clearly addressed in any guideline’s, documents, or peer-reviewed publications at this time. This publication focused on this need and on the prioritisation of information given to the public

We looked for information about PA on the internet using the terms "COVID-19," "coronavirus," "physical activity," "exercise," "home-based," and "training." Various documents were acquired from institutions and governmental authorities in six different countries (Table 1). The key information from the major sources is summarized in Figure 1 together with the helpful characteristics for PA during the COVID-19 pandemic and the level of priority.

In order to exercise within the WHO worldwide recommendations of 150 minutes of moderate-intensity PA or 75 minutes of vigorous-intensity PA (or a combination of both) each week, there are some simple suggestions that are easy to implement (World Health Organization; (Emmanuel Stamatakis Professor of Physical Activity et al., 2022). The recommendations are based on useful advice like taking quick activity breaks and attending online classes. Moreover, to show how a vigorous home activity can be set up, advertising and promotions on electronic platforms like YouTube, Facebook, Twitter, exercise apps for phones or tablets, and video conference type software are available. Of course, this is not without limitations due to a lack of space and specialized training equipment. Device such as pedometers or other wearable devices, such as smartwatches, are promising tools that can be used to track, improve, and measure home-based workouts. Nevertheless, especially at the beginning of the pandemic, specific recommendations, or indications on how these tools should be used and their associated goals were lacking. Moreover, digital technology can be used to record physical parameters that may indicate the level of fitness as well as to advertise and promote exercise interactively, including sharing the results of performance with peers or, potentially, health providers.

In conclusion, PA is recommended during the COVID-19 pandemic due to its numerous advantages for both physical and mental health, provided that social distance is respected. It is essential to customize training for each individual based on age, clinical circumstances, and level of fitness; as a result, evidenced-based, specific guidelines for home-based training are highly needed.

Not all sources, however, reported criteria such as references or personalised training according to age or comorbidities. Several had figures included and easy-to-perform exercise, but only a minority were interactive or covered psychological aspects such as stress or isolation that could have been improved through exercise. The possibility of providing a follow-up was generally limited. Some of these limitations may be overcome, in the future, by digital technology and wearables, as explored in the following sessions.

Table 1.

Sources reporting statements and indications for exercising at home at the beginning of the pandemic (e.g., during lockdown and COVID-19-related restrictions)

The table below reproduces the one published in the related article (Dwyer et al., 2020)

Country	Source	Type of document	Reference provided	Website
Australia	Australian Institute of Sport (AIS)	Website statements on PA as an important part of physical and mental health; suggests continuing to train for those who are well; athletes should discuss training strategies with their national sporting organisations and coaching staff	No reference to published guidelines provided	https://ais.gov.au/healthwellbeing/covid-19#covid-19_and_sport_faq
	Exercise and sport science Australia (ESSA)	Reinforces the association between PA and improved immunity Provides downloadable posters about exercising at home	Links to peer-reviewed articles are provided	https://exerciseright.com.au/exercise-home/ https://www.essa.org.au/Public/News_Room/Media_Releases1/2020/Exercise%20Right%20at%20Home.aspx
Canada	Canadian Society for Exercise Physiology (CSEP)	Short PDF document on maintaining healthy movement behaviours during COVID-19	Refers to age-related, 1-page national guidelines for PA, sleep and sedentary time	https://csep.ca/Movement_Behaviours_and_COVID-19_%20CSEP_Members%202.pdf
WHO Europe	WHO	Document "Stay physically active during self-quarantine" with vignettes providing examples of exercises	Reference to WHO recommendation (e.g., 150 minutes of moderate-intensity or 75 minutes of vigorous-intensity physical activity per week, or a combination of both)	https://www.who.int/news-room/q-a-detail/be-active-during-covid-19
New Zealand	NZ Government	Brief advice on exercise safely HealthNavigator NZ (endorsed by Royal NZ College of General Practitioners) provides links to apps and TV programs dedicated to exercising at home	No reference to published guidelines provided	https://covid19.govt.nz/individuals-and-households/health-and-wellbeing/exercising-safely/
Singapore	Department of Physiotherapy and LIFE Centre at Singapore General Hospital	Does not specifically refers to COVID-19; website page "Exercising at Home: Workout Essentials and Tips to Stay Safe" Provides a brief list of exercises and useful items to use; refers as a target of 150 minutes of moderate-intensity aerobic activity per wk	No reference to published guidelines provided	https://www.healthxchange.sg/fitness-exercise/exercise-tips/exercising-home-workout-essentials-tips-stay-safe
UK	National Health Service (NHS)	Guidance on looking after physical and mental wellbeing for the community Provides links to 1. Public health England 10-minute home workout (cardio, strengthening, stretching) with videos; 2. NHS Fitness studio with exercise videos	Reference to NHS recommendations provided	https://www.gov.uk/government/publications/covid-19-guidance-for-the-public-on-mental-health-and-wellbeing/guidance-for-the-public-on-the-mental-health-and-wellbeing-aspects-of-coronavirus-covid-19
United States	American College of Sports Medicine (ACSM)	PDF document with recommendation on performing regular moderate-intensity PA to maintain better immune function and to reduce stress and anxiety Provides 1-page practical examples for aerobic activity and strength training	Refers to Physical Activity Guidelines for Americans (150-300 min/wk of moderate-intensity aerobic PA and 2 sessions/wk of muscle strength training) Provides link to CDC website for COVID-19 updates	https://www.exerciseismedicine.org/assets/page_documents/EIM_Rx%20for%20Health_%20Staying%20Active%20During%20Coronavirus%20Pandemic.pdf https://www.cdc.gov/coronavirus/2019-ncov/about/index.html

Wk= week; PA= physical activity

Figure 1.

Characteristics of home-based exercise addressed by media and organisation during the COVID-19 pandemic restrictions. Plus (+) and minus (-) signed relates to the level of prioritisation

The table below reproduces the one published in the related article (Dwyer et al., 2020)

Features	World Health Organisation	National Sport Societies	Government sources	Online platforms and social media
References to published guidelines	++	+	+	-
Based on level of expertise or fitness	+	++	+	+
Age-related	+	++	+	+/-
Explanation of expected effects	++	++	+	+/-
Practical exercises included	+++	++	++	+++
Providing follow-up	+/-	+/-	+/-	+
Figures included	+++	++	++	+
Video available	-	+/-	+/-	+++
Interactive	-	+/-	-	++
Psychological aspects covered	++	+	++	+/-
Clinical status considered	+/-	++	+	+/-
Easy to perform	+++	++	+++	++

4.1 References

Ahmed, H. M., Blaha, M. J., Nasir, K., Rivera, J. J., & Blumenthal, R. S. (2012). Effects of physical activity on cardiovascular disease. *American Journal of Cardiology*, *109*(2), 288-295. https://doi.org/10.1016/j.amjcard.2011.08.042

Campbell, J. P., & Turner, J. E. (2018). Debunking the Myth of Exercise-Induced Immune Suppression: Redefining the Impact of Exercise on Immunological Health Across the Lifespan. *Frontiers in immunology*, *9*, 648. https://doi.org/10.3389/fimmu.2018.00648

Chen, N., Zhou, M., Dong, X., Qu, J., Gong, F., Han, Y., Qiu, Y., Wang, J., Liu, Y., Wei, Y., Xia, J., Yu, T., Zhang, X., & Zhang, L. (2020). Epidemiological and clinical characteristics of 99 cases of 2019 novel coronavirus pneumonia in Wuhan, China: a descriptive study. *Lancet (London, England)*, *395*(10223), 507–513. https://doi.org/10.1016/S0140-6736(20)30211-7

Chen, P., Mao, L., Nassis, G. P., Harmer, P., Ainsworth, B. E., & Li, F. (2020). Coronavirus disease (COVID-19): The need to maintain regular physical activity while taking precautions. *Journal of sport and health science*, *9*(2), 103–104. https://doi.org/10.1016/j.jshs.2020.02.001

Dong, E., Du, H., & Gardner, L. (2020). An interactive web-based dashboard to track COVID-19 in real time. *The Lancet. Infectious diseases*, *20*(5), 533–534. https://doi.org/10.1016/S1473-3099(20)30120-1

Emmanuel Stamatakis Professor of Physical Activity, Andrew Murray Consultant, Fiona Bull Professor, & Kate Edwards Associate Professor. (2022, July 20). *How to stay fit and active at home during the coronavirus self-isolation*. The Conversation. Retrieved December 4, 2022, from https://theconversation.com/how-to-stay-fit-and-active-at-home-during-the-coronavirus-self-isolation-134044

Karapolat, H., Akkoc, Y., Sari, I., Eyigor, S., Akar, S., Kirazli, Y., & Akkoc, N. (2008). Comparison of group-based exercise versus home-based exercise in patients with ankylosing spondylitis: effects on Bath Ankylosing Spondylitis Indices, quality of life and depression. *Clinical rheumatology*, *27*(6), 695–700. https://doi.org/10.1007/s10067-007-0765-0

Kawagoshi, A., Kiyokawa, N., Sugawara, K., Takahashi, H., Sakata, S., Satake, M., & Shioya, T. (2015). Effects of low-intensity exercise and home-based pulmonary rehabilitation with pedometer feedback on physical activity in elderly patients with chronic obstructive pulmonary disease. *Respiratory medicine*, *109*(3), 364–371. https://doi.org/10.1016/j.rmed.2015.01.008

Hawryluck, L., Gold, W. L., Robinson, S., Pogorski, S., Galea, S., & Styra, R. (2004). SARS control and psychological effects of quarantine, Toronto, Canada. *Emerging infectious diseases*, *10*(7), 1206–1212. https://doi.org/10.3201/eid1007.030703

Hegde, S. M., & Solomon, S. D. (2015). Influence of Physical Activity on Hypertension and Cardiac Structure and Function. *Current hypertension reports*, *17*(10), 77. https://doi.org/10.1007/s11906-015-0588-3

Motta-Santos, D., Dos Santos, R. A., Oliveira, M., Qadri, F., Poglitsch, M., Mosienko, V., Kappes Becker, L., Campagnole-Santos, M. J., M Penninger, J., Alenina, N., & Bader, M. (2016). Effects of ACE2 deficiency on physical performance and physiological adaptations of cardiac and skeletal muscle to exercise. *Hypertension research : official journal of the Japanese Society of Hypertension*, *39*(7), 506–512. https://doi.org/10.1038/hr.2016.28

Nieman, D. C., & Wentz, L. M. (2019). The compelling link between physical activity and the body's defense system. *Journal of sport and health science*, *8*(3), 201–217. https://doi.org/10.1016/j.jshs.2018.09.009

Nunes-Silva, A., Rocha, G. C., Magalhaes, D. M., Vaz, L. N., Salviano de Faria, M. H., & Simoes E Silva, A. C. (2017). Physical Exercise and ACE2-Angiotensin-(1-7)-Mas Receptor Axis of the Renin Angiotensin System. *Protein and peptide letters*, *24*(9), 809–816. https://doi.org/10.2174/0929866524666170728151401

Remuzzi, A. and Remuzzi, G. (2020) COVID-19 and Italy: What Next? Lancet, 395 1225-1228. https://doi.org/10.1016/S0140-6736(20)30627-9

Simpson, R. J., Kunz, H., Agha, N., & Graff, R. (2015). Exercise and the Regulation of Immune Functions. *Progress in molecular biology and translational science*, *135*, 355–380. https://doi.org/10.1016/bs.pmbts.2015.08.001

Wan, Y., Shang, J., Graham, R., Baric, R. S., & Li, F. (2020). Receptor Recognition by the Novel Coronavirus from Wuhan: an Analysis Based on Decade-Long Structural Studies of SARS Coronavirus. *Journal of virology*, *94*(7), e00127-20. https://doi.org/10.1128/JVI.00127-20

World Health Organization. (n.d.). World Health Organization. Retrieved December 4, 2022 From https://www.euro.who.int/en/health-topics/health-emergencies/coronavirus-covid-19/publications-and-technical-guidance/noncommunicable-diseases/stay-physically-active-during-self-quarantine

5. The use of active breaks for office workers to reduce stress and improve wellbeing

In the previous academic years and especially during 2020-2021, I focused my research in the field of physical activity benefits in various fields, including SARS-CoV-2 research and the impact on occupational health and on the general population. As previously mentioned in this report, in 2020 I have published a brief report in the Scandinavian Journal of Medicine & Science in Sports entitled "COVID-19 pandemic: Benefits and challenges for physical activity and psychological consequences". As reported in the introduction, the COVID-19 pandemic has posed challenges for university PhD students, administrators, and supervisors. Daily activities were disrupted. Initially, for most students and academics, the focus may have been on lost opportunities for skill development, training, network building, travel, and research, including access to specific populations and settings made unavailable because of lockdown and other restricting government measures. Access and implementation of remote work seemed a significant burden for all those involved and highlighted a plethora of social, psychological, and physical issues associated with sedentary behaviours and isolation. It has now been widely reported that stress, anxiety, and depression increased in multiple populations, not only frontline workers during COVID-19, and the reasons were multifaceted. From another perspective, the pandemic has provided novel opportunities to observe and measure psychological variables through remote monitoring, Apps, and devices. Since the publication of our report, which put a flag on the limited coordinated action and guidelines for home-based physical activity, a wide range of global and national recommendations have been published. While sedentary activity and *smart working* increased, the need for performing "active breaks", intended as physically active breaks during work or study, became highly relevant for people's wellbeing. Online platforms such as Zoom or others may be used not only for meetings and, consequently, for increasing the risk of sedentary activities in the office, but also to receive messages or videos on how to engage in positive activities and be physically active.

Although most nations are now looking to return to a relatively normal life, there is still uncertainty about the future and it seems that heightened stress, anxiety, and depression will continue for some time. Poorer mental health has also been reported as a consequence of the COVID-19 pandemic. From the point of view of experimental research in occupational health, considering the recent pandemic and the risk of sedentary behaviour in office workers, coupled with the potential of using digital technology as a vehicle for delivering positive messages, particular relevance can be seen in the study performed under the supervision of Prof. De Dominicis at KU. The related article in submission is entitled “Active breaks at the office: a viable solution to reduce stress and improve wellbeing”. COVID-19 restrictions impacted on the study layout; therefore, the project was partially conducted remotely, incorporated digital technology and wearable use, and was unique and added to existing research. The overall research is reported and divided into 3 studies. Full-time office workers of different companies were randomly assigned to a 3-to-4-month intervention engaging in either active breaks or as a control group. Study 1 was performed using self-reported measures. Study 2 used behavioural data measured via wearable physical activity trackers. In study 3, the sustainability of the Digital Behaviour Change Intervention (DBCI, based on social-psychological variables such as social norms) was tested to promote office workers’ long-term engagement in active breaks over a 4-month period. A DBCI can be defined in this context as a physical activity intervention based on employees’ engagement and delivered through an online platform. The project was performed in collaboration with a Danish Start-up which promotes sustainable health across multinational and national enterprises, institutions, and small-to-medium companies.

This work has been submitted for publication and is currently under review. I am a coauthor on the paper that was led by Prof. Stefano De Dominicis.

The study outline and main results are reported below.

Scope. The aim of the study was to reduce sedentary behaviour and stress in office workers using a digital behaviour change intervention (DBCI) involving full-time office workers. A physical activity intervention based on employees’ engagement delivered through an online platform.
Methods. Full-time office workers who were included from different enterprises in Scandinavia were randomly assigned to a 3-to-4-month intervention (e.g., engaging in active breaks), or to be on a waiting list control group. Randomisation was blocked to account for the subjects’ previous overall physical activity. Univariate repeated measures mixed ANOVAs and multiple regression models were performed using, as main outcome variables, self-report psychological measures (such as perceived stress) and physiological and behavioural variables (e.g., resting heart rate, physical activity) measured via a wearable physical activity tracker.
Results. The intervention groups, compared to the control groups, were significantly more physically active and also improved physiological markers. A significant interaction effect was documented between time and experimental condition, showing a significant effect of active breaks in reducing stress for office workers. A post-hoc analysis also showed that not performing active breaks was related to a 10% reduction of overall wellbeing, while a 1% increase in wellbeing was registered for those who engaged in active breaks
Conclusions. The results show that the intervention represents a viable, easy-to-perform strategy to help reducing sedentary behaviour and stress in the office and remotely in the setting of occupational health. Providing office workers with an empowering digital solution to increase their

activity levels by performing active breaks during the workday might be effective and target the mental and physical health risks levels that they may experience.

5.1 Introduction

There is a constant interest in investigating the impact of sedentary occupations, such as office-based work, on physical, psychological, and general social health and well-being. Desk-based office work is a common example of sedentary behaviour (any waking behaviour characterized by an energy expenditure of 1.5 METS or lower while sitting, reclining, or lying; Jetté et al., 1990; World Health Organization, 2020) that continues to grow (Parry & Straker, 2013). Due to the lockdown measures implemented by governments to control the COVID-19 pandemic, physical inactivity and, consequently, chronic diseases have increased worldwide (Chandrasekaran, & Ganesan, 2021; Dwyer et al., 2020), and the impact of this behaviour and attitudes will be more evident in the upcoming years. During 2020-2022, the COVID-19 pandemic amplified the number and weight of stressors both in the general population and in the work landscape (Chandrasekaran & Ganesan, 2021; Dwyer et al., 2020; Kniffin et al., 2021; Salari et al., 2020). In this scenario, evidence-based solutions should be tested and developed in order to help at risk groups, such as office workers, to cope with the new challenges imposed by the unexpected situation. As the World Health Organization (WHO) defines health as a "state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity" (World Health Organization, 2020), wellbeing can be viewed as a holistic entity that is linked explicitly with and encompasses health. The biopsychosocial model of health (Engel, 1977) also highlights this holistic concept and recognizes physiological, psychological, and social aspects as well as the interactions that take place between these aspects (Borrell-Carrió 2004). Further recognizing various influences and interactions between different health factors is Bronfenbrenner's ecological model of human development (Bronfenbrenner, 1977). In this perspective, health provides not only for individual but also for context-related systems as they mutually interact and are interdependent (Stokols, 1996). Consequently, physical, mental, and social health aspects are governed by the relationships that individuals have with various micro and macro environments and how they interact with them (Coutts & Hahn, 2015).

5.1.1 Physical wellbeing

Physical health represents, as defined by Capio et al., the ability to engage in various activities, including physical activities and social duties, without restrictions caused by physical limitations or bodily pain (Capio et al., 2014). Pain limits health on a global scale (Goldberg & McGee, 2011), resulting from a complex interaction of biological, psychological, and social elements (Gatchel et al., 2007). Musculoskeletal pain is a predictor of poor physical health (Andersen et al., 2012; Brooks, 2006). Also, cross-sectional studies have found a relationship between pain and decreasing physical function and disability in the elderly (Eggermont et al., 2009; Lihavainen et al., 2010), while in longitudinal studies, pain has been shown to increase functional decline and disability (Bryant et al., 2007; Buchman et al., 2010; Leveille, 2009).

Therefore, because musculoskeletal discomfort is a prominent cause of sickness in the United States and Europe, resulting in early retirement and lost productivity (Andersen et al., 2012; Manchikanti et al., 2009), it is imperative that organizations worldwide find and implement solutions (Yazdani & Wells, 2018). Given the amount of time office workers spend sitting at work, which accounts for a significant portion of the day, the workplace could provide an ideal setting for pain management and relief (Jakobsen et al., 2017). Research suggests that effective strategies to address pain should include physical, psychological, and social health factors (Steffens et al., 2016; Van Eerd et al., 2016).

5.1.2 Psychological wellbeing

Psychological wellbeing has been cited as a public health concern by the European Regional Office of the WHO (as cited in Bastianon et al., 2020) and, more specifically, work-related stress has been identified as one of the largest problems in the European Union working environment (Skakon et al., 2010). In fact, work-related stress and its negative effect on employees' psychological and physical wellbeing has been widely documented in many occupations (Kniffin et al., 2021). Stress in this context can be defined as "the degree to which situations in one's own life are appraised as stressful, specifically to which degree life is experienced as unpredictable, uncontrollable, and overloaded" (Cohen et al., 1983). Therefore, work-related stress can be used as a predictor for mental health and psychological wellbeing (Amaro et al., 1987). The human stress response is known to affect physiological processes regulated by the autonomic nervous system, including cardiovascular, respiratory, digestive, repair and defence functions (Porges, 1992), and several medical conditions have been linked to stress including, among others, heart disease (Dimsdale, 2008), asthma (Yonas et al., 2012), and obesity (Tomiyama, 2019). Regular, moderate exercise has been recognised as a way to achieve stress reduction (Fleshner, 2005).

Furthermore, research has shown a strong relationship between physical exercise and mental health (Ohrnberger et al., 2017), and this relationship seems to be bidirectional with physical health affecting mental health and vice versa (Ku et al., 2016; Steinmo et al., 2014). Specifically, for work-related stress, a meta-analysis of interventions based on physical activity in the workplace found that exercise programs are effective in promoting the reduction of job-related stress (Conn et al., 2009). Further studies have shown that sports activities lead to low job stress and higher job satisfaction, while less exercise tends to be accompanied by higher stress in the workplace (Kouvonen et al., 2013; Yook, 2020).

5.1.3 Social wellbeing

Social dynamics include the effects of actual or perceived social relationships on health and wellbeing (Lehman et al., 2017). Interpersonal dynamics, including those in work environments with both direct or indirect interactions with others should be taken into account in promoting health and wellbeing in the workplace. Correlations have been shown between the social dimensions of the workplace and stress and job satisfaction (Fairbrother & Warn, 2003). Low levels of job satisfaction are linked to increased levels of work stress, which in turn leads to job discontent and encourages employees dropouts (Hoboubi et al., 2017). Social risk factors can affect a person's physical and mental health as well as the way they evaluate the social assistance available to them (Fairbrother & Warn, 2003). The workplace could be a key place for exercise promotion, for example by building on existing social networks where exercise interventions can be based on social support and relatedness to be implemented (Dugdill et al., 2008). Research has demonstrated that physically active groups, compared with less active groups, feel less pressure and are more socially orientated and interested in interaction (Fang et al., 2019). Physical exercise can also improve working relationships (Andersen et al., 2015). Therefore, it seems relevant to consider physical, psychological and social factors in order to promote healthy behaviours and wellbeing in the workplace.

5.2 Study design

Effective solutions to reduce physical inactivity should be theory-driven, personalised, and based on long-term actions that raise awareness, coach individuals and promote behaviour change towards wellbeing (Tan et al., 2020). In this scenario, accessible, user-friendly, context-integrated technologies can be successfully employed to drive DBCI (Yardley, Choudhury, et al., 2016a). The aim of the research program was to design and implement a DBCI specifically targeting office workers to improve their health and wellbeing. Given that increased physical activity and reduced sedentarism are related to better physical, psychological and social wellbeing (Sloan et al., 2013), the intervention aimed at reducing sedentarism in office workers by promoting engagement in active breaks during the workday (Salmon, 2001).

The results describe the findings of three studies in which the feasibility and effectiveness of a DBCI designed to increase wellbeing and reduce stress in office workers was tested. To deliver the intervention, we partnered up with Pleaz, a Danish start-up that promotes sustainable health in the workplace. Through its online platform, Pleaz provides office workers from different companies (encompassing multinational and national enterprises, institutions, and SMEs) with a video library of active breaks called "pleazers". We hypothesized that daily engagement in active breaks would exert positive effects on physical activity, overall wellbeing, and stress. We tested this general hypothesis both via self-report measures (Study 1) and behavioural data measured via wearable physical activity trackers (Study 2). Furthermore, we tested the sustainability of the DBCI (based on social-psychological variables such as social norms), in promoting office workers' long-term engagement in active breaks over a 4-month period (Study 3).

5.3 Study 1: Reduced perceived stress and improved wellbeing promoted by active breaks

5.3.1 Aims and hypotheses

The aim of Study 1 was to understand whether office workers daily engagement in active breaks could exert positive effects on their wellbeing. Three operational hypotheses were formulated: 1. Engaging in active breaks daily vs. not engaging in active breaks increases overall amount of physical activity; 2. Engaging in active breaks daily vs. not engaging in active breaks reduces perceived stress; 3. Engaging in active breaks daily vs. not engaging in active breaks increases overall wellbeing.

5.3.2 Methods

A prospective randomized control field experiment implementing a DBCI was conducted as previously described (De Dominicis et al., 2019). Participants were recruited between September 2020 and February 2021. The intervention consisted of performing at least one active break per every working day (experimental group, defined as "active"), for a period of 12 weeks. Active breaks were defined as short 2-to-10 minutes breaks performed during the workday, in which people engage in physical, mental and/or social exercises or activities to restore physiological and psychological wellbeing, readiness, and capacity. Details about the chosen activity (active break), such as the effort level required, its benefits, and the science behind it, were also available on the Pleaz platform. In the control group (defined as "inactive"), participants were instructed to maintain their usual daily habits at work.

5.3.3 Participants

A total of 147 office workers employed into 7 different companies were included either into the experimental (48.3%) or control group (51.7%). To ascertain the effects of the intervention (namely, daily engagement vs. lack of engagement in active breaks) on the main outcome variables, hypotheses testing was performed on participants who complied with the intervention. Of the initial sample, 52 participants complied with the intervention, engaging in active breaks daily (active) or not (inactive). The demographics, activity-related, social and educational characteristics are reported in Table 1 and stratified by type of sample (whole group or intervention compliers).

Table 1.

Characteristics of the full sample and sub-sample of intervention compliers

Characteristics	**Full sample (N = 147)**	**Intervention compliers (N=52)**
Mean age, years (SD)	41.5 (10.3)	41 (9.1)
Intervention group %		
Active	48.3	53.8
Inactive	51.7	46.2
Gender %		
Female	57.8	59.6
Male	42.2	40.4
Relationship status %		
Married	48.3	51.9
In a relationship	21.8	21.2
Single	12.9	13.5
Divorced	6.8	3.8
Number of children %		
0	51	42.3
1	16.3	19.2
2	25.2	26.9
3 or more	6.8	11.5
Educational level %		
Doctorate/post university education	3.4	7.7
Graduate school/master degree	44.2	42.3
College/bachelor degree	32.7	32.7
High school/professional diploma or lower education	19.0	17.2

5.3.4 Procedure

Participants were office workers recruited in the research via their employers, which subscribed to membership with Pleaz and provided them with company access to the website. Each employer sent out information about the availability of the new platform and the related research project to their own employees. Participation in the research project was voluntary with an opt-out choice, so that all employees with access to the platform would receive the first survey (T_0; via their work email) and decide to participate or decline participation. The first survey was therefore administered to measure baseline physical activity (T_0). A blocking variable (e.g., weekly amount of physical activity converted into metabolic equivalents, METs) was computed and used to perform the block-randomization of participants. Participants were then randomly assigned to the intervention group (active) or control group (inactive). Surveys were then administered at pre-intervention (T_1) and post-intervention (T_2) to measure engagement in active breaks, physical activity, perceived stress, and overall wellbeing.

5.3.5 Measures

Physical activity (PA) was measured using the International Physical Activity Questionnaire-Short Form (IPAQ-SF) that records the intensity of PA, the number of days per week, and the time per day spent at that intensity (Craig et al., 2003; Lee et al., 2011). According to the IPAQ-SF scoring protocol, data collected were converted into continuous measures using METs. To exclude the potential confounding effect of being or not being physically active, weekly METs were used as the operationalization of weekly amount of PA and as the blocking variable to perform the study randomization.

The 10-item version of the Perceived Stress Scale (PSS-10) was used to measure perceived stress on a 5-point Likert Scale (from 0 = never to 4 = very often) (Cohen et al., 1983; Lee, 2012; Warttig et al., 2013). After reversing the negatively worded items, a factor score of perceived stress was computed by averaging the item's scores. The explained variance of a single-factor principal component analysis was 39.3% and 41.8% at T_1 and T_2, respectively, and reliability was optimal (Cronbach's α = .83 and .87).

Engagement in active breaks was measured by recording the weekly number of active breaks performed in the previous three months. This information was then merged with the experimental condition to check for our manipulation. Thus, compliance with the intervention, defined as daily engagement in active breaks (i.e., performing at least one active break per working day), was applied to meet the experimental condition. As mentioned, of 147 office workers included, 52 complied with the intervention and were included in the final analysis reported in this study.

Overall wellbeing was operationalized as the aggregate measure of physical, psychological, and social wellbeing. Respectively, physical wellbeing was measured by 4 *ad hoc* items. The four items were: "1. Do you suffer any physical pain or discomfort during your work? - (if yes, please specify which kind of pain is the most troubling)" (open ended question), "2. How much of that pain or discomfort you suffer? (0=no pain at all; to 10=a great amount of pain)", "3. Do you experience pain or discomfort if you do not vary your job tasks or activities during your workday? - (if yes, please specify which kind of pain is the most troubling)" (open ended question), and "4. How much of pain or discomfort you suffer if you do not vary your job tasks or activities during your workday (0=no pain at all; to 10=a great amount of pain)". To operationalize physical wellbeing, Items 2 and 4 were reverse coded, aggregated, and standardized. The correlation among the two item was positive and significant (T1: $r = 0.74$, $p < 0.001$; T2: $r = 0.66$, $p < 0.001$). Psychological wellbeing was measured by reverse-coding, aggregating and standardizing scores of the PSS scale (previously described), and the Patient Health Questionnaire-4 (PHQ-4; Löwe et al., 2010). The PHQ-4 The 4-item Patient Health Questionnaire-4 (PHQ-4) is a brief self-report questionnaire that consists of a 2-item depression scale (PHQ-2; Kroenke et al., 2003; Löwe et al., 2005) and a 2-item anxiety scale (GAD-2; Kroenke et al., 2007). Participants are asked to respond the question "Over the last 2 weeks, how often have you been bothered by the following problems?" and response options are "not at all", "several days", "more than half the days", and "nearly every day". The reliability was optimal (Cronbach's $\alpha = 0.77$ and 0.81, respectively for T_1 and T_2). The correlations between the PSS and PHQ-4 were positive and significant (T1: $r = 0.66$, $p < 0.001$, T2: $r = 0.67$, $p < 0.001$).

Finally, social wellbeing was measured by aggregating measures of and group and organizational identity. Group identity was measured with 8 items inspired by De Dominicis et al., 2019 and Schultz et al., 2015. Items include "I feel I belong to the group" and "I am glad to be a member of the group". Respondents were asked to rate the degree to which any of the statements in the scale applies to them using a 9-point response scale (1 = does not apply to me at all; 5 = neutral; 9 = applies to me completely). Reliability of this scale was optimal (T1: $\alpha = 0.95$; T2: $\alpha = 0.97$). Organizational identity was measured with 12 inspired by Ashforth & Mael, 1989; van Dick et al., 2004, 2008. Items include "Being a member of my organization reflects my personality well" and "I identify myself as a member of my organization" and are measured on a 7-points Likert-type scale (from "strongly disagree" to "strongly agree"). Reliability of this scale was optimal (T1: $\alpha = 0.85$; T2: $\alpha = 0.86$). The correlation between the group identity and the organizational identity scale were positive and significant (T1: $r = 0.41$, $p < .001$, T2: $r = 0.36$, $p < .001$).

5.3.6 Data analysis

Statistical analyses were performed (via IBM SPSS v.27) to ascertain the effect of our manipulation on the amount of PA (expressed as weekly METs) conducting two protected t-tests, while to test for the main hypotheses a series of two-way mixed ANOVA was used.

5.3.7 Results

1. Active breaks and PA: At T1, the two groups did not differ in weekly METs ($t_{(48)} = 1.71$, $p = 0.10$, $d = 0.50$; inactive: $M = 2638.3$, $SD = 2106.5$; active: $M = 1982.5$, $SD = 1483.1$), while at T2 a statistically significant difference was shown in weekly METs, with the active group showing a greater amount of PA compared to the inactive group ($t_{(48)}$ = 2.74, p = 0.009, d = 0.79; inactive: M = 1406.4, SD = 807.9; active: M = 2453.8, SD = 2299.1).

2. Active breaks and stress reduction: Results of a two-way mixed ANOVA (between-subjects variable: engagement vs. no engagement in active breaks; within-subjects variable: stress at pre- and post-test; covariate: workplace) showed a non-significant effect of active breaks ($F_{(1, 49)}$ = 0.87, p = 0.35, ηp^2 = .017) on stress scores, with inactive (M = 2.49, SE = 0.09) and active (M = 2.38, SE = 0.08) participants performing similarly. There was no significant main effect of time on stress ($F_{(1, 49)}$ = 0.02, p = 0.88, ηp^2 = 0.001), with participants showing similar stress scores at T_1 (M = 2.37, SE = 0.07) and T_2 (M = 2.50, SE = 0.07). Importantly, a significant interaction between engagement in active breaks and time occurred ($F_{(1, 49)}$ = 4.65, p = 0.036, ηp^2 = 0.09). Specifically, while active and inactive participants showed similar stress scores at T_1 (active: M = 2.39, SE = 0.10; inactive: M = 2.35, SE = 0.11), active participants showed significantly lower stress scores than inactive ones at T_2 ($t_{(49)}$ = 2.49, p = 0.016, d = 0.71; active: M = 2.36, SE = 0.10; inactive: M = 2.64, SE = .10).

3. Active breaks and wellbeing: A significant interaction was also shown between engagement in active breaks and time on overall wellbeing ($F_{(1, 25)}$ = 4.34, p = 0.048, ηp^2 = 0.15). While overall wellbeing of inactive participants significantly decreased before and after the intervention ($t_{(25)}$ = 2.68, p = 0.012, d = 1.07; inactive T_1: M = 27.9, SE = 4.8; inactive T_2: M = 17.6, SE = 3.7), active participants' wellbeing did not change ($t_{(25)}$ = .31, p = 0.75, d = 0.12; active T_1: M = 14.7, SE = 4.9; active T_2: M = 15.9, SE = 3.9).

5.3.8 Discussion

In Study 1, we tested the hypotheses that office workers engaging in active breaks, compared to those that do not, will be more physically active, will experience lower work-related stress, and will report more positive wellbeing. Generally, our results confirm these hypotheses. However, results of Study 1 open new questions. As a starting point, the question of whether engaging in active breaks might exert positive effects above and beyond the self-reported social-psychological variables, remains. In fact, before applying the intervention in a more natural setting, it is important to ascertain its possible effects on other physiological and behavioural variables, such as cardiovascular adaptations and actual amount of PA performed. This question is addressed in Study 2. Furthermore, given that 35.4% of participants complied with the intervention, the issue of whether a DBCI such the one we implemented is sustainable or not for office workers should be understood. That is, which factors would affect office workers engagement in active breaks in a real setting? This question will be addressed in Study 3.

5.4 Study 2: Sedentary behaviour, resting heart rate, and stress decreased by active breaks

5.3.7 Aims and hypotheses

The main aim of Study 2 is to replicate the results of Study 1 using both objective and subjective measures of amount of PA, physiological adaptations related to stress, and perceived stress. To do so, we used wearable devices (Fitbit Charge 4 fitness tracker) to measure the amount of PA and sedentary behaviour, as well as participants' resting hearth rate. Therefore, the specific aims of Study 2 included three main elements: 1. It was deemed relevant to understand what kind of PA is changed when introducing active breaks daily; 2. It is relevant to understand whether office workers' engagement in daily active breaks could exert positive physiological adaptations, such as reduced resting hearth rate; 3. It is important to ascertain that daily engagement in active breaks, if followed by the expected behavioural and physiological changes, would correspond to a reduction in perceived stress. Therefore, 4 operational hypotheses were proposed: 1. Engaging in active breaks daily vs. not engaging in active breaks increases overall amount of physical activity; 2. Engaging in active breaks daily vs. not engaging in active breaks decreases overall amount of sedentary behaviour; 3. Engaging in active breaks daily vs. not engaging in active breaks reduces resting hearth rate; 4. Engaging in active breaks daily vs. not engaging in active breaks reduces perceived stress.

5.4.2 Methods

The experimental design of Study 2 is similar to Study 1 with the main difference of providing participants with a fitness tracker device to be used during the intervention. Participants were recruited (between September 2020-February 2021) via a survey that was initially administered to measure the baseline physical activity (T_0). As per Study 1, METs was used as blocking variable to perform the randomization of participants in the two experimental conditions. Participants were subsequently randomly assigned to the intervention group (active) or control group (inactive) based on the blocking variable. and were provided with a wearable fitness tracker (Fitbit Charge 4), reliable for research purposes (Cadmus-Bertram et al., 2015; Diaz et al., 2015), to be used during the 12 weeks of intervention. Surveys were administered at pre-intervention (T_1) and post-intervention (T_2) to measure engagement in active breaks, physical activity, and perceived stress.

5.4.3 Participants

A total of 42 office workers (employed into the same 7 different companies that participated in Study 1) accepted to participate in the study. Of those, 36 participants successfully received and activated the device, and completed their participation in the study. Of those, 16 participants did not comply with the intervention or did not synchronize their device on a weekly basis (resulting in more than 66% of missing data), and therefore are excluded for the final analyses. Thus, a finalized sample of 20 participants (75% women, 55% below graduate education, 90% full time job, 70% married, 75% with 1 or more children) who complied with the intervention and used the fitness tracker for 8 or more weeks was used to test our main hypotheses.

5.4.4 Measures

Similarly, to Study 1, we used: a) the International Physical Activity Questionnaire-Short Form (IPAQ-SF) to measure PA at T_0 and to perform the block randomization; and b) the PSS-10 to measure perceived stress, showing optimal reliability both at T_1 and T_2 (Cronbach's $\alpha = .87$ and .93). Engagement in active breaks was measured by recording the weekly number of active breaks performed in the previous three months. This information was then merged with the experimental condition to check for our manipulation. Thus, compliance with the intervention, defined as daily engagement in active breaks (i.e., performing at least one active break per working day), was applied to meet the experimental condition. The following measures were taken from the wearable devices to compute our main outcome variables: weekly amount of very active, fairly active and lightly active minutes; weekly number of sedentary minutes; daily resting hearth rate (RHR). Then, three objective measures were computed from the data derived from the wearable devices to test for our main hypotheses. Weekly average amount of PA was computed as the weekly average of the sum of very active, fairly active and lightly active minutes, as registered by the fitness tracker. Weekly average of sedentary behaviour is the weekly average of sedentary minutes, as registered by the fitness tracker. RHR change was computed as the difference between the weekly average of RHR at the last week of intervention minus the weekly average RHR at the first week of intervention (RHR T_2 – RHR T_1): thus, positive values represent an increase in RHR, while negative values represent a decrease in RHR, over time. Finally, one subjective measure of perceived stress change was computed as the difference between perceived stress at T_2 minus perceived stress at T_1 (PSS T_2 – PSS T_1): thus, positive values represent an increase in perceived stress, while negative values represent a decrease in perceived stress, over time.

5.4.5 Data analysis

Statistical analyses were performed via IBM SPSS v.27. An independent samples *t*-test was used to compare groups at T_1. Then, to test for our main hypotheses, a one-way MANOVA was performed to ascertain the effect of our manipulation on the amount of PA, amount of sedentary behaviour, change in RHR between T_1 and T_2, and change in perceived stress between T_1 and T_2.

5.4.6 Results

First, a *t*-test was performed to ascertain that the two groups were comparable in terms of amount of PA after the block-randomization. Indeed, at T_0 the two groups did not differ in weekly METs ($t_{(18)}$ = -0.81, *p* = 0.43, *d* = 0.37; inactive: *M* = 2043.6, *SD* = 903.5; active: *M* = 2881.8, *SD* = 2821.5).

Active breaks, sedentary behaviour, RHR and perceived stress: A one-way MANOVA was conducted to determine whether there was a difference in the inactive group and the active group on weekly average of total minutes of PA, weekly average of sedentary behaviour, change in RHR and change in perceived stress. Results show a significant difference in the outcome variables based on daily engagement in active breaks, *F*(4, 15) = 5.47, *p* = 0.006, Wilk's lambda = 0.407, ηp^2 = 0.59. Given the multivariate effect, we ascertain the univariate effects. Specifically, there is no significant effect of group on weekly average of total minutes of physical activity, *F*(1, 18) = 0.325, *p* = 0.570, ηp^2 = 0.04. However, there is a significant effect of group on weekly average of sedentary behaviour, *F*(1, 18) = 14.470, *p* = 0.001, ηp^2 = 0.45. Importantly, there is also a significant effect of group on change in perceived stress, *F*(1, 18) = 9.253, *p* = 0.007, ηp^2 = 0.34. Means and SD of outcome variables for the inactive and active groups are shown in Table 2.

Table 2.

Results of the one-way MANOVA showing the effects of daily engagement in active breaks on outcome variables in Study 2.

	Value	F	Hypothesis df	Error df	p
Wilks' lambda	0.407	5.47	4	15	0.006

	Inactive (n = 8)		Active (n = 12)				
Outcome variables	*M*	*SD*	*M*	*SD*	*t*	*df*	*p*
Weekly average of total minutes of physical activity	245.5	40.9	275.3	72.7	-1.05	18	0.31
Weekly average of sedentary behaviour	1052.9	159	809.2	183.5	3.804	18	0.001
Change in RHR	2.53	3.31	-0.98	4.73	1.818	18	0.086
Change in perceived stress	0.57	0.55	-1.14	0.48	3.042	18	0.007

5.4.7 Discussion

Taken together, results of Study 2 show that engaging in active breaks daily exerts positive effects of office workers. Specifically, although there was no difference in the weekly average amount of physical activity (vigorous, moderate and light) performed by office workers, our results show a significant reduction in sedentary behaviour, which has been related to a series of mental and physiological benefits (Després, 2016; Ku et al., 2016; Lewis et al., 2017; Parry & Straker, 2013; Rezende et al., 2014; Sloan et al., 2013). Also, our results show that performing daily active breaks in the workplace can exert positive physiological adaptations, such as reducing resting heart rate. Although our result are only marginally significant, this is a remarkable result given that an increase in RHR has long been recognized as an independent predictor of cardiovascular risk and related mortality risk (see for example, Nauman et al., 2011). Finally, confirming results of Study 1, results show that daily engagement in active breaks results in lower work-related stress. In general, results of Study 2 further support the idea that daily engagement in active breaks increases office workers' health, and that it might be a feasible and effective solution to prevent and reduce the psychological and physiological risks related to prolonged sitting time that office workers undergo daily. However, the question of whether such behaviour could be or not be sustainable in the long-term into a real context, is still not answered. Study 3 will aim at solving this issue.

5.5 Study 3: Long-term engagement in active breaks

5.5.1 Aims and hypotheses

In Study 3 the role of social-psychological variables (such as group identity and social norms) was investigated into the acceptance and engagement of a new behaviour, namely performing active breaks daily. Operationally, we introduced active breaks in a big organization in Denmark (see method section for details), and measured self-efficacy, social norms, group identity and engagement in active breaks before this implementation and 4 months later. The main purpose of Study 3 is to understand whether engaging in active breaks daily to break and reduce prolonged sitting could be a feasible and sustainable solution for office workers. To reach this aim, we developed a series of operational hypothesis. Initially, we considered that individual behaviour that is enacted mainly in social contexts (such as engaging in active breaks at the workplace) is largely determined by: a) the perception of whether others approve and engage in the target behaviour, namely if the behaviour is socially normative (Cialdini, 2007; Cialdini et al., 1991, 2006; Schultz et al., 2007, 2018); and b) by the personal belief in one's own capacity to execute behaviour necessary to attain a specific and desirable outcome, namely the individual's self-efficacy in the target behaviour (Bandura, 1978, 1982, 2001). Accordingly, 2 hypotheses were made, specifically: 1. Before introducing the new target behaviour, social norm is a significant predictor of individuals' engagement in active breaks; 2. Before introducing the new target behaviour, self-efficacy is a significant predictor of individuals' engagement in active breaks.

Subsequently, we acknowledge that a new behaviour might be embraced and maintained over time by individuals if the following processes occur. Given the modelling role of others on individuals' behaviours in social contexts, individuals' acceptance and engagement in a new target behaviour should be more likely to occur when the target behaviour is socially normative and, in turn, enhances individuals' self-efficacy (Bandura, 2001; Cialdini et al., 1991). However, this process should occur more significantly for those who strongly identify with the group that value and enact the target behaviour (De Dominicis et al., 2019; Hogg et al., 1995; Hogg & Reid, 2006; van Vugt et al., 2014). Accordingly, we also hypothesized that: 1. 4-months after the introduction of the new target behaviour, engagement in active breaks is predicted by social norms through the mediating effect of self-efficacy; 2. Furthermore, this mediation model would be moderated by group identity: namely, the effect of social norm via self-efficacy on engagement in active break would be stronger for those who highly identify with the referent group engaging in the target behaviour.

5.5.2 Methods

5.5.3 Study design

Study 3 is a longitudinal study in which we measured several variables before and after introducing the target behaviour (namely, engaging in active breaks daily) within a big private company (+250 employees bank) in Denmark.

5.5.4 Procedure

Participants were recruited (February 2021) with the same method used in Study 1, namely, they were office workers recruited in the research via their employer, which subscribed to membership with Pleaz and provided them with company access to the website. The employer sent out information about the availability of the new platform and the related research project to their own employees. Furthermore, managers and team leaders presented this initiative to their teams in a team meeting also with practical activities and group engagement in the target behaviour. This crucial step was taken to ensure that everyone could see that: a) both the leadership and their colleagues were involved in the initiative; and b) therefore the reference group accepted and engaged in the target behaviour. Similarly, to Study 1, participation in the initiative and the related research project was voluntary with an opt-out choice, all employees could access the platform and received the first survey (T_1; via their work email) and decided to participate or decline participation. After 4 months, participants received a second survey (T_2) and were informed about the end of the research project and that they could continue to use the platform provided by their employer.

5.5.5 Participants

A total of 263 office workers (employed in the same bank) participated in the study. Of those, 53 participants did not complete the first survey and were removed from the analysis. Thus, the finalized sample of Study 3 is composed of 210 participants: 77% women, 30.6% below graduate education, 88.6% full time job, 63.4% married, 66% with 1 or more children; also, participants were mainly employed in finance (31%), administration (21%), HR (14.3%) and sales (14.3%).

5.5.6 Measures.

Similarly to Study 1 the IPAQ-SF was used to measure PA. Social norms were measured using two *ad hoc* items developed following previous research (De Dominicis et al., 2019; Schultz, 1999; Schultz et al., 2014, 2015) measuring injunctive and descriptive social norms (Goldstein et al., 2008; Schultz et al., 2007) respectively (“Would you say that the typical person at your organization approve of those who do active breaks on a daily basis?", and "Would you say that the majority of persons at your organization would engage in active breaks on a daily basis?"). The two items were measured on a 7-point Likert-type scale (from "definitely not" to "definitely yes"), were positively correlated (T_1: $r_{(194)} = 0.56$, $p < .001$; T_2: $r_{(110)} = 0.55$, $p < .001$), and were averaged to create the aggregate scores at T_1 and T_2. Self-efficacy was measured via two *ad hoc* items developed following previous research (Bandura, 1982, 2006). The two items asked participants "How confident are you that you can do active breaks?" and "How confident are you that you can make active breaks part of your daily work routine?" and were measured with an 11-point scale ranging from 0% (extremely low confidence), to 50% (moderate level of confidence), to 100% (extremely high confidence). The two items were highly correlated (T_1: $r_{(190)} = 0.67$, $p < 0.001$; T_2: $r_{(115)} = 0.74$, $p < 0.001$), and were averaged to create the aggregate scores at T_1 and T_2. We measured group identity via a 8-items adapted from previous research (De Dominicis et al., 2019; Schultz et al., 2015). Participants were asked to "Please rate the extent to which each of the following statements applies to you". Example of items were "I feel I belong to the group", and "I am glad to be a member of the group". The scale was measured via a 9-steps Likert-type scale from 1 (does not apply to me at all), to 5 (neutral), to 9 (applies to me completely). The scale showed optimal reliability (T_1: $\alpha = 0.95$; T_2: $\alpha = 0.98$). Finally, engagement in active breaks was measured at T_1 by asking participants how many active breaks they usually do (or not) on average in a typical 5-days working-week; while, at T_2, engagement in active breaks was measured by recording the weekly number of active breaks performed in the previous three months.

5.5.7 Data analysis

Statistical analyses were performed via IBM SPSS v.27. A multiple linear regression was used to test the effects of social norms and self-efficacy on engagement in active breaks, controlling for amount of physical activity, at T_1. Then, to test for the moderated mediation model, a conditional process analysis (Hayes, 2013; Hayes & Montoya, 2017) was performed (via PROCESS MACRO 3.5 for IBM SPSS) to ascertain the effect of social norms on long-term engagement in active breaks via self-efficacy at different levels of group identity, at T_2.

5.5.8 Results

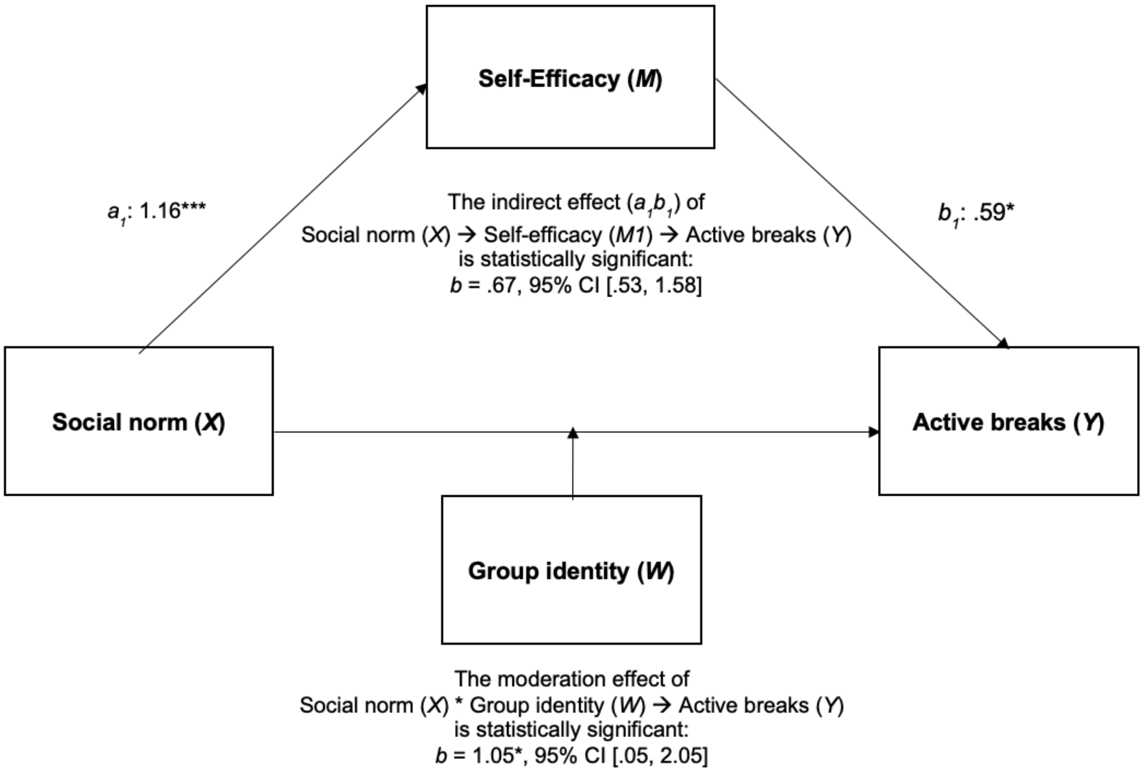
Social norms, self-efficacy and past engagement in active breaks: A multiple linear regression was used to test the effects of social norms and self-efficacy on past engagement in active breaks, controlling for amount of physical activity (weekly MET), at T_1. Results indicated that weekly

MET was a significant covariate, $F_{(1, 189)} = 10.06$, $p = 0.002$, $R^2 = 0.05$). Importantly, results showed that there was a collective significant effect between social norms and self-efficacy on past engagement in active breaks $F_{(3, 187)} = 12.05$, $p < 0.001$, $\Delta R^2 = 0.11$. The individual predictors were examined further and indicated that both social norms ($b = 5.43$, $t = 3.85$, $p < 0.001$) and self-efficacy ($b = 1.52$, $t = 2.74$, $p = 0.007$) were significant predictors in the model, confirming both H8 and H9. Therefore, before the intervention, engagement in active breaks was predicted by social norms and self-efficacy.

Effect of social norms on long-term engagement in active breaks via self-efficacy: A conditional process analysis was conducted to test for the significance of a moderated mediation model. Specifically, the tested model (Model 5, Hayes & Montoya, 2017) assumed that the independent variable (X) exerts an effect on the dependent variable (Y) via a mediating variable (M), and that this effect is conditional to a variable (W) that moderates the effect of X on Y. Results showed that the overall model ($n = 110$) was statistically significant, $R^2 = 0.15$, $F_{(4, 105)} = 4.65$, $p < 0.002$. As predicted, after the intervention, social norm was related to higher self-efficacy ($b = 1.16$, 95% CI: 0.59, 1.71, $p < 0.001$), which in turn was associated with a greater engagement in active breaks ($b = 0.59$, 95% CI: 0.02, 1.14, $p = 0.041$). Importantly, results (Figure 1) support a mediation hypothesis (H10) as the indirect effect of social norms on active breaks via self-efficacy is significant ($b = 0.67$, 95% CI: 0.53, 1.58).

Figure 1.

Indirect effect of social norm (X) on Active breaks (Y) through Self-Efficacy (M) (n = 191) using bias-correcting bootstrapping (resampled 10,000 times) and moderation effect of Group identity (W) on the effect of Social norm and Active breaks.

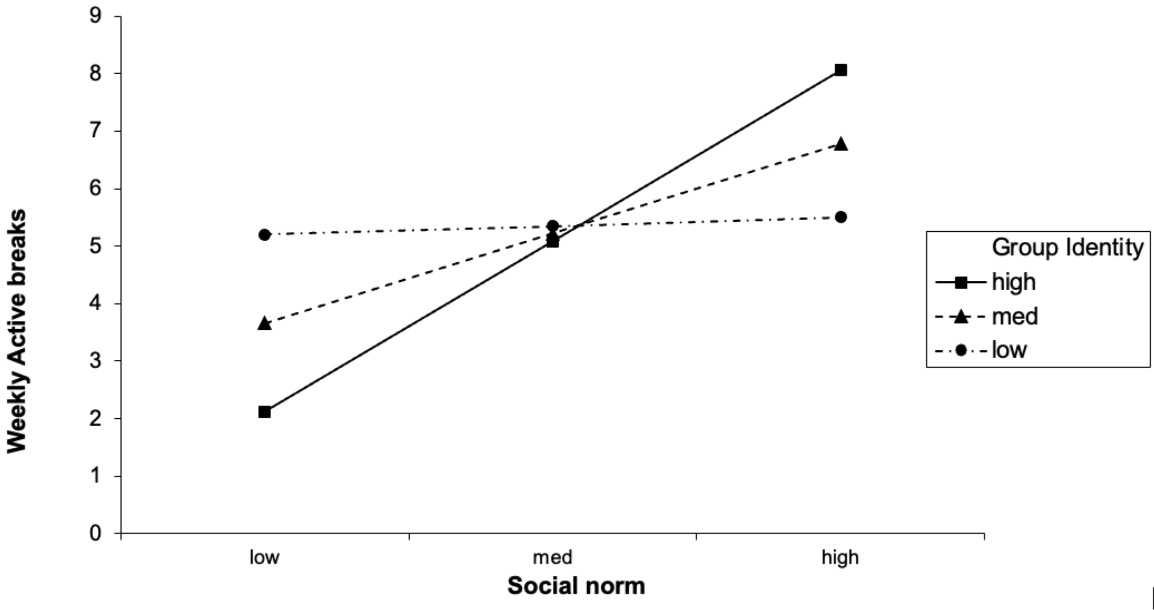


Values represent standardized estimates. *: $p < .05$; **: $p < .01$; ***: $p < .001$. *CI*: confidence interval; *b*: unstandardized regression coefficients; a_1 = effect of X on M; b_1: effect of M on Y; a_1b_1: indirect effect of X on Y through M.

Conditional effect of social norms on long-term engagement in active breaks by group identity (Figure 2). Results also support the moderation hypothesis of group identity on the social norms-active breaks relationship. Specifically, the interaction effect of social norms and group identity on long-term engagement in active breaks was significant (b = 1.05, 95% CI: 0.05, 2.05, p = 0.04), confirming (H11).

Figure 2.

Slope analysis probing the interaction effect of Social norm and Group identity on Active breaks.

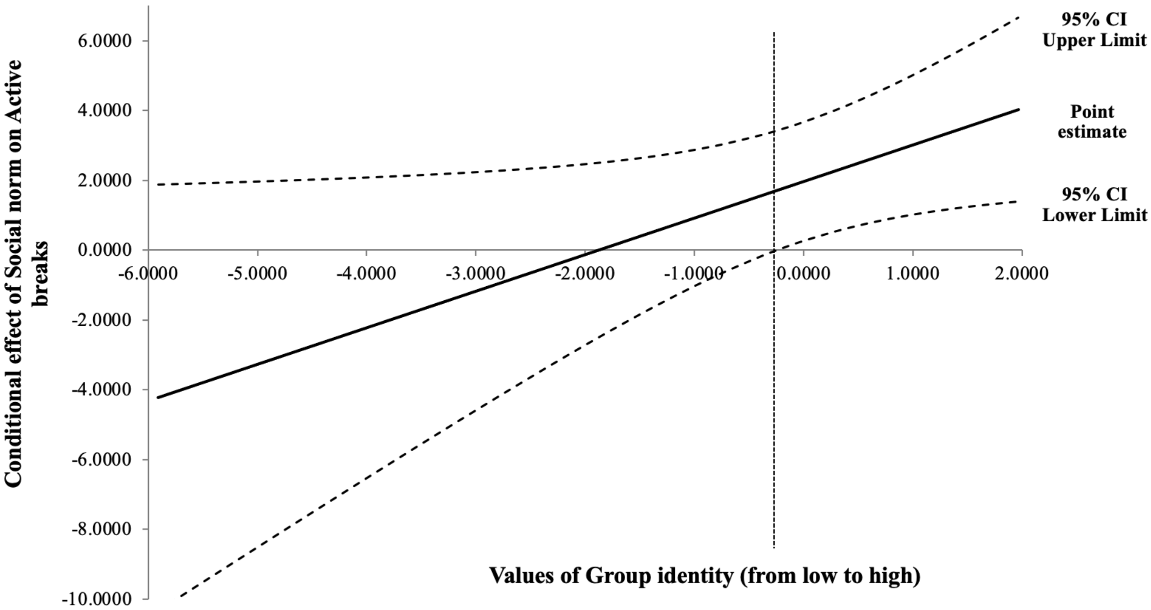


The conditional effect of Social norm on Active breaks is shown for low Group identity (−1 standard deviation), moderate Group identity (mean) and high Group identity (+1 standard deviation) in the reference group. The slopes are significantly different at a 95% Confidence Interval.

We proceeded to probe the interaction through a spotlight analysis and through the Johnson-Neyman technique (Johnson & Fay, 1950) (Figure 3).

Figure 3.

Johnson-Neyman technique showing the full range of conditional effect of Social norm on Active breaks through Group identity.



The effect of Social norm on Active breaks is significant for the top 69% of identifiers (i.e., Group identity > -.24) at a 95% Confidence Interval.

Specifically, we report conditional effects of social norms on long-term engagement in active breaks for low identification (−1 standard deviation), average identification (mean) and high identification (+1 standard deviation) with their reference group, namely their team of colleagues. Results show that the strength of the effect increases for higher scores of group identification. This indicates that as identification with their teams strengthens, social norms exhibit a stronger effect on long-term engagement in active breaks (Fig. 2), respectively with low identification (M = -1.69, b = .19, t = .16, p = .87), average identification (M = 0.00, b = 1.96, t = 2.30, p = .024), and high identification (M = 1.69, b = 3.74, t = 3.05, p = .003). The full range of conditional effects are plotted in Fig. 3 using the Johnson-Neyman technique (Hayes & Montoya, 2017), showing that the conditional effect of social norms on long-term engagement in active breaks through identification with their team of colleagues is significant for the top 69% of identifiers. Overall, these results suggest that increased identification with the reference group enacts the desired healthy behaviour (in our case, performing active breaks daily) in the context of perceiving higher social norm on the behaviour of teammates. In other words, the more individuals are identified with a referent group for which they perceived aligned descriptive and injunctive norms, the more they will engage in active breaks.

5.5.9 Discussion

Taken together, results of Study 3 support the idea that engaging in active breaks daily might be a sustainable long-term healthy behaviour for office workers. First, we showed that, when controlling for past behaviour, people's healthy habits in the workplace (e.g., engaging in active breaks) are driven by the perceptions that others in the same social context approve and engage in the same behaviour, and by their perceived self-efficacy of being able to effectively perform the target behaviour. Furthermore, we showed that people might embrace a new health initiative behaviour promoted within their organization if they will perceive that the promoted behaviour is enacted and approved by their leaders and teammates, which in turn enhances their sense of self-efficacy in performing the target behaviour. Importantly, we also showed that this process might occur only for those that strongly identify with the referent group.

5.6 General Discussion

The 2019 coronavirus pandemic (COVID-19) forced governments across the globe to undergo unforeseen lockdown measures that have, among other effects, exasperated physical inactivity (Chandrasekaran & Ganesan, 2021; Dwyer et al., 2020; E. Lee & Kim, 2019) and significantly increased stress in various scenarios, including the workplace (Kniffin et al., 2021). Within such circumstances, we run a series of experiments focusing specifically on office workers, who are generally exposed to sedentary behaviour (caused by continued sitting) and to other forms of work-related stress (Kilpatrick et al., 2013). Given the above-mentioned effects of the pandemic, a cost-efficient and effective solution to reduce stress and prolonged sitting in office workers is highly needed (Lee & Kim, 2019). Due to the general effectiveness of DBCIs (Hekler et al., 2016; Michie et al., 2017; Pinder et al., 2018; Roberts et al., 2017; Stockwell et al., 2019; Yardley, Choudhury, et al., 2016b; Yardley et al., 2015; Yardley, Spring, et al., 2016), we deemed relevant to investigate the effects of a DBCI aimed at reducing sedentarism (in essence, increasing physical activity) and stress in office workers.

To the best of our knowledge, no research to date has addressed the issue of prolonged sitting at work by increasing engagement in active breaks through the implementation of a DGBI. In a randomized-block field experiment (Study 1), we observed a significantly increase in participants' PA over time compared with people who did not perform active breaks. This is consistent with previous studies suggesting that modern technology, including computer and mobile applications, can assist in supporting and promoting increased PA (Kilpatrick et al., 2013; Walsh & Groarke, 2019). Importantly, the active group reported lower stress levels, as well as higher overall wellbeing. This is in line with studies showing that meeting recommended PA guidelines is associated with lower psychological distress (De Dominicis et al., 2014; Fang et al., 2019; Kilpatrick et al., 2013; Kouvonen et al., 2013; E. Lee & Kim, 2019; Sloan et al., 2013; Stanton et al., 2020; Yardley, Choudhury, et al., 2016a; Yook, 2020).

Furthermore, results of a second randomized-block field experiment (Study 2) replicated results of Study 1 with both self-report and observed measures derived from wearable devices (fitness trackers). Specifically, participants engaging in active breaks daily were less sedentary, had a lower RHR, and reported less stress. This is also in line with previous research showing that reducing sedentarism is associated with both better physical and mental health (Chandrasekaran & Ganesan, 2020; Lewis et al., 2017; Narici et al., 2020; Parry & Straker, 2013; Rezende et al., 2014).

Finally, our longitudinal intervention (Study 3) showed that daily engagement in active breaks could be a sustainable healthy behaviour for office workers. Specifically, our results show that social norms and past behaviour predict engagement in the target healthy behaviour under normal circumstances (namely, daily engagement in active breaks; Ball et al., 2010; De Dominicis et al., 2019; Grant et al., 2015; Hogg & Reid, 2006; Liu et al., 2019; Rimal & Real, 2005; Schultz et al., 2007, 2015, 2018; Terry et al., 1999). Importantly, following a DBCI aiming at promoting long-term engagement in daily active breaks, the effect of social norms on long-term engagement in the target behaviour is mediated by self-efficacy (Ashford et al., 2010; Baretta et al., 2019; De Dominicis et al., accepted manuscript; Oman & King, 1998), and group identity moderates the effect of social norms on the target behaviour such that only those that are highly identified with the reference group will embrace the target behaviour over the long term (Ball et al., 2010; De Dominicis et al., 2019; Grant et al., 2015; Hogg & Reid, 2006).

In short, we showed that a target healthy behaviour might be initiated by past engagement in the behaviour itself, as well as by perceiving others approving and engaging in that same behaviour. However, for promoting long-term engagement, two processes should occur. First, perceiving others approving and engaging in the target behaviour should support, rather than thwart, the personal belief in one's own capacity to execute the behaviour —that is, one's own perceived self-efficacy in the target behaviour. Second, the target behaviour should be aligned with what others do and believes is right to do, as well as with the reference group's values. As such, identification with the reference group should be promoted so that people would be more likely to embrace the target behaviour.

5.7 Limitations and future directions

Although this research presents interesting and encouraging insights, the present results should be interpreted considering some limitations. Engagement in the target behaviour has been measured over 3 or 4 months. Our experiments (Study 1 and 2) and intervention (Study 3) lasted respectively 12 and 18 weeks, consistently with the majority of behaviour change interventions aiming at increasing physical activity in inactive adults (Samdal et al., 2017). However, future research should investigate whether the effects reported here would last at follow up too, namely at 6 and 12 months after the conclusion of the intervention. Limited focus on broader work-related psychological wellbeing. Our results support the idea that if office workers would engage in active breaks daily, they will improve their psychological wellbeing (Biddle et al., 2000; Sloan et al., 2013). However, we did not investigate whether such improvements are linked to greater job satisfaction and better job performance, or lower sick leave and turnover. According to a substantial amount of literature confirming this idea (Wright et al., 2007; Wright & Bonett, 2007; Wright & Cropanzano, 2000), we believe that future research should investigate the relationship between office workers' reduction of sedentarism, their psychological wellbeing, and variables related to occupational health and satisfaction, such as job satisfaction, job performance, sick leave, absenteeism, and turnover. Context of intervention. Our studies have been conducted on employees that were able to access the platform providing the DBCI via their employers, namely financially sound and successful SMEs and big corporations with a clear focus and concern for their employees mental and physical health and wellbeing generally based in Northern Europe and Scandinavia. This provided us an opportunity to test the effectiveness of the proposed solution among those companies that could be considered early adopters. Although some of our participants were based in other countries and continents, future research should investigate the generalizability of our intervention to other contexts and cultures.

5.8 Practical implications

Despite such limitations, the results of our experiments present a series of useful insights for possible applications that are highlighted here in view of future developments.

At the individual level, HR managers and consultants within SMEs and larger organizations should promote engagement in physical activity and reduction of sedentarism across all organizational levels, from the CEO to the interns. For example, individualized and targeted initiatives could motivate employees across different organizational levels because those initiatives will more likely meet individuals' needs, constrains and necessities. At the organizational levels, initiatives aiming at promoting healthy behaviours should be planned and implemented holistically, such that organizational values, believes and behaviours will all be affected in the direction of supporting and promoting the target behaviour. For example, leaders should embrace such initiatives and act as role models, the target behaviour should be performed also at the group level, and communication around the initiative should be pervasive and persuasive. Finally, at the broader perspective, local authorities, policy makers, opinion leaders and other institutional stakeholders could potentially support and facilitate the transition toward healthier workplaces at the community level. For example, regulations and certifications that support physically active workplaces (such as the EU initiative Workplace Active Certification – WAC; https://activeworkplacecertification.eu/) could accelerate the adoption of solutions and initiatives from various organizations.

5.9 Conclusion

Although further research should be undertaken to determine a clear relationship between DBCIs in the workplace aiming at increasing physical activity, wellbeing and long-term healthy behaviour change, our data suggests that promoting office workers' engagement in active breaks could lead them toward a healthier lifestyle. Overall, DBCI-guided active breaks could provide valid alternatives for exercise, stress relief and increased wellbeing for office workers affected by consequences of COVID-19-related restrictions, as well as for their general wellbeing and healthy lifestyles above and beyond the consequences related to the coronavirus pandemic.

5.10 References

Amaro, H., Russo, N. F., & Johnson, J. (1987). Family and Work Predictors of Psychological Well-Being Among Hispanic Women Professionals. *Psychology of Women Quarterly*, *11*(4), 505–521. https://doi.org/10.1111/j.1471-6402.1987.tb00921.x

Andersen, L. L., Clausen, T., Burr, H., & Holtermann, A. (2012). Threshold of Musculoskeletal Pain Intensity for Increased Risk of Long-Term Sickness Absence among Female Healthcare Workers in Eldercare. *PLOS ONE*, *7*(7), e41287. https://doi.org/10.1371/journal.pone.0041287

Andersen, L. L., Poulsen, O. M., Sundstrup, E., Brandt, M., Jay, K., Clausen, T., Borg, V., Persson, R., & Jakobsen, M. D. (2015). Effect of physical exercise on workplace social capital: Cluster randomized controlled trial. *Scandinavian Journal of Public Health*, *43*(8), 810–818. https://doi.org/10.1177/1403494815598404

Ashford, S., Edmunds, J., & French, D. P. (2010). What is the best way to change self-efficacy to promote lifestyle and recreational physical activity? A systematic review with meta-analysis. *British Journal of Health Psychology*, *15*(2), 265–288. https://doi.org/10.1348/135910709X461752

Ashforth, B. E., & Mael, F. (1989). Social Identity Theory and the Organization. *Academy of Management Review*, *14*(1), 20–39. https://doi.org/10.5465/AMR.1989.4278999

Ball, K., Jeffery, R. W., Abbott, G., McNaughton, S. A., & Crawford, D. (2010). Is healthy behavior contagious: Associations of social norms with physical activity and healthy eating. *International Journal of Behavioral Nutrition and Physical Activity*, *7*, 86. https://doi.org/10.1186/1479-5868-7-86

Bandura, A. (1978). Self-efficacy: Toward a unifying theory of behavioral change. *Advances in Behaviour Research and Therapy*, *1*(4), 139–161. https://doi.org/10.1016/0146-6402(78)90002-4

Bandura, A. (1982). Self-efficacy mechanism in human agency. *American Psychologist*, *37*(2), 122–147.

Bandura, A. (2001). Social Cognitive Theory: An Agentic Perspective. *Annual Review of Psychology*, *52*(1), 1–26. https://doi.org/10.1146/annurev.psych.52.1.1

Bandura, A. (2006). Guide for Constructing Self-Efficacy Scales. In *Self-Efficacy Beliefs of Adolescents* (pp. 307–337). IAP.

Baretta, D., Sartori, F., Greco, A., D'Addario, M., Melen, R., & Steca, P. (2019). Improving Physical Activity mHealth Interventions: Development of a Computational Model of Self-

Efficacy Theory to Define Adaptive Goals for Exercise Promotion. *Advances in Human-Computer Interaction*, *2019*, 1–11. https://doi.org/10.1155/2019/3068748

Bastianon, C. D., Klein, E. M., Tibubos, A. N., Brähler, E., Beutel, M. E., & Petrowski, K. (2020). Perceived Stress Scale (PSS-10) psychometric properties in migrants and native Germans. *BMC Psychiatry*, *20*(1), 450. https://doi.org/10.1186/s12888-020-02851-2

Biddle, S., Fox, K. R., & Boutcher, S. H. (Eds.). (2000). *Physical activity and psychological well-being*. Routledge.

Bronfenbrenner, U. (1977). Toward an experimental ecology of human development. *American Psychologist*, *32*(7), 513–531. https://doi.org/10.1037/0003-066X.32.7.513

Brooks, P. M. (2006). The burden of musculoskeletal disease—A global perspective. *Clinical Rheumatology*, *25*(6), 778–781. https://doi.org/10.1007/s10067-006-0240-3

Bryant, L. L., Grigsby, J., Swenson, C., Scarbro, S., & Baxter, J. (2007). Chronic Pain Increases the Risk of Decreasing Physical Performance in Older Adults: The San Luis Valley Health and Aging Study. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, *62*(9), 989–996. https://doi.org/10.1093/gerona/62.9.989

Buchman, A. S., Shah, R. C., Leurgans, S. E., Boyle, P. A., Wilson, R. S., & Bennett, D. A. (2010). Musculoskeletal pain and incident disability in community-dwelling older adults. *Arthritis Care & Research*, *62*(9), 1287–1293. https://doi.org/10.1002/acr.20200

Cadmus-Bertram, L. A., Marcus, B. H., Patterson, R. E., Parker, B. A., & Morey, B. L. (2015). Randomized Trial of a Fitbit-Based Physical Activity Intervention for Women. *American Journal of Preventive Medicine*, *49*(3), 414–418. https://doi.org/10.1016/j.amepre.2015.01.020

Capio, C. M., Sit, C. H. P., & Abernethy, B. (2014). Physical Well-Being. In A. C. Michalos (Ed.), *Encyclopedia of Quality of Life and Well-Being Research* (pp. 4805–4807). Springer Netherlands. https://doi.org/10.1007/978-94-007-0753-5_2166

Chandrasekaran, B., & Ganesan, T. B. (2020). Sedentarism and chronic disease risk in COVID 19 lockdown – a scoping review: *Scottish Medical Journal*. https://doi.org/10.1177/0036933020946336

Chandrasekaran, B., & Ganesan, T. B. (2021). Sedentarism and chronic disease risk in COVID 19 lockdown – a scoping review. *Scottish Medical Journal*, *66*(1), 3–10. https://doi.org/10.1177/0036933020946336

Cialdini, R. B. (2007). Descriptive Social Norms as Underappreciated Sources of Social Control. *Psychometrika*, *72*(2), 263–268. https://doi.org/10.1007/s11336-006-1560-6

Cialdini, R. B., Demaine, L. J., Sagarin, B. J., Barrett, D. W., Rhoads, K., & Winter, P. L. (2006). Managing social norms for persuasive impact. *Social Influence*, *1*(1), 3–15. https://doi.org/10.1080/15534510500181459

Cialdini, R. B., Kallagren, C. A., & Reno, R. R. (1991). A focus theory of normative conduct: A theoretical refinement and reevaluation of the role of norms in human behavior. In *Advances in experimental social psychology* (Vol. 24, pp. 1–243). Academic Press.

Cohen, S., Kamarck, T., & Mermelstein, R. (1983). A global measure of perceived stress. *Journal of Health and Social Behavior*, *24*(4), 385–396.

Coutts, C., & Hahn, M. (2015). Green Infrastructure, Ecosystem Services, and Human Health. *International Journal of Environmental Research and Public Health*, *12*(8), 9768–9798. https://doi.org/10.3390/ijerph120809768

Craig, C. L., Marshall, A. L., Sjöström, M., Bauman, A. E., Booth, M. L., Ainsworth, B. E., Pratt, M., Ekelund, U., Yngve, A., Sallis, J. F., & Oja, P. (2003). International physical activity questionnaire: 12-country reliability and validity. *Medicine and Science in Sports and Exercise*, *35*(8), 1381–1395. https://doi.org/10.1249/01.MSS.0000078924.61453.FB

De Dominicis, S., Crano, W. D., Ganucci Cancellieri, U., Mosco, B., Bonnes, M., Hohman, Z., & Bonaiuto, M. (2014). Vested interest and environmental risk communication: Improving willingness to cope with impending disasters: Vested interest and environmental risk. *Journal of Applied Social Psychology*, *44*(5), 364–374. https://doi.org/10.1111/jasp.12229

De Dominicis, S., Pilin, M., & Seidel, L. (accepted manuscript). Vested Interest and Exercise Engagement: Overcoming negative Attitudes and promoting Self-efficacy and Intrinsic Motivation. *Sport, Exercise, and Performance Psychology*.

De Dominicis, S., Sokoloski, R., Jaeger, C. M., & Schultz, P. W. (2019). Making the smart meter social promotes long-term energy conservation. *Palgrave Communications*, *5*(1), 51. https://doi.org/10.1057/s41599-019-0254-5

Després, J.-P. (2016). Physical Activity, Sedentary Behaviours, and Cardiovascular Health: When Will Cardiorespiratory Fitness Become a Vital Sign? *Canadian Journal of Cardiology*, *32*(4), 505–513. https://doi.org/10.1016/j.cjca.2015.12.006

Diaz, K. M., Krupka, D. J., Chang, M. J., Peacock, J., Ma, Y., Goldsmith, J., Schwartz, J. E., & Davidson, K. W. (2015). Fitbit®: An accurate and reliable device for wireless physical activity tracking. *International Journal of Cardiology*, *185*, 138–140. https://doi.org/10.1016/j.ijcard.2015.03.038

Dimsdale, J. E. (2008). Psychological Stress and Cardiovascular Disease. *Journal of the American College of Cardiology*, *51*(13), 1237–1246. https://doi.org/10.1016/j.jacc.2007.12.024

Dugdill, L., Brettle, A., Hulme, C., McCluskey, S., & Long, A. F. (2008). Workplace physical activity interventions: A systematic review. *International Journal of Workplace Health Management*, *1*(1), 20–40. https://doi.org/10.1108/17538350810865578

Dwyer, M. J., Pasini, M., De Dominicis, S., & Righi, E. (2020). Physical activity: Benefits and challenges during the COVID-19 pandemic. *Scandinavian Journal of Medicine & Science in Sports*, *30*(7), 1291–1294. https://doi.org/10.1111/sms.13710

Eggermont, L. H. P., Milberg, W. P., Lipsitz, L. A., Scherder, E. J. A., & Leveille, S. G. (2009). Physical Activity and Executive Function in Aging: The MOBILIZE Boston Study: PHYSICAL ACTIVITY AND EXECUTIVE FUNCTION IN AGING. *Journal of the American Geriatrics Society*, *57*(10), 1750–1756. https://doi.org/10.1111/j.1532-5415.2009.02441.x

Fairbrother, K., & Warn, J. (2003). Workplace dimensions, stress and job satisfaction. *Journal of Managerial Psychology*, *18*(1), 8–21. https://doi.org/10.1108/02683940310459565

Fang, Y.-Y., Huang, C.-Y., & Hsu, M.-C. (2019). Effectiveness of a physical activity program on weight, physical fitness, occupational stress, job satisfaction and quality of life of overweight employees in high-tech industries: A randomized controlled study. *International Journal of Occupational Safety and Ergonomics*, *25*(4), 621–629. https://doi.org/10.1080/10803548.2018.1438839

Fleshner, F. (2005). Physical Activity and Stress Resistance: Sympathetic Nervous System Adaptations Prevent Stress-Induced Immunosuppression: *Exercise and Sport Sciences Reviews*, *33*(3), 120–126. https://doi.org/10.1097/00003677-200507000-00004

Gatchel, R. J., Peng, Y. B., Peters, M. L., Fuchs, P. N., & Turk, D. C. (2007). The biopsychosocial approach to chronic pain: Scientific advances and future directions. *Psychological Bulletin*, *133*(4), 581–624. https://doi.org/10.1037/0033-2909.133.4.581

Goldberg, D. S., & McGee, S. J. (2011). Pain as a global public health priority. *BMC Public Health*, *11*(1), 770. https://doi.org/10.1186/1471-2458-11-770

Goldstein, N. J., Cialdini, R. B., & Griskevicius, V. (2008). A Room with a Viewpoint: Using Social Norms to Motivate Environmental Conservation in Hotels. *Journal of Consumer Research*, *35*(3), 472–482. https://doi.org/10.1086/588568

Grant, F., Hogg, M. A., & Crano, W. D. (2015). Yes, we can: Physical activity and group identification among healthy adults. *Journal of Applied Social Psychology*, *45*(7), 383–390. https://doi.org/10.1111/jasp.12305

Hayes, A. F. (2013). *Introduction to Mediation, Moderation, and Conditional Process Analysis: A Regression-Based Approach*. Guilford Press.

Hayes, A. F., & Montoya, A. K. (2017). A Tutorial on Testing, Visualizing, and Probing an Interaction Involving a Multicategorical Variable in Linear Regression Analysis. *Communication Methods and Measures*, *11*(1), 1–30. https://doi.org/10.1080/19312458.2016.1271116

Hekler, E. B., Michie, S., Pavel, M., Rivera, D. E., Collins, L. M., Jimison, H. B., Garnett, C., Parral, S., & Spruijt-Metz, D. (2016). Advancing Models and Theories for Digital Behavior Change Interventions. *American Journal of Preventive Medicine*, *51*(5), 825–832. https://doi.org/10.1016/j.amepre.2016.06.013

Hoboubi, N., Choobineh, A., Kamari Ghanavati, F., Keshavarzi, S., & Akbar Hosseini, A. (2017). The Impact of Job Stress and Job Satisfaction on Workforce Productivity in an Iranian Petrochemical Industry. *Safety and Health at Work*, *8*(1), 67–71. https://doi.org/10.1016/j.shaw.2016.07.002

Hogg, M. A., & Reid, S. A. (2006). Social Identity, Self-Categorization, and the Communication of Group Norms. *Communication Theory*, *16*(1), 7–30. https://doi.org/10.1111/j.1468-2885.2006.00003.x

Hogg, M. A., Terry, D. J., & White, K. M. (1995). A Tale of Two Theories: A Critical Comparison of Identity Theory with Social Identity Theory. *Social Psychology Quarterly*, *58*(4), 255–269. https://doi.org/10.2307/2787127

Jakobsen, M. D., Sundstrup, E., Brandt, M., & Andersen, L. L. (2017). Psychosocial benefits of workplace physical exercise: Cluster randomized controlled trial. *BMC Public Health*, *17*(1), 798. https://doi.org/10.1186/s12889-017-4728-3

Jetté, M., Sidney, K., & Blümchen, G. (1990). Metabolic equivalents (METS) in exercise testing, exercise prescription, and evaluation of functional capacity. *Clinical Cardiology*, *13*(8), 555–565. https://doi.org/10.1002/clc.4960130809

Johnson, P. O., & Fay, L. C. (1950). The Johnson-Neyman technique, its theory and application. *Psychometrika*, *15*(4), 349–367. https://doi.org/10.1007/BF02288864

Kilpatrick, M., Sanderson, K., Blizzard, L., Teale, B., & Venn, A. (2013). Cross-sectional associations between sitting at work and psychological distress: Reducing sitting time may benefit mental health. *Mental Health and Physical Activity*, *6*(2), 103–109. https://doi.org/10.1016/j.mhpa.2013.06.004

Kniffin, K. M., Narayanan, J., Anseel, F., Antonakis, J., Ashford, S. P., Bakker, A. B., Bamberger, P., Bapuji, H., Bhave, D. P., Choi, V. K., Creary, S. J., Demerouti, E., Flynn, F. J., Gelfand, M. J., Greer, L. L., Johns, G., Kesebir, S., Klein, P. G., Lee, S. Y., … Vugt, M. van. (2021). COVID-19 and the workplace: Implications, issues, and insights for future research and action. *American Psychologist*, *76*(1), 63–77. https://doi.org/10.1037/amp0000716

Kouvonen, A., Vahtera, J., Oksanen, T., Pentti, J., Väänänen, A. K. P., Heponiemi, T., Salo, P., Virtanen, M., & Kivimäki, M. (2013). Chronic workplace stress and insufficient physical activity: A cohort study. *Occupational and Environmental Medicine*, *70*(1), 3–8. https://doi.org/10.1136/oemed-2012-100808

Kroenke, K., Spitzer, R. L., & Williams, J. B. W. (2003). The Patient Health Questionnaire-2: Validity of a two-item depression screener. *Medical Care*, *41*(11), 1284–1292. https://doi.org/10.1097/01.MLR.0000093487.78664.3C

Kroenke, K., Spitzer, R. L., Williams, J. B. W., Monahan, P. O., & Löwe, B. (2007). Anxiety disorders in primary care: Prevalence, impairment, comorbidity, and detection. *Annals of Internal Medicine*, *146*(5), 317–325. https://doi.org/10.7326/0003-4819-146-5-200703060-00004

Ku, P.-W., Fox, K. R., & Chen, L.-J. (2016). Leisure-Time Physical Activity, Sedentary Behaviors and Subjective Well-Being in Older Adults: An Eight-Year Longitudinal Research. *Social Indicators Research*, *127*(3), 1349–1361. https://doi.org/10.1007/s11205-015-1005-7

Lee, E., & Kim, Y. (2019). Effect of university students' sedentary behavior on stress, anxiety, and depression. *Perspectives in Psychiatric Care*, *55*(2), 164–169. https://doi.org/10.1111/ppc.12296

Lee, E.-H. (2012). Review of the Psychometric Evidence of the Perceived Stress Scale. *Asian Nursing Research*, *6*(4), 121–127. https://doi.org/10.1016/j.anr.2012.08.004

Lee, P. H., Macfarlane, D. J., Lam, T., & Stewart, S. M. (2011). Validity of the international physical activity questionnaire short form (IPAQ-SF): A systematic review. *International Journal of Behavioral Nutrition and Physical Activity*, *8*(1), 115. https://doi.org/10.1186/1479-5868-8-115

Lehman, B. J., David, D. M., & Gruber, J. A. (2017). Rethinking the biopsychosocial model of health: Understanding health as a dynamic system. *Social and Personality Psychology Compass*, *11*(8), e12328. https://doi.org/10.1111/spc3.12328

Leveille, S. G. (2009). Chronic Musculoskeletal Pain and the Occurrence of Falls in an Older Population. *JAMA*, *302*(20), 2214. https://doi.org/10.1001/jama.2009.1738

Lewis, B. A., Napolitano, M. A., Buman, M. P., Williams, D. M., & Nigg, C. R. (2017). Future directions in physical activity intervention research: Expanding our focus to sedentary behaviors, technology, and dissemination. *Journal of Behavioral Medicine*, *40*(1), 112–126. https://doi.org/10.1007/s10865-016-9797-8

Lihavainen, K., Sipila, S., Rantanen, T., Sihvonen, S., Sulkava, R., & Hartikainen, S. (2010). Contribution of Musculoskeletal Pain to Postural Balance in Community-Dwelling People Aged 75 Years and Older. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, *65A*(9), 990–996. https://doi.org/10.1093/gerona/glq052

Liu, J., Thomas, J. M., & Higgs, S. (2019). The relationship between social identity, descriptive social norms and eating intentions and behaviors. *Journal of Experimental Social Psychology*, *82*, 217–230. https://doi.org/10.1016/j.jesp.2019.02.002

Löwe, B., Kroenke, K., & Gräfe, K. (2005). Detecting and monitoring depression with a two-item questionnaire (PHQ-2). *Journal of Psychosomatic Research*, *58*(2), 163–171. https://doi.org/10.1016/j.jpsychores.2004.09.006

Löwe, B., Wahl, I., Rose, M., Spitzer, C., Glaesmer, H., Wingenfeld, K., Schneider, A., & Brähler, E. (2010). A 4-item measure of depression and anxiety: Validation and standardization of the Patient Health Questionnaire-4 (PHQ-4) in the general population. *Journal of Affective Disorders*, *122*(1), 86–95. https://doi.org/10.1016/j.jad.2009.06.019

Manchikanti, L., Singh, V., Datta, S., Cohen, S. P., Hirsch, J. A., & American Society of Interventional Pain Physicians. (2009). Comprehensive review of epidemiology, scope, and impact of spinal pain. *Pain Physician*, *12*(4), E35-70.

Michie, S., Yardley, L., West, R., Patrick, K., & Greaves, F. (2017). Developing and Evaluating Digital Interventions to Promote Behavior Change in Health and Health Care: Recommendations Resulting From an International Workshop. *Journal of Medical Internet Research*, *19*(6), e232. https://doi.org/10.2196/jmir.7126

Narici, M., Vito, G. D., Franchi, M., Paoli, A., Moro, T., Marcolin, G., Grassi, B., Baldassarre, G., Zuccarelli, L., Biolo, G., Girolamo, F. G. di, Fiotti, N., Dela, F., Greenhaff, P., & Maganaris, C. (2020). Impact of sedentarism due to the COVID-19 home confinement on neuromuscular, cardiovascular and metabolic health: Physiological and pathophysiological implications and recommendations for physical and nutritional countermeasures. *European Journal of Sport Science*, *0*(0), 1–22. https://doi.org/10.1080/17461391.2020.1761076

Nauman, J., Janszky, I., Vatten, L. J., & Wisløff, U. (2011). Temporal Changes in Resting Heart Rate and Deaths From Ischemic Heart Disease. *JAMA*, *306*(23), 2579. https://doi.org/10.1001/jama.2011.1826

Ohrnberger, J., Fichera, E., & Sutton, M. (2017). The relationship between physical and mental health: A mediation analysis. *Social Science & Medicine*, *195*, 42–49. https://doi.org/10.1016/j.socscimed.2017.11.008

Oman, R. F., & King, A. C. (1998). Predicting the adoption and maintenance of exercise participation using self-efficacy and previous exercise participation rates. *American Journal of Health Promotion: AJHP*, *12*(3), 154–161. https://doi.org/10.4278/0890-1171-12.3.154

Parry, S., & Straker, L. (2013). The contribution of office work to sedentary behaviour associated risk. *BMC Public Health*, *13*(1), 296. https://doi.org/10.1186/1471-2458-13-296

Pinder, C., Vermeulen, J., Cowan, B. R., & Beale, R. (2018). Digital Behaviour Change Interventions to Break and Form Habits. *ACM Transactions on Computer-Human Interaction*, *25*(3), 1–66. https://doi.org/10.1145/3196830

Porges, S. W. (1992). Vagal tone: A physiologic marker of stress vulnerability. *Pediatrics*, *90*(3 Pt 2), 498–504.

Rezende, L. F. M. de, Lopes, M. R., Rey-López, J. P., Matsudo, V. K. R., & Luiz, O. do C. (2014). Sedentary Behavior and Health Outcomes: An Overview of Systematic Reviews. *PLOS ONE*, *9*(8), e105620. https://doi.org/10.1371/journal.pone.0105620

Rimal, R. N., & Real, K. (2005). How Behaviors are Influenced by Perceived Norms A Test of the Theory of Normative Social Behavior. *Communication Research*, *32*(3), 389–414. https://doi.org/10.1177/0093650205275385

Roberts, A. L., Fisher, A., Smith, L., Heinrich, M., & Potts, H. W. W. (2017). Digital health behaviour change interventions targeting physical activity and diet in cancer survivors: A systematic review and meta-analysis. *Journal of Cancer Survivorship*, *11*(6), 704–719. https://doi.org/10.1007/s11764-017-0632

Salari, N., Hosseinian-Far, A., Jalali, R., Vaisi-Raygani, A., Rasoulpoor, S., Mohammadi, M., Rasoulpoor, S., & Khaledi-Paveh, B. (2020). Prevalence of stress, anxiety, depression among the general population during the COVID-19 pandemic: A systematic review and meta-analysis. *Globalization and Health*, *16*(1), 57. https://doi.org/10.1186/s12992-020-00589-w

Salmon, P. (2001). Effects of physical exercise on anxiety, depression, and sensitivity to stress. *Clinical Psychology Review*, *21*(1), 33–61. https://doi.org/10.1016/S0272-7358(99)00032-X

Samdal, G. B., Eide, G. E., Barth, T., Williams, G., & Meland, E. (2017). Effective behaviour change techniques for physical activity and healthy eating in overweight and obese adults; systematic review and meta-regression analyses. *International Journal of Behavioral Nutrition and Physical Activity*, *14*(1), 42. https://doi.org/10.1186/s12966-017-0494-y

Schultz, P. W. (1999). Changing Behavior With Normative Feedback Interventions: A Field Experiment on Curbside Recycling. *Basic and Applied Social Psychology*, *21*(1), 25–36. https://doi.org/10.1207/s15324834basp2101_3

Schultz, P. W., Estrada, M., Schmitt, J., Sokoloski, R., & Silva-Send, N. (2015). Using in-home displays to provide smart meter feedback about household electricity consumption: A randomized control trial comparing kilowatts, cost, and social norms. *Energy*, *90, Part 1*, 351–358. https://doi.org/10.1016/j.energy.2015.06.130

Schultz, P. W., Messina, A., Tronu, G., Limas, E. F., Gupta, R., & Estrada, M. (2014). Personalized Normative Feedback and the Moderating Role of Personal Norms A Field Experiment to Reduce Residential Water Consumption. *Environment and Behavior*, 0013916514553835. https://doi.org/10.1177/0013916514553835

Schultz, P. W., Nolan, J. M., Cialdini, R. B., Goldstein, N. J., & Griskevicius, V. (2007). The Constructive, Destructive, and Reconstructive Power of Social Norms. *Psychological Science*, *18*(5), 429–434. https://doi.org/10.1111/j.1467-9280.2007.01917.x

Schultz, P. W., Nolan, J. M., Cialdini, R. B., Goldstein, N. J., & Griskevicius, V. (2018). The Constructive, Destructive, and Reconstructive Power of Social Norms: Reprise. *Perspectives on Psychological Science*, *13*(2), 249–254. https://doi.org/10.1177/1745691617693325

Skakon, J., Nielsen, K., Borg, V., & Guzman, J. (2010). Are leaders' well-being, behaviours and style associated with the affective well-being of their employees? A systematic review of three decades of research. *Work & Stress*, *24*(2), 107–139. https://doi.org/10.1080/02678373.2010.495262

Sloan, R. A., Sawada, S. S., Girdano, D., Liu, Y. T., Biddle, S. J., & Blair, S. N. (2013). Associations of sedentary behavior and physical activity with psychological distress: A cross-sectional study from Singapore. *BMC Public Health*, *13*(1), 885. https://doi.org/10.1186/1471-2458-13-885

Stanton, R., To, Q. G., Khalesi, S., Williams, S. L., Alley, S. J., Thwaite, T. L., Fenning, A. S., & Vandelanotte, C. (2020). Depression, Anxiety and Stress during COVID-19: Associations with Changes in Physical Activity, Sleep, Tobacco and Alcohol Use in Australian Adults. *International Journal of Environmental Research and Public Health*, *17*(11), 4065. https://doi.org/10.3390/ijerph17114065

Steffens, D., Maher, C. G., Pereira, L. S. M., Stevens, M. L., Oliveira, V. C., Chapple, M., Teixeira-Salmela, L. F., & Hancock, M. J. (2016). Prevention of Low Back Pain: A Systematic Review and Meta-analysis. *JAMA Internal Medicine*, *176*(2), 199. https://doi.org/10.1001/jamainternmed.2015.7431

Steinmo, S., Hagger-Johnson, G., & Shahab, L. (2014). Bidirectional association between mental health and physical activity in older adults: Whitehall II prospective cohort study. *Preventive Medicine*, *66*, 74–79. https://doi.org/10.1016/j.ypmed.2014.06.005

Stockwell, S., Schofield, P., Fisher, A., Firth, J., Jackson, S. E., Stubbs, B., & Smith, L. (2019). Digital behavior change interventions to promote physical activity and/or reduce sedentary behavior in older adults: A systematic review and meta-analysis. *Experimental Gerontology*, *120*, 68–87. https://doi.org/10.1016/j.exger.2019.02.020

Stokols, D. (1996). Translating social ecological theory into guidelines for community health promotion. *American Journal of Health Promotion: AJHP*, *10*(4), 282–298. https://doi.org/10.4278/0890-1171-10.4.282

Tan, W., Hao, F., McIntyre, R. S., Jiang, L., Jiang, X., Zhang, L., Zhao, X., Zou, Y., Hu, Y., Luo, X., Zhang, Z., Lai, A., Ho, R., Tran, B., Ho, C., & Tam, W. (2020). Is returning to work during the COVID-19 pandemic stressful? A study on immediate mental health status and psychoneuroimmunity prevention measures of Chinese workforce. *Brain, Behavior, and Immunity*, *87*, 84–92. https://doi.org/10.1016/j.bbi.2020.04.055

Terry, D. J., Hogg, M. A., & White, K. M. (1999). The theory of planned behaviour: Self-identity, social identity and group norms. *British Journal of Social Psychology*, *38*(3), 225–244. https://doi.org/10.1348/014466699164149

Tomiyama, A. J. (2019). Stress and Obesity. *Annual Review of Psychology*, *70*(1), 703–718. https://doi.org/10.1146/annurev-psych-010418-102936

van Dick, R., van Knippenberg, D., Kerschreiter, R., Hertel, G., & Wieseke, J. (2008). Interactive effects of work group and organizational identification on job satisfaction and extra-role behavior. *Journal of Vocational Behavior*, *72*(3), 388–399. https://doi.org/10.1016/j.jvb.2007.11.009

van Dick, R., Wagner, U., Stellmacher, J., & Christ, O. (2004). The utility of a broader conceptualization of organizational identification: Which aspects really matter? *Journal of*

Occupational and Organizational Psychology, *77*(2), 171–191. https://doi.org/10.1348/096317904774202135

Van Eerd, D., Munhall, C., Irvin, E., Rempel, D., Brewer, S., van der Beek, A. J., Dennerlein, J. T., Tullar, J., Skivington, K., Pinion, C., & Amick, B. (2016). Effectiveness of workplace interventions in the prevention of upper extremity musculoskeletal disorders and symptoms: An update of the evidence. *Occupational and Environmental Medicine*, *73*(1), 62–70. https://doi.org/10.1136/oemed-2015-102992

van Vugt, M., Griskevicius, V., & Schultz, P. W. (2014). Naturally Green: Harnessing Stone Age Psychological Biases to Foster Environmental Behavior. *Social Issues and Policy Review*, *8*(1), 1–32. https://doi.org/10.1111/sipr.12000

Walsh, J. C., & Groarke, J. M. (2019). Integrating Behavioral Science With Mobile (mHealth) Technology to Optimize Health Behavior Change Interventions. *European Psychologist*, *24*(1), 38–48. https://doi.org/10.1027/1016-9040/a000351

Warttig, S. L., Forshaw, M. J., South, J., & White, A. K. (2013). New, normative, English-sample data for the Short Form Perceived Stress Scale (PSS-4). *Journal of Health Psychology*, *18*(12), 1617–1628. https://doi.org/10.1177/1359105313508346

World Health Organization. (2020). *WHO guidelines on physical activity and sedentary behaviour*. World Health Organization. https://apps.who.int/iris/handle/10665/336656

Wright, T. A., & Bonett, D. G. (2007). Job Satisfaction and Psychological Well-Being as Nonadditive Predictors of Workplace Turnover. *Journal of Management*, *33*(2), 141–160. https://doi.org/10.1177/0149206306297582

Wright, T. A., & Cropanzano, R. (2000). Psychological well-being and job satisfaction as predictors of job performance. *Journal of Occupational Health Psychology*, *5*(1), 84–94. https://doi.org/10.1037/1076-8998.5.1.84

Wright, T. A., Cropanzano, R., & Bonett, D. G. (2007). The moderating role of employee positive well being on the relation between job satisfaction and job performance. *Journal of Occupational Health Psychology*, *12*(2), 93–104. https://doi.org/10.1037/1076-8998.12.2.93

Yardley, L., Choudhury, T., Patrick, K., & Michie, S. (2016a). Current Issues and Future Directions for Research Into Digital Behavior Change Interventions. *American Journal of Preventive Medicine*, *51*(5), 814–815. https://doi.org/10.1016/j.amepre.2016.07.019

Yardley, L., Choudhury, T., Patrick, K., & Michie, S. (2016b). Current Issues and Future Directions for Research Into Digital Behavior Change Interventions. *American Journal of Preventive Medicine*, *51*(5), 814–815. https://doi.org/10.1016/j.amepre.2016.07.019

Yardley, L., Morrison, L., Bradbury, K., & Muller, I. (2015). The Person-Based Approach to Intervention Development: Application to Digital Health-Related Behavior Change Interventions. *Journal of Medical Internet Research*, *17*(1), e30. https://doi.org/10.2196/jmir.4055

Yardley, L., Spring, B. J., Riper, H., Morrison, L. G., Crane, D. H., Curtis, K., Merchant, G. C., Naughton, F., & Blandford, A. (2016). Understanding and Promoting Effective Engagement With Digital Behavior Change Interventions. *American Journal of Preventive Medicine*, *51*(5), 833–842. https://doi.org/10.1016/j.amepre.2016.06.015

Yazdani, A., & Wells, R. (2018). Barriers for implementation of successful change to prevent musculoskeletal disorders and how to systematically address them. *Applied Ergonomics*, *73*, 122–140. https://doi.org/10.1016/j.apergo.2018.05.004

Yonas, M. A., Lange, N. E., & Celedón, J. C. (2012). Psychosocial stress and asthma morbidity. *Current Opinion in Allergy & Clinical Immunology*, *12*(2), 202–210. https://doi.org/10.1097/ACI.0b013e32835090c9

Yook, Y.-S. (2020). Relationship between physical activity and job stress among public office workers. *Journal of Physical Therapy Science*, *32*(12), 839–843. https://doi.org/10.1589/jpts.32.839

6. Studying and exercising: use of wearables in university students

As reported in the previous research topic concerning office workers, physical inactivity could be considered a real pandemic, being a leading cause of chronic noncommunicable diseases (Hall et al., 2020). This has been confounded recently with the COVID-19 pandemic and lockdown measures implemented worldwide to counter the spread of the virus (De Dominicis et al., 2022). Similar to office workers, university students are at risk of sedentary diseases, and it is urgent to understand how to counteract an increase in this type of lifestyle in this population that may have been enhanced by the current epidemiological situation. Moreover, university students could double the benefit from regular physical activity (PA), since physical exercise may positively impact also mental health through enhancement of executive functions and neuroplasticity (Hötting & Röder, 2013; Ruscheweyh et al., 2011).

6.1 Targeted messaging promoting exercise: a joint KU-UNIVR Project

One effective intervention aimed to increase exercise and reduce stress could be through regular messages emphasizing the value of exercise (St Quinton et al., 202; Childs & de Wit, 2014). The relaying of regular messages emphasizing the value of exercise are beneficial in enhancing both mental and physical performance (Carfora et al., 2022; De Dominicis et al., 2022). In the present study, named "Study and Exercising Project", the free app PsyMe, developed by the University of Pavia and the Catholic University of the Sacred Heart of Milan (Carfora et al., 2022), delivered messages to a group of 485 university students over the course of a month. The students were enrolled from the University of Verona (UNIVR) and Catholic University of the Sacred Heart (CUSH) of Milan. The details of the study design are reported in the methods section. Three types of messages were delivered, with the overall purpose of stressing the importance of performing PA, specifically: goal-setting messages (about when and how to pursue a goal), educational messages (about the advantages of completing particular levels of activities), or a combination of the two types. The participants were divided into 4 different intervention groups that included wearable users (with/without intervention, n=122) and no wearable (with/without intervention, n=644). Among the groups, 122 participants wore a Garmin Vívosmart® 5 activity tracker (www.garmin.com), which tracks heart rate, sleep, and the quantity and type of physical activity, to monitor their actual behaviour (Garmin & subsidiaries, Garmin Vivosmart 5: Fitness activity tracker 2022). The Fitrockr data analytics platform was used by the research team in conjunction with the Garmin Health SDK to monitor and study participants' health parameters**.** Unsurprisingly, the experiment showed that all messages helped to increase PA (Carfora et al., 2022; De Dominicis et al., 2022). A deeper dive into the data analysis showed a combination of both goal setting and vested-interest messages to be more persuasive than each message type alone, specifically among participants with a higher BMI - a group of individuals who may need a more physically active lifestyle (Carfora et al., 2022). This suggests that individuals with higher BMI may need more information about how and why achieving a regular activity goal is important. Additionally, the positive effect was still noticeable one month after the research team stopped sending these messages, suggesting that this information can provide sustainable increases in activity. *"These findings are important learnings in the journey of providing more tailored and personalised advice on exercise to inactive individuals"*, my current supervisor at KU, Professor De Dominicis, states. He advises that *"…our results provide another proof that we can indeed leverage new technology for helping people being more active, but this must be informed by solid psychological and behavioural science. Ultimately, we are dealing with changing behaviours, habits, motivations, and identity. To apply coaching psychology through wearable devices such as those developed and produced by Garmin, could be extremely effective for promoting long-term engagement in physical activity and exercise*." The NEXS research team's next step is to apply the same concepts to increase PA to different target groups and eventually the wider community beyond students, and thereby add one more piece to the puzzle solving our global *"*physical inactivity crisis*"*.

6.2 Scope

My work within this project has focused on the specific aspects of stress monitoring among students either receiving (intervention group) or not receiving (non-intervention group) tailored messages aimed to focuse students on the importance of PA. Stress was reported using a questionnaire (self-reporting) and though the use of wearables that measured participants' stress levels quantitatively.

6.3 Background

Even though regular exercise has numerous known and proven advantages in reducing stress, according to the World Health Organization, 1 in 4 persons do not engage in the recommended 75 to 150 minutes per week of vigorous to moderate aerobic activity (Herbert et al., 2020). Physical inactivity is one of the main risk factors for stress and noncommunicable related diseases (NCDs) worldwide because of individuals becoming more and more sedentary (World Health Organization, 2022). Furthermore, due to the lockdown measures implemented by governments to control the COVID-19 pandemic, physical inactivity and, consequently, chronic diseases have increased globally (Chandrasekaran, & Ganesan, 2021; Dwyer et al., 2020). Moreover, the pandemic amplified the number and weight of stressors both in the general population and in the work landscape (Chandrasekaran & Ganesan, 2021; De Dominicis et al., 2022; Dwyer et al., 2020; Kniffin et al., 2021; Salari et al., 2020). One way to ascertain the impact of sedentary lifestyles and the impact of stress is to measure the monetary cost of stress within a work-related context (Kalia, 2002). Sedentary behaviour related health costs associated with non-communicable diseases was estimated to be INT$53.8 billion worldwide in 2013, of which INT$31billion was paid by the public sector (Kruk, 2014; Ding et al., 2016). Stress, in particular work-related stress stemming from western economic zones such as Australia, Canada, Denmark, France, Sweden, Switzerland, the United Kingdom, suggested an estimated total cost of between US$ 221.13 million to $187 billion per year (Hassard et al., 2018). University students run the same risk of developing excessive levels of sedentary behaviours as office workers do (Lee & Kim, 2019). Evidence suggests that university students are quite sedentary, and that their levels of sedentary behaviour are on par with or higher than those of desk-based office workers (Farinola & Bazán, 2011). Recent research shows that academic stress is correlated to reduced performance, disenrollment, and students' dropout (Chyu & Chen, 2022). Kitsantas et al. (2008) claim that up to 75% of undergraduate students may report stress, especially during their first year of university. As a confirmation, Ros & González (2009) suggest that stress accounts for half of university dropouts during the first year. This has an impact on public universities and represents a considerable cost for society. There is also a burden on healthcare services globally and a strain on the ability to diagnose mental health, including stress ("Mental Health: Facing the Challenges, Building Solutions," 2006). Modern technology, particularly linked to the use of cell phones and wearable technology, in conjunction with psychological interventions to promote physical exercise holds promise when diagnosing stress, motivating patients, and enhancing exercise as a form of prescription (Scheid & West, 2019).

6.4 Stress

Stress has been previously defined by the World Health Organization (WHO) as "the health epidemic of the 21st century" (Fink, 2017). The definition of stress according to the WHO refers to "any type of change that causes physical, emotional, or psychological strain and represents the body's response to a stimulus that requires attention or an action" (World Health Organization, Stress 2022).

The modern meaning of the word "stress" was first used by Hans Selye in 1976. According to Claude Bernard (1865–1961), maintaining our internal milieu in the face of a changing world is crucial for maintaining life. To describe the phenomena of "how a body's nerve system is activated when faced with a stressor, forcing the body to generate stress hormones for its protection," Cannon (1929) coined the term "homeostasis" and later popularized the phrase "fight or flight." According to Selye (1956), "stress" refers to the results of anything that poses a significant threat to homeostasis.

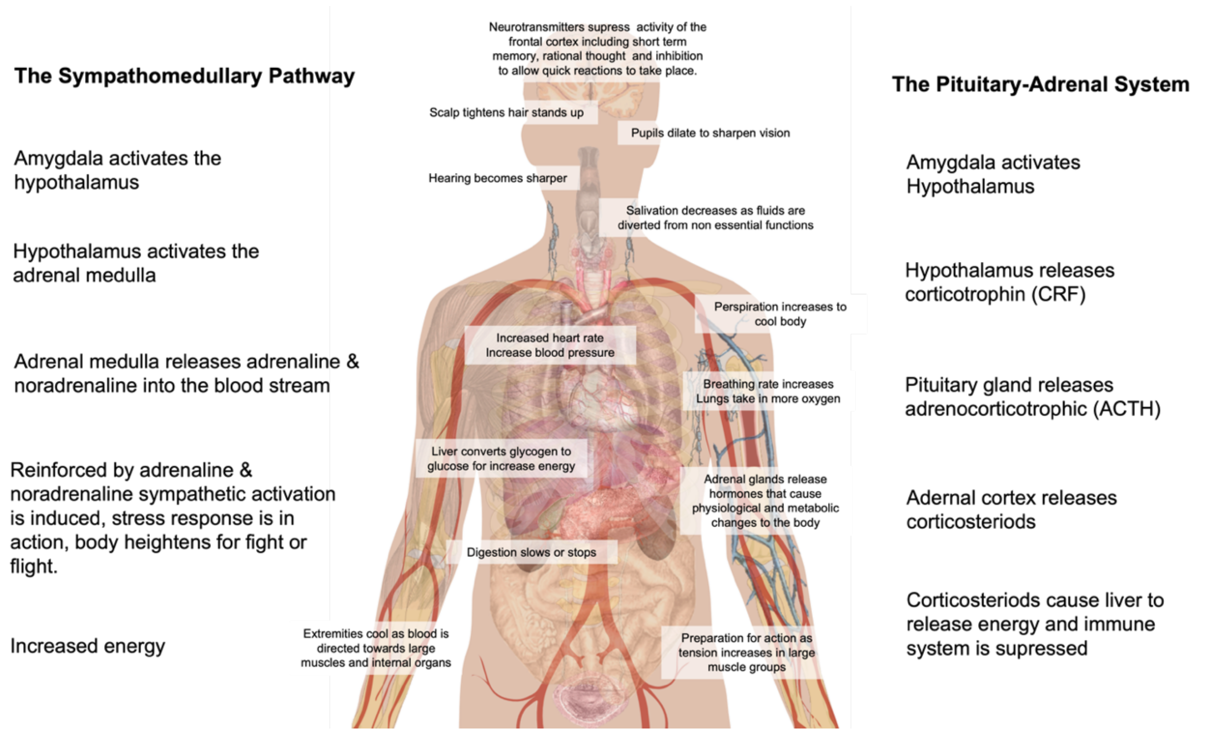
The "stressor" is the actual or imagined danger to an organism, and the "stress response" is the organism's reaction to the stressor. Selye recognized that strong, sustained stress reactions could result in tissue damage and disease, even though stress responses have developed as adaptive processes (Schneiderman et al., 2005).

Different physical or psychological stimuli (real or perceived) that provide for stress can initiate a series of stress hormones producing physiological adaptations within the body (Chu et al., 2020). Commonly known as the "stress response" or "fight or flight" response, these reactions to stress sequence hormonal changes that provide people with the ability to fight off the threat or escape from danger (Godoy et al., 2018). Hence the stress response works as a survival mechanism that has evolved over time to enable the continuation of species (Taborsky et al., 2020).

During a real or perceived stress event, human sensors such as sight, hearing, touch, smell, and taste provide stimuli to the amygdala within the brain. The amygdala helps to interpret and control such senses as well as the emotional processing associated with this interpretation (Carosella et al., 2021). Sensing a stressful event or danger the amygdala transmits distress signals to the hypothalamus (Ressler, 2010) The hypothalamus, in turn, communicates with the rest of the body via the autonomic nervous systems (ANS) (Waxenbaum et al., 2022). The ANS is made up of the sympathetic nervous system and parasympathetic enteric nervous systems (Waxenbaum et al., 2022). Activation of the sympathetic nervous system initiates the stress response by sending signals to adrenal glands that respond by producing epinephrine (adrenaline) into the bloodstream fostering several physiological adaptations, including increased breathing, lung capacity, and oxygen uptake (as increased oxygen is transferred to the brain to increase sensitivity and alertness), increased heart rate and blood pressure (to provide extra oxygenated blood to and deoxygenated blood away from the bodies muscles and vital organs), and the release of glucose and fats into the bloodstream for increased energy supply (Goldstein, 2010; Chu et al., 2020; Waxenbaum et al., 2022). The hypothalamus also activates the hypothalamic-pituitary-adrenal axis (HPA axis) which refers to the interaction between the hypothalamus, adrenal and pituitary glands and plays an important part in the stress response especially when the initial injection of epinephrine subsides (Smith & Vale, 2006). Herman et al. (2016) suggests that, after the initial stress trigger and when facing continued real or perceived stress, the hypothalamus releases corticotropin releasing hormone (CRH) to the pituitary gland, that sequentially releases adrenocorticotropic hormone (ACTH) to the adrenal glands signalling them to release cortisol which enables the continued level and heightening of the stress response (Smith & Vale, 2006; Toi et al., 2004). Once the stressor subsides or passes the parasympathetic nervous system initiates to lower the stress response (Lamotte, et al., 2021) by telling the body it is safe to recover and going back to a more relaxed status (e.g., reduced blood pressure, breathing rate and heart rate; promoting other less urgent functions such as digestion, etc).

Figure 1.

Diagram summarizing two stress pathways (bodily responses).



The sympathoadrenal medullary system is related to acute stress (e.g., the brain centres trigger the hypothalamus that activates the sympathetic branch of the autonomic nervous system and in turn the adrenal medulla to release adrenaline/noradrenaline and ultimately energy (e.g., increased heart rate, faster breathing, sweaty palms). 2. The pituitary adrenal pathway involved in chronic stress. The pituitary gland releases ACTH and stimulates the adrenal cortex to release cortisol in order to keep constant glucose supply and enabling the body to deal with stressors (picture from Wikipedia, description is author's work).

Although the stress response provides heightened metabolism as a survival mechanism, acute stress repeated activation can also provide for detrimental effects in the form of chronic stress. Research highlights that even chronic low-level stress can stimulate both the initial stress response and the HPA axis and overtime contribute to ailments and has been referred to as a silent killer (Herman et al., 2016). For example, continued epinephrine release can lead to increased blood pressure, damaged blood vessels and artery blocking initiating the risk of strokes and heart attacks. High blood cortisol levels can decrease sleep and exercise, increase appetite and the storage of unused energy as fat that can lead to obesity. Research also suggests that repeated activation of the stress response plays an important role in anxiety, depression and consequently addiction. It also represents a significant risk factor for multiple comorbidities such hypertension and cardiovascular disease, irritable bowel syndrome, gastroesophageal reflux disease, etc. A summary of methods for stress detection is reported in Table 1.

Table 1.

Stress detection

Blood tests to detect cortisol levels.	Blood tests can be used to gauge a person's level of stress (Duthie & Reynolds, 2013; Koś, & Waszkiewicz, 2021). One of the most popular blood tests for determining the impact of stress is cortisol test. In reaction to stress, the hypothalamic-pituitary-adrenal axis (HPA axis) releases the hormone cortisol from the adrenal glands (Stephens & Wand, 2012). Cortisol levels that are higher are a sign of increased stress (Cay et al., 2018).
Urine, Saliva Tests to detect cortisol levels.	Stress-related cortisol levels can also be determined through urine and simple mouth swab tests (El-Farhan et al., 2017). Like blood tests, saliva can be used to detect cortisol levels (Duthie & Reynolds, 2013). Furthermore, measuring cortisol levels through urine and simple swab saliva test is a relatively cheap and non-invasive method (Vlenterie et al 2016). Previous studies have shown that urine and salivary cortisol levels are reliable biomarkers to help assess stress (Law et al., 2013; Vlenterie et al., 2016).
Brain activity: Electroencephalogram (EEG)	Stress and emotional shifts have an impact on the brain's processes (Bremner, 2006). Electroencephalogram (EEG) is used to measure the brain activity via electrodes placed onto the person's scalp. Stress is detected using alpha, beta, and theta frequency, mean power ratios, fractal dimension features, and mean amplitudes of the EEG signal and Event-Related Potentials (ERP) (Newson & Thiagarajan, 2019). Alpha signals are usually associated with calm and balanced states and decreased stressful states. Conversely, beta activity may relate with emotional processes and increases with stress (Paszkiel et al., 2020).
Heart rate activity: Electrocardiogram (ECG) and wearable chest strap device	Since the Autonomous Nervous System directly affects heart rate, heart rate activity can be used to detect stress (Gordan et al., 2015). The most popular and reliable method for detecting stress through heart rate activity is the electrocardiogram (ECG) (Szakonyi et al., 2021). Heart rate activity is often detected and measured using body-worn electrodes or a wearable chest strap device (Szakonyi et al., 2021). Chest strap devices provided built in contact patches and a module that detect and measure electrical signals produced by the heart. Information is detected and recorded within the device so that data can be read and determined by the user (Hinde et al., 2021).
Blood volume pulse	Heart rate and heart rate variability are determinants of stress (Kim et al 2018). Blood volume and pressure can change

Photoplethysmography (PPG)	according to heart rate, determined by the autonomic nervous system (Kawase et al., 2002). Blood volume pulse (BVP) represents the variability in the blood volume for every inter-beat interval. Photoplethysmography (PPG) measures BVP using an optical technique, namely the absorption of infrared or infra-green light by blood. Following a light emitted from a source, different amounts of blood absorb different amount of light allowing to quantify the blood volume (Allen, 2007). Heart rate is derived from the raw BVP signal by measuring the inter-beat interval (distance between the peaks of the waveform representing blood circulation) (Gordan et al., 2015).
Muscle activity: Electromyogram (EMG)	Muscles are also impacted by the brain activity associated with stress (Pribék, 2021). Electrodes are applied to specific muscles to produce an electromyogram (EMG), which measures muscular action potentials to detect stress (Tosato et al., 2015). Muscle activity such over arousal causing poor posture and psychogenic issues such as tremors can be attributed to the stress mechanism (Harrington & Feuerstein 2010; Bloemsaat et al., 2005; Waersted, 2000; Waersted & Westgaard 1996).
Electrodermal Activity (EDA) Galvanic Skin Response (GRS)	Electrodermal activity EDA, also known as Galvanic Skin Response (GSR) is the modification of electrical properties of skin. Body sweating and an increase in skin conductance occur under stressful events. Applying a small amount of current and measuring the skin's resistance between two electrodes can be used to calculate EDA (Sanchez-Comas et al., 2021).
Skin temperature	Stress may determine changes in skin temperature (Vinkers et al., 2013). Herborn et al. demonstrated that stress can cause 0.1 to 0.2 Celsius change in temperature (Herborn et al., 2015) due to the fact that the blood flow is controlled by their sympathetic nervous system, and under stress the blood is transferred from the “less important” peripheral skin area to the core and main organs in the body (Herborn et al., 2015) Skin temperature can be measured non-invasively using infrared thermography (IRT), that is the process of using a thermal imager to detect radiation from an object (Herborn et al., 2015).
Speech	The system that produces human voice alters because of stress (Van Puyvelde et al., 2018). Stressful situations have an impact on pitch, speaking rate, energy, and spectral features. Since speech is non-invasive and data collection is simple in controlled quiet situations, speech is favoured by many researchers over more invasive techniques (König et al., 2021). The variables that are frequently employed to

	identify stress levels include pitch, higher frequency bands ratio, speaking pace, voice intensity, smoothed energy, voiced-unvoiced speech ratio, and Mel Frequency Cepstral Coefficients (MFCC) (Alberdi et al., 2016; Van Puyvelde et al., 2018; König et al., 2021).
Facial expressions	Stress and emotional states can correlate with facial expression (Sato et al., 2021). This is because facial expressions can reflect emotions more than self-reports (Höfling et al., 2021; Franěk et al., 2022). Facial Electromyography (EMG) and camera-derived image recognition have been used to detect facial expressions during stress (Höfling et al., 2021). Facial EMG is the measurement of the underlying electrical activity that's generated when facial muscles contract (Sato et al., 2021). Both EMG and image recognition used in conjunction with facial action coding system (FACS) and extracted action units (AUs) are the predominant indicators of stress through facial expression (Zhang et al., 2020). The three key facial characteristics for spotting stress are average smile intensity, brow movement, and mouth movement (Jia et al., 2021).
Body gestures and movements	When under stress, people adjust their body gestures and movements. Another indicator of stress is a change in posture. Research has demonstrated that stressful circumstances cause postural modifications in subjects (Coco et al., 2020). These modifications include arm motions, finger rubbing, and tightening of the jaw (Lin et al.,2021).
Writing, Keystroke and mouse dynamics	Writing, keyboard typing (keystroke) behaviour, and mouse usage are non-intrusive ways of analysing stress (Kołakowska & Landowska 2021). Writing, typing speed, keyboard and mouse usage styles vary from person to person (Khan et al., 2008). When a person is stressed, their muscles contract more than normal, affecting keystrokes and mouse dynamics. You can rely on this change to recognize stress (Vizer et al., 2009). Writing style, Keystroke and Mouse Dynamics is a non-invasive stress detection technique that requires no additional equipment other than a pen, mouse and keyboard. The most important and measurable characteristics that distinguish stress related to writing, keystrokes and mouse dynamics are dwell and flight times, pause rate, frequency of use of certain keys such as backspace and spacebar, digraph and trigraph duration, and key and pen pressure (Li et al.,2011; Kołakowska & Landowska 2021). Important features of mouse dynamics when detecting stress are acceleration, average movement speed, movement frequency, silence and click frequency (Banholzer et al., 2021).

Mobile phone usage	Smartphone usage can be used as a predictor of stress (Yang et al., 2021). Collecting information about smartphone usages is easy and non-invasive and highly investigated. Call logs, SMS logs, app usage, types of apps, battery usage, the screen on–off frequency, internet browsing, and Bluetooth proximity are all detected and can correlate with stress (Yang et al., 2021).
Questionnaires and surveys	Surveys and questionaries can be used to gather information about stress (Hanna et al., 2018). Questionnaires and surveys are a relatively cheap and quick way to gather a large amount of data about stress that respondents are feeling. Since questionnaires and surveys can be completed privately and anonymously, responses are likely to be honest. Another benefit is that surveys and questionnaires allow researchers to gather large amounts of data about stress from different populations (McInroy 2016). Negative aspects in the use of surveys or questionnaires is that they cannot fully capture emotional responses or feelings of respondents. Facial expressions cannot be captured if the questionnaire is not administered face-to-face, furthermore body language cannot be observed. Also, people often forget experiences and the emotions involved at the time of those experiences hence this can lead to miss represented data collection and measures regarding stressful experiences (Labott 2016).
Interviews	Interviews with qualified stress related practitioners and researchers allows for the detection of the stress (Perming et al., 2022). Interviews can be more beneficial than questionnaires as they allow practitioners to collect both verbal and non-nonverbal data and provide the structure to clarify the meaning of questions if the subjects do not understand them (Mathers et al., 1998). Research suggests that interviews have a higher response rate compared to surveys and questionaries especially when they have been recorded. This allows practitioners and researchers to analyse in greater detail emotional and nonverbal cues (Rutakumwa et al., 2020; DeJonckheere & Vaughn, 2019). For example, when a subject becomes nervous or cannot answer a question properly. Furthermore, interviews are also useful when one wants to know the story behind a stress response. Interviews are further preferred when a topic is complex requiring deeper dialogue and deeper explanation (Read 2018).

6.5 Economic Burden of Stress

One way to ascertain the impact of stress is to measure the monetary cost of stress within a work-related context (Kalia, 2002). Stress, acute or chronic, is known to encourage a wide range of physical and mental health conditions, therefore causing a large economic impact (Mariotti et al., 2015). A series of studies including Béjean & Sultan (2005); Kraatz et al., (2013); Kivimäki & Kawachi (2015); Bonde, (2008); Madsen et al., (2017); Hassard et al., (2018); Russo et al., (2021) have estimated the economic costs associated with stress using direct costs, for example those associated with healthcare and social security, as well as indirect costs that include various elements associated, for example, with lost productivity and income. Indirect impact also includes the relationship between workplace stress and workers' health problems such as musculoskeletal problems, heart disease, and mental health issues. Hassard et al., (2018) performed a systematic review estimating cost of illness; the estimated economic burden of work-related stress ranged from US$221 million to US$187 billion across recognized research from various parts of the world. Moreover, the anticipated cost per working person ranged from US$17.79 to US$1211.84; of these, 10 - 30% were related to medical care, while 70–90% were related to lost productivity. In another study by Russo et al., (2021) the European Agency for Safety & Health at Work estimated that the cost of work-related stress ranged from $221 million to $187 billion, and the entire annual cost of mental health disorders including stress in Europe reached up to €240 billion, of which €136 billion was attributable to lost productivity such as absenteeism, and €104 billion to direct costs, such as medical care. A survey conducted by OSHA found that the estimated economic impact of stress on US employers was $300 billion due to reduced productivity, increased health care costs, and increased legal costs (Financial costs of job stress: Total worker health for employers: CPH-New: Research). According to a World Health Organization (WHO) and World Bank report, the global economic output lost due to untreated mental illnesses including stress is estimated to total more than 10 billion days of lost work per year, or US$1 trillion, due to decreased productivity, lower rates of labour participation, and increased welfare payments (WHO, Mental health at work; Public disclosure authorized - world bank). According to Mitchell (Mitchell S, Ethical Marketing News, April 2022), 79% of employed British adults have experienced some forms of workplace-related stress with an increase of 20% compared to 2021. This phenomenon appears to impact all sectors and occupations, and according to these results, the academic sector is high in the rank with 83% of workers in this field reporting a stressful work-related situation. Other sectors with similar rates include media and marketing (85%) and healthcare (84%).

Strategies to reduce stress, including performance of PA, are nowadays advertised as flyers for office workers, student or laypeople highlighting the benefits of an active life (e.g., Motion connected flyer from the Cleveland Clinic, that uses Garmin devices as well, available at www.motionconnected.com)

6.6 Measures of stress

The HPA axis, with cortisol representing its final metabolite, has been proposed as a biological mechanism that can be associated to depression and stress symptoms (King & Hegadoren, 2002). In medicine, the measurement of stress hormones such as cortisol can help identify subjects who may be at risk for development of stress-related disorders or in monitoring the efficacy of interventions aimed at stress reduction. An easy-to-use method can test the cortisol levels in the saliva. However, cortisol measures may not clearly be associated with emotional responses (Lee et al., 2015).

If levels of cortisol in blood are not available, symptoms related to stress severity can be assessed, and subjective levels of stress measured, although these measures may be subjective and not provide adequate data to fully understand the effects of stress or the impact of interventions trying to reduce stress disorders. A longitudinal study using a 6 repeated measures survey in undergraduate students in India used questionnaires such as PSS14 and K10 (distress scale) and salivary cortisol levels to measure stress in male and female students. Compared to women, it was observed that men showed significantly reduced cortisol salivary levels and corresponding lower perceived stress (using PSS-14) and distress (using K10). Over time, at the end of the academic year, women had comparable perceived levels of stress and distress levels but higher cortisol levels, highlighting that there are relevant gender-related differences in psychological stress responses (Batabyal et al., 2021).

6.7 Academic sedentarism, stress, and exercise prescription

In most developed countries, approximately 35% of young adults are university students, which is a significant share of the population (Dragoescu, 2013). University students run the same risk of developing excessive levels of sedentary behaviour as office workers do (Lee & Kim, 2019). Evidence suggests that university students are quite sedentary and that their levels of sedentary behaviour are similar or higher than those of desk-based office workers (Farinola & Bazán, 2011). In high-income countries, university students reported increased levels of self-reported sedentary time than the broader population of young adults (Gallè et al., 2020). In the past ten years, US self-reported sedentary time has grown across all examined sub-groups and according to factors such as age, gender, educational attainment, race/ethnicity, and BMI (Ussery et al., 2021). University students spend long periods of sitting in sedentary tasks, such as listening to lectures or studying at their desk or at home (Paulus et al., 2021). According to a cross-sectional study performed in Brazil, university students self-report spending 8.3 hours per day being inactive (Mussi et al., 2017). In another survey, it was shown that, on average, American university students spent 4.2 hours each day sitting down (Buckworth & Nigg, 2004). The average time appeared even longer (e.g., two to three hours longer) when accelerometers were used to monitor activity (Clark et al., 2016; Conroy et al., 2013). Physical inactivity is considered as a risk factor contributing to over three million premature deaths a year worldwide (Lee et al., 2012). Even before the COVID-19 pandemic, the European population did not meet the global recommendations of the World Health Organization (WHO, 2020) of physical activity. A further decrease in the percentages of adherence to these recommendations followed the COVID-19 pandemic (López-Valenciano et al., 2021). This decrease is attributable to the various measures to contain the spread of the virus, such as quarantine, home confinement, and various restrictions. Despite their effectiveness in terms of health emergencies, these measures have resulted in drastic lifestyle changes for everyone, including college students. Italian university students, in particular, have carried out their academic activities remotely for a long time and until recently they could only access universities on a limited basis. These changes further worsened the already high levels of sedentary lifestyle observed in the Italian university population (Brancaccio et al., 2021).

With a growing amount of research relating sedentary behaviour to negative health outcomes such as poor mental health, depression, and anxiety it seems plausible that sedentary behaviour may also be linked to stress, including “academic” stress (e.g., academic-related demands that exceed adaptive capabilities of students) which has been exasperated during the COVID-19 pandemic. The connection between stress and anxiety is covered in academic stress research (Yang & Yang 2022; Zhang et al., 2022; Pascoe et al., 2020). Evidence suggests that sedentary behaviours within student populations might affect perceived stress and anxiety levels through changes in inflammatory responses (Endrighi et al., 2016) and via several psychosocial mechanisms including limited social participation (Vancampfort et al., 2019) and displacement of time that could have been spent in active pursuits (i.e., displacement theory) (Mutz et al., 1993). Maturana and Vargas (2015) define anxiety states as part of the clinical consequences of academic stress in students that can cause repercussions on their quality of life and academic performance. De Witte et al. claim that stress-related emotional states lead to anxiety within student populations. Furthermore, anxiety is a crucial component of the academic stress observed in anxious behaviours and symptoms of anxiety or distress (De Witte et al., 2021). Academic stress was originally described as mental distress brought on by frustration over academic failure, looking ahead to the future, or being aware that failure might be possible (Verma and Gupta1990). An interruption brought on by a student's impression of potential future results or consequences connected to academic performance is considered as academic stress (Putwain, 2007). This term, which has also been used to refer to "academic pressure," "educational stress," and "educational pressure," has been used interchangeably in several studies (Bossy, 2000; Jones & Hattie, 1991; Putwain, 2007; Verma & Gupta, 1990). It is understood to refer to a bad psychological state associated with academic activities like tests, exams, schoolwork, homework, grades, and future education (Thoits, 1995). Academic stresses are any academic requirements (such as external, internal, or social requirements) that force a student to modify his or her behaviour (Thoits, 1995). Time management, examinations and exams, the dread of failing, and family expectations are among the stresses that kids are most likely to encounter, according to research on academic stress in adolescence (Ang & Huan, 2006; Coney & West, 1979; Kouzma & Kennedy, 2004). According to recent studies, academic stress is linked to poor academic performance and student dropout (Pascoe et al., 2019). Stress may result in students dropping out of public universities, which has a significant financial impact on society. Academic stress can cause anxiety when students face stressful educational circumstances, such as exams, or have deadlines for assignments. That anxiety arises from emotional conditions associated to stress, and students are required to employ all their coping mechanisms to adjust or experience state anxiety. Along with the related stress symptoms, this process also demonstrates adaptive, behavioural, emotional, and anxiety characteristics. Academic stress may influence the equilibrium of the pupils' psychological, cognitive, social, and affective states.

Exercise interventions have been shown to impact positively on sedentary behaviours and negatively on stress. Exercise may decrease stress through multiple biological pathways. As an example, PA act in the HPA axis regulations, impact anti-inflammatory and immunological activities, can modulate neurotransmitters and the endogenous opioid system, stimulate neurogenic processes, and finally promote changes in the brain, acting on stress-related conditions (Anderson & Shivakumar, 2013; Hamer et al., 2012; Kandola et al., 2018). PA may also enhance mental health via improvements in self-perceptions (i.e., self-concept and self-esteem) and through distraction from everyday stressors (Anderson & Shivakumar, 2013). In finding ways to combat its effects, stress reduction was recognized as a benefit of regular moderate exercise (Fleshner, 2005). Research has shown a strong relationship between PA and mental health (Ohrnberger et al., 2017), and this relationship seems to be bidirectional with physical health affecting mental health and vice versa (Ku et al., 2016; Steinmo et al., 2014). Specifically for work-related stress, Conn et al. 2009 in their meta-analysis of workplace PA interventions found that PA programs are effective in reducing job-related stress. Further studies have confirmed that exercise positively impacts work-related stress. In particular, PA leads to higher job satisfaction, while less exercise tends to be accompanied by higher levels of job stress (Kouvonen et al., 2013; Yook, 2020). A study including students from China reported that those who were physically inactive were five times more likely to report symptoms of stress and anxiety than their active peers (Zeng et al., 2019).

Understanding the volume and nature of sedentary behaviours and its impact on stress and related mental health parameter among university students could help future policy and interventions (Lee & Kim, 2019). The university years are a crucial time for the formation of future life patterns since many adult health-related behaviours are set throughout late adolescence and young adulthood (Paulus et al., 2021). With teenagers and young adults, sedentary behaviour reduction and other behaviour change interventions present an opportunity to support well-being and stress relief for the rest of one's life (Edelmann, et al., 2022). This is crucial since, after graduation, university students are more likely to work in white-collar jobs where they could be subjected to prolonged periods of sedentary behaviour (Cotten and Prapavessis, 2016). It is therefore urgent to understand how to counteract an increase in sedentary lifestyle in this population. In fact, university students could obtain benefits not only in terms of physical health but also in terms of mental health. This is thanks to its ability to enhance executive functions (Barenberg et al., 2011) and, in particular, memory abilities (Ruscheweyh et al., 2011; Pesce et al., 2009), neuroplasticity, and the ability to respond to new requests through behavioural adaptations (Hötting & Röder, 2013).

6.8 Stress and wearable technology for measurement, diagnosis, and delivery of interventions

Since stress is an increasing and inescapable problem in modern life (Hutmacher, 2021), and physical and emotional stressors can work together to cause or worsen a wide range of illness states Schneiderman et al., (2005), scientists are working to develop more precise, accessible, and portable technologies to track stress levels (Samson, & Koh, 2020).

Furthermore, people are more interested in becoming autonomous in their health, and digital technology is more and more used in the medical and psychological fields. Digital technologies and data science represent a true revolution that is taking place, transforming the way health is perceived and will be managed, for example through telemedicine, remote monitoring, health mobile apps and applications of artificial intelligence (Cordeiro et al., 2021).

Results of patients being able to seek assistance sooner or take steps to lessen symptoms or triggers will see such devices ultimately and positively impact on morbidity and the financial strain on the healthcare system (Dias, et al 2018). The development of wearable technology and commercially available smart gadgets to monitor health has hugely increased over the last ten to fifteen years, including wearable, implantable, injectable and ingestible digital medical devices. Smartphones and wearable technology are easy to use, often affordable, and are more commonly employed as the preferred tools to identify and monitor stress since they are frequently carried on people as a must-have component of everyday life (Muaremi et al., 2013).

The Economist (May 2, 2022) reports that "wearable devices are connecting health care to daily life" and that this technology will revolutionise how people look after themselves. The shipment shipment of smartwatches and fitness trackers have exponentially grown in the past decade especially in North America, Western Europe, and China.

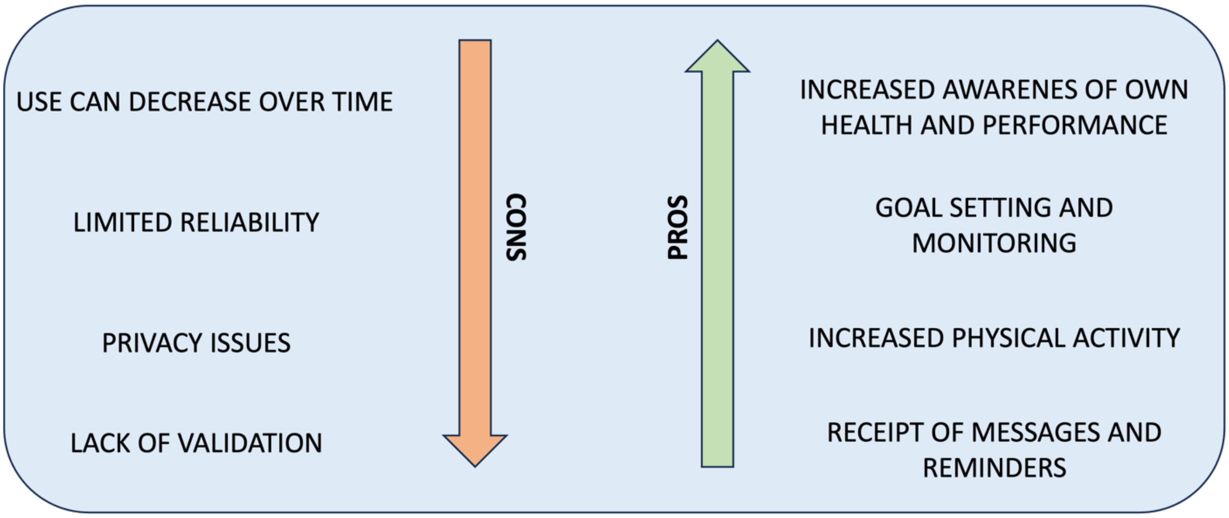
Cell phones and accompanying applications can deliver a plethora of health and exercise related information, messages, and programs to enhance health and wellbeing status as well as exercise duration and frequency (Kamel et al., 2021). Vital signs such as brain activity, heart rate (HR), electrocardiogram, skin temperature, and skin conductance response can be used as key indicators for monitoring a person's health (Dias, et al., 2018; Prieto-Avalos et al., 2022). Moreover, cell phones and diagnosis-based applications, smart watches with photoplethysmography sensors to measure HR variability and stress levels, smart jewellery (rings and earing's), smart helmets and glasses, pedometers, chest straps including EEG systems are amongst a growing array of inventions that non-invasively assess various health-related parameters (Hickey et al., 2012).

A national US survey performed in 2020 showed that about 30% (1266/4551) of responders use wearable health care devices and that over 80% of them would have shared the health data collected with their care providers. Increased use was associated with female gender, higher education, and increased income. Individuals who were more likely to use wearables for tracking their health reported feeling healthier (OR 1.17, 95% CI 0.98-1.39), were overweight (OR 1.16, 95% CI 1.06-1.27), enjoyed exercise (OR 1.23, 95% CI 1.06-1.43), and had higher levels of technology self-efficacy (OR 1.33, 95% CI 1.21-1.46) (Chandrasekaran et al., 2020).

Pros and cons of the use of the exponential increase in the use of trackers, smart watches and wearables is reported in Figure 2.

Figure 2.

Advantages and disadvantages of wearable use



Specifically, negative aspects of wearable-driven interventions include the fact that the effect and excitement for novelty can decrease over time, and that their reliability, given the fact that hundreds of brands are available on the market, is questionable and advertisement and marketing needs may prevail on research and validation. On the other side, wearables has been part of the digital revolution increasing people's interest in their own health and fitness levels, helping in setting goals and monitoring one's performance and increasing, among others, physical activity.

6.9 The Garmin Vivosmart 5 tracker

The Garmin Vivosmart 5 (Garmin International Inc, Kansas, US; www.garmin.com) is an example of a wearable device that provides an opportunity to examine stress through HRV in real-world environments, across longer periods of time, and with high resolution at a low cost using photoplethysmography (PPG) and an associated algorithm (Rodrigues et al., 2022). The Garmin Vivosmart 5 is a wrist worn multisensory activity tracker that provides a wide range of real time and delayed data to the wearer, including sleep monitoring with REM sleep, the gauging of blood oxygen saturation levels during the night with the wrist-based Pulse Ox² sensor, activity timers for walks, runs, strength training, yoga, pool swims are some examples. Furthermore, it allows the user to connect with compatible smartphones for GPS tracking and the syncing to smart phone compatible applications such as the Garmin App to gather and process sensor related data into usable data sets that may enable researchers to determine cause and effect relations between such variables as exercise and stress (Evenson, & Spade 2020). PPG measures the volumetric change of the heart by utilizing LED light transmission that is reflected into a photodiode (PD) sensor on the underside of the Vivosmart 5 whilst in contact with the skin. As the heart contracts, blood pressure within the left ventricle increases and is eventually released through the left ventricular valve as a pressurized blood pulse wave "pulse" into the arteries of the body which causes them to swell slightly before once again returning to their previous state. Like waves, a blood pulse wave has peaks and troughs (Castaneda et al., 2018). The Vivosmart 5 uses a green-coloured light-emitting diode LED that transmits infra-green light waves from its contact on the skin into the blood vessels within the anterior of the wrist, reflecting the rising and shallowing effect on tissue produced by the blood pulse wave back into a PD. In turn, the PD generates a current proportional to the amount of light received from the reflected LED which is amplified and converted into voltage signals by a transimpedance amplifier before being converted by an optical algorithm running on the system's microcontroller that reads and produces numerical data that can be processed by the device into readable and easy-to-read data for the consumer. The signal, however, can be weak if measured on the skin and far from the heart (e.g., wrist area); nevertheless, changes in pressure still allow for arteries expansion to a measurable level. Each blood pressure peak in the resulting signal can be identified through the PGG process and interpreted by the heart rate algorithm that ultimately reads and translates the amount of time it takes between each successive blood pressure peak, providing the ability to measure heart rate variability (Chowdhury et al., 2020). Heart rate variability measures the amount of time between consecutive heartbeats and PPG can track how that duration changes over time through the measurement of peaks from blood wave to blood wave. Analysis of the beat-to-beat duration may provide insight into how the body is responding to certain events. For example, and in regard to stress measurement, the time between beats is shortened when people are under stress and longer when at rest. The algorithm used to measure HR variability in the Garmin Vivosmart 5 is a product of Firstbeat Analytics (Firstbeat analytics: The strong partner that joined Garmin 2020). Since exercise initiates an increase in HR variability and to ensure that changes in HRV are due to stress and not solely to exercise, the device takes a baseline HR variability measurement when the users are inactive. Following this the algorithm, it compares the resting value to the current value, ignoring the variability in data caused by exercising from initial algorithm reading.

The types of stress measurements assessed by this wearable are reported in Table 2.

Table 2.

Stress measurements by Garmin Vivosmart 5: Reported unchanged from the Fitrockr manual

Garmin Vivosmart 5 Stress Measures	Description
Average Stress Level	An abstraction of the user's average stress level in this monitoring period, measured from 1 to 100, or -1 if there is not enough data to calculate average stress. Scores between 1 and 25 are considered "rest" (i.e. not stressful), 26-50 as "low" stress, 51-75 "medium" stress, and 76-100 as "high" stress.
Max Stress Level	The highest stress level measurement taken during this monitoring period
Stress Duration In Seconds	The number of seconds in this monitoring period where stress level measurements were in the stressful range (26-100).
Rest Stress Duration In Seconds	The number of seconds in this monitoring period where stress level measurements were in the restful range (1 to 25).
Activity Stress Duration In Seconds	The number of seconds in this monitoring period where the user was engaging in physical activity and so stress measurement was unreliable.
Low Stress Duration In Seconds	The portion of the user's stress duration where the measured stress score was in the low range (26-50).
Medium Stress Duration In Seconds	The portion of the user's stress duration where the measured stress score was in the medium range (51-75).
High Stress Duration In Seconds	The portion of the user's stress duration where the measured stress score was in the high range (76-100).
Stress Qualifier	A qualitative label applied based on all stress measurements in this monitoring period. Possible values: unknown, calm, balancer, stressful, very_stressful, calm_awake, balanced_awake, stressful_awake, very_stressful_awake.

6.10 The "Studying and Exercising" Project

The research I have performed represents a substudy derived from the wider "Studying and Exercising" joint interventional project involving UNIVR, KU, and CUSH. This prospective, longitudinal study was performed starting from November 2021 following ethics approval at both universities enrolling subjects (UNIVR and CUSH). A total of 482 students were included in the study.

A sample size of about 200 people was hypothesised. Specifically, using GPower 3.1, an estimate of the sample size considering an average Cohen effect size d (ES = 0.25) was calculated. With an alpha = 0.05, power = 0.95, number of groups = 4, number of measurements = 6 (2 measurements at 3 time points) and p = 0.05 the projected sample size needed was approximately N = 153 and in particular about 39 participants per group. To ensure that the final sample, excluding dropouts, reaches the estimated size, a sample of 200 participants (50 participants per group) was estimated.

To prevent students from feeling obliged to participate, the researchers emphasized the absolute freedom for students to participate or not and to withdraw their consent at any time during the research. No financial compensation was given in exchange for their participation.

The aim of the study was to develop an effective communication method to promote and easily measure regular PA, reducing sedentary behaviour among healthy adults (≥ 18 of age), in this case university students, using a psychosocial intervention based on persuasive "vested" messages. Previous studies have shown that "vested" persuasive messages can be effective in stimulating behavioural change (Crano et al., 2002). This general objective also included three main methodological components. Firstly, the framing of persuasive messages aimed at increasing the perceived importance and the hedonic relevance of the outcomes (e.g., performing regular PA) and leverage its positive effects in terms of enhancing cognitive functions such as memory, attention, and learning that are useful and relevant for the target population for improving university performance (De Dominicis et al., 2021). Framing was intended as a way of "framing" a message to favour a specific interpretation in the recipient at the expense of others (Bertolotti & Catellani, 2014). The framing of the message could concern both the content and the style of the messages, which can be effectively used to promote the adoption of healthy behaviours, including regular PA (e.g., Carfora et al., 2021). Secondly, PA was monitored not only through self-assessment via questionnaires but also quantitatively through the use of wearables. Numerous studies have shown the importance of monitoring one's own healthy behaviours (Carfora et al., 2022) and to objectively monitor daily activity levels, especially in the case of PA (Caso et al., 2021). The project also aimed at evaluating the effectiveness of these devices as an alternative method to help people stay physically active. Given that the effects of communication interventions on PA are often short-term (for a review, Brickwood et al., 2019), in this project we also wanted to test whether the inclusion of such devices could provide an effective tool for sustained and increased long-term PA, initially promoted through the persuasive communication strategies described above. In particular, self-reported measures appear to both underestimate and overestimate the amount of PA compared to direct measures of the latter, which poses a series of problems related to the validity and reliability of these measures, and their use. Thirdly, the project also aimed at comparing direct and self-report measures of PA, as well as to test their validity in relation to different biometric measures (such as, for example, the amount and type of physical activity, sleep quality, stress, resting heart rate, etc.). Numerous studies show that the data relating to physical activity differ significantly depending on the measurement method used, be it self-report or direct (Prince et al., 2008). A peculiarity of the study was the use of an instant, App-based, delivery of the messages. Furthermore, the vested interest was connected to the perceived importance of the outcome and the effects on students' performance.

The participants were divided int 4 groups using a block randomisation intervention that included different groups receiving vested messages and/or wearable-based assessment. Overall, group 1 received only vested messages, group 2 received only wearable devices, group 3 had both, while the control group 4 did not receive any intervention. The study duration was nine weeks.

The psychometric measures included four questionnaires. At time 0, a pre-screening schema was followed with the aim of allowing for a randomized block research design to minimize the effects of systematic error due to the random assignment of participants to the experimental conditions. Basic information were collected, including student's contacts to receive communications and information. Height, weight, age and gender were collected so that body mass index (BMI) could be calculated. Basic demographic information was also collected by asking participants to answer the university they were attached to and what province of Italy they live in. Further health related information was gathered about tobacco and alcohol use by asking respondents to supply information about quantity and frequency of use. A code was generated to identified participants, using the day they were born in numbers, the last two letters in their surname and the last three digits of their mobile numbers. Participants were then asked if they were in the habit of monitoring their PA and if they used a wearable device to do so and moreover what type of device they used. Furthermore, participants were asked if they ever used apps to monitor their physical activity and which brand of app they used.

The International Physical Activity Questionnaire (IPAQ) Short form (IPAQ-SF) was used to evaluate participants' PA levels. IPAQ-SF is a self-administered short form of the International Physical Activity Questionnaire (IPAQ) is a seven-item self-report instrument that assesses PA and requires respondents to report the number of days and the duration of the vigorous (V), moderate (M), walking activity (W), and sitting activity (S) to achieve a combined total PA score. Weekly time spent in vigorous activity, moderate activity, and walking was determined by multiplying reported frequency and duration within each category of activity. Total weekly time in PA is calculated by summing the three categories of activities listed above. The following questions were included in the questionnaire: In the last 7 days, how many days have you been doing vigorous, moderate, walking and sitting physical activity? On average, how many minutes have you been doing vigorous, moderate, walking and sitting PA in one of these days? Regarding the definitions, vigorous PA was defined as an activity that requires high physical effort, accompanied by a much higher breathing rate than normal (during this activity you sweat and cannot speak). Examples are sports or aerobic activities such as running or cycling at high speed, swimming, team sports, sustained activity in the gym or weightlifting, etc. Moderate PA is an activity that requires moderate physical effort, accompanied by a rhythm of breathing that is only moderately higher than normal (for example during this activity you cannot sing but you can speak). Examples of moderate PA are bike rides or rides at a regular speed, stretching activities in the gym or at home, prolonged physical work around the house (housework), carrying light weights, etc. Walking activity considers the walks that students may have taken at university and at home, those to move from one place to another and any other walking they may have ever done for pleasure, exercise, or sport. Sitting or sedentary activities considers activities carried out at university, at home, while you went to university or returned home and during your free time (e.g., at a desk, at the table, at a friend's house, on TV, reading etc). Questionnaire at time 1 gathered information regarding personal exercise, PA, and sport that respondents partake in including the type, level they perform at, and quantity. The Self-Report Habit Index (SRHI; Verplanken & Orbell, 2003) was designed to measure habit strength, and was developed on the basis of features of habit: a history of repetition, automaticity (lack of control and awareness, efficiency), and expressing identity. The instrument contains 12 items. The items are accompanied by response scales anchored by agree/disagree and preferably should contain five or more response categories. The perceived stress scale (PSS-10) is described in detail in the sub study below. A summary of the investigations or thematic areas explored at baseline, time 1, time 2 and time 3 is reported in Table 3.

Table 3.

Investigations performed at different study timepoints

Pre-screening (baseline)	Time 1, 2*, 3*
• Informed consent signed • Habit of monitoring their biometric data • Levels of physical activity / inactivity • Habit of drinking • Habit of smoking	• Intention to engage in regular physical activity • Positive and negative anticipatory emotions • Attitudes towards regular physical activity • Self-efficacy • Subjective injunctive and descriptive rules • Personal interest ("Vested interest") in physical activity • Motivation for physical activity • Amount and type of physical activity

*The questionnaires at time 2 and time 3 re-proposed the same measures presented in the questionnaire at time 1, to verify their possible change following the messaging intervention.

Study participants were placed in one of 4 experimental conditions through a randomized block research design. The experimental conditions included:

- Message group: receiving “vested” persuasive messages (no wearable)
- Wearable group: wearing the device for measuring biometric data
- Message group and wearable: wearing the device for measuring biometric data and receiving the “vested” persuasive messages
- Control group: not receiving the messages and not wearing the device.

The timeline of the study occurred as follows:

- All participants completed the questionnaire at time 1 (week 2)
- The persuasive messages were sent through the App for a period of 4 weeks. The contents of the messages, based on scientific evidence, promoted regular PA by leveraging the possible benefits for university performance
- All participants filled out the questionnaire at time 2 (week 6)
- All participants completed the questionnaire at time 3 (end of week 9).

The research ended with a debriefing phase. During an online meeting, all participants will receive information regarding:

- the objectives and design of the research
- the relationship between PA and physical and mental health (to compensate for the absence of such information in groups that have not received the messages)
- the use of electronic devices for the objective measurement of one's PA (to compensate for the absence of such information in groups that have not received the device)

- instructions on how to receive further information on the data relating to their psycho-physical conditions, collected during the research.

The outcome was quantitatively assessed through the wearable devices and associated app and recorded online using validated instruments including and enabling the measuring levels of activity / inactivity and the amount and type of physical activity. Other measures included positive and negative anticipatory emotions, attitudes towards regular PA and other variables such as self-efficacy, injunctive and descriptive subjective rules, personal "vested" interest in PA and motivation.

6.11 Stress and wearables substudy (SWS)

I performed a substudy of the "Study and Exercising" project previously described as the Stress and Wearable Substudy (SWS). The SWS included the collection and analysis of demographic data, sports habit, self-reported stress, and biometric parameters (such as heart rate, number of steps/days, PA level) as well as stress levels recorded using wearable electronic devices. For this study, only the population using wearables (group 2) was selected, and the research focus was centred on the stress assessments.

The main aims of the SWS included:

1. Investigate the correlation between self-reported stress (SRS), measured with a reference questionnaire (PSS-10) and using wearable-assessed stress (WAS) measures
2. Quantify the effect of the intervention (participants receiving and not receiving persuasive messages) on SRS and WAS.

6.11.1 SWS Methods

Among the 122 subjects receiving the wearable in the "Study and Exercising" research project, a total of 104 participants were included in the SWS. The inclusion criteria in this substudy were the availability of both SRS and WAS data.

The PsyMe App, a smartphone App previously described and tested in previous research at the CUSH, was used to convey persuasive messages (that were combined goal and vested messages) on the importance of PA and to record the participants' answers to sports habits and to the stress questionnaires. The electronic wearable devices Garmin Vivosmart 5 were used to monitor biometric data and to evaluate the outcomes (stress levels).

Data retrieved from the PsyMe App and from the wearables were recorded online and included in an Excel database using the Fitrockr (https://www.fitrockr.com) to connect the wearable data to a platform to download the recordings from the wearables. A summary of the variables used for the SWS is reported in Figure 3.

Figure 3.

SWS variables

General

Age
Gender
Exercising (Y/N)
Sport level
Wearable use
App use
Smoking
Drinking
BMI
Activity intensity
Walking frequency

Self-reported

10-item Perceived Stress Scale (PSS)
Higher score = higher stress
4 reverse questions
Likert 1-5

Wearable

Stress measures
Time in high stress range (H)*
Time in moderate stress range (M)*
Time in low stress range (L)*

* Time in the stress range / Time in the monitoring period

Stress measured on a 1 to 100 scale: 1 - 25 “rest”, 26-50 “low”, 51-75 “medium”, 76-100 “high” stress

Around half of the participants (49/104, 47%) were randomised in the intervention group and received the persuasive messages on the importance to perform PA.

The PSS-10 was used to measure SRS through participants’ perceived stress. This is a 10-item scale that assesses the degree to which events are perceived by respondents as uncontrollable, unpredictable, and/or overwhelming (Cohen, 1994). Respondents rate their responses to each item using a 5-point Likert-scale (1= never; 5= very often). In our case, the results were not reported in the range 0 to 40 (as described in some articles for this scale) but from 10 to 50.

Internal consistency for PSS-10, from now on reported as “PSS”, is good (0.85), and the stability of the test-retest coefficients ranges from 0.75 to 0.86 (Cohen, et al., 1983). The PSS is a widely used measure of perceived stress and is easy to administer (Kain, et al., 2000). Out of 10 questions, 4 were reversed scored in order to obtain the correct overall perceived stress score. Interestingly, the PSS authors have stated that the scale was not intended to be a diagnostic tool, so there is no “high stress” nor “low stress” thresholds. However, it can be used for comparison with other populations. A mean score of 15.8 (in a scale measured from 0 to a maximum of 40) was found in a national survey of 2000 adults from the general population, administered in 2009.

WAS data were recorded using the electronic wearable. Among the WAS measured (Table 2), the duration of low, medium, and high stress recorded in the monitoring period were chosen for the analysis. The choice of these parameters was based on the quantitative nature of the measure and the possibility to assess different stress levels daily. To increase the readability of the measures, the amount of time spent in the three stress categories was converted from seconds into minutes. To avoid the variability caused by different monitoring period (e.g., subject using the wearable for less than 24 hours per day), WAS data were adjusted by the daily duration of monitoring (duration of WAS in minutes per day/duration in minutes of the daily monitoring). Finally, to compare SRS and WAS, a 7-day period of wearable recording was chosen and centred on the day in which the questionnaire was completed through the App. For example, if the questionnaire was completed on day 11 of the month, WAS data from day 8 until day 14 were included. If daily consecutive data were not available, the closest day was chosen (e.g., day 9 or 15) allowing for a maximum of 14 days from the day of SAS measurement.

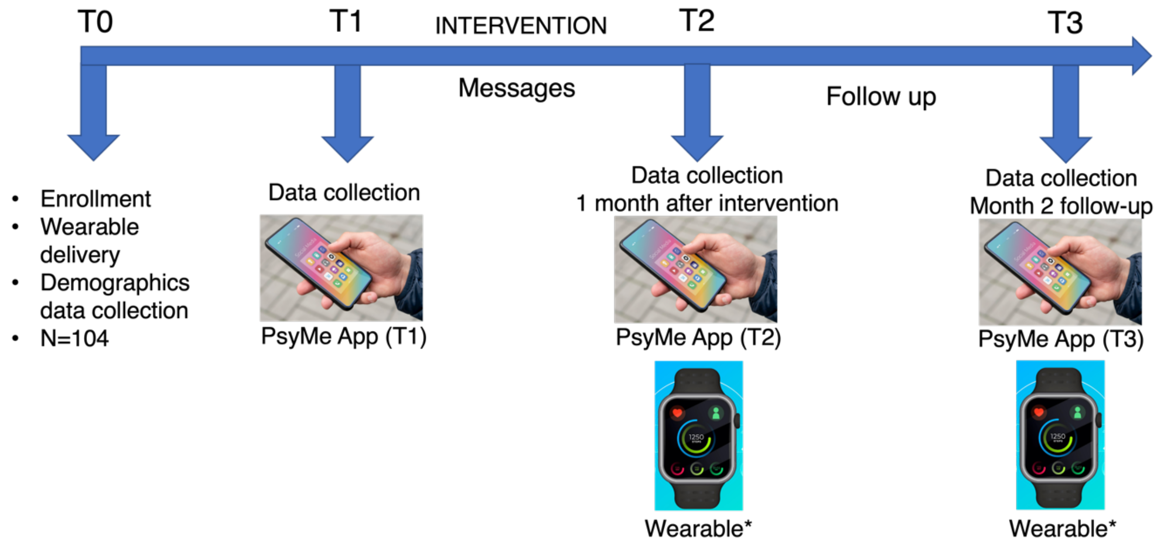
The rational for this choice was based on two factors: 1. SAS measures is based on the stress perception of the last 4 weeks and does not reflect a one-day feeling; 2. Multiple consecutive measures reduce the error caused by the choice of a single measure that may be affected by unforeseen daily events (e.g., the student may experience academic stress on the day of the questionnaire completion but not on the following days).

If multiple WAS recording duration were available daily, the longest one (ideally, 24-hour data monitoring) was chosen. As less than 3% of subjects had uncomplete (< 24 hours) measures, the adjustment for the time of recording was not consistently performed to allow a better readability of the measure (e.g., minutes per day). Participants with data not fulfilling the described criteria (no recordings available within 14 days from the questionnaire) and with less than three WAS measures in at least two timepoints were excluded from the analysis.

The study was approved by the local ethics committees and informed consent was provided by all participants. A summary of the study design is reported in Figure 4.

Figure 4.

Longitudinal study design



Messages were conveyed between T1 and T2. *7-day measurement. Image from Freepik (www.freepik.com)

At time 0 (baseline), patients were enrolled in the study, the wearables were distributed, and demographic data (age, gender, contacts) were collected. The students received with the device also the instructions for its use. The device was used for 8 weeks. At T1 (week 2) SRS was assessed, and the wearable monitoring of stress and other parameters started along with the intervention (messages delivery) that was continued for 4 weeks until T2 (week 6). Both SRS and WAS were longitudinally monitored at T2 (corresponding to 4 weeks of intervention) and for other 4 weeks until T3 (follow-up time with no messages delivered, corresponding to week 9).

6.11.2 Statistical analysis

For continuous variables, mean and standard deviation or median and IQR were calculated. For nominal variables, count and percentages were used. Wilcoxon–Mann–Whitney test was used for comparing independent groups. Differences in the assessments of stress at different timepoints were analysed using ANOVA and Boferroni tests. The association between categorical variables was assessed using Fisher's test. For longitudinal analysis at different time points, factors associated with WAS were identified using a two-level multivariate linear mixed-effects regression model with a random intercept at individual level. Predictors included in the analyses were age, gender, SRS and vigorous activity levels. Interactions among the variables were included in the models' estimation in order to improve the comparability of the models. The random component accounted also for the longitudinal nature of the data. Analyses were carried out on all available cases of each measurement occasion. A model was developed for each dependent variable. Specifically, based on theoretical assumptions, a hierarchical list of all significantly associated variables was developed for each dependent variable. Individual independent variables that were statistically significantly associated with the dependent variable based on bivariate analysis were entered sequentially for each model. The variable indicating the measurement occasions was included at the beginning of the modelling and retained for all successive model building steps. Variables from the significantly associated pool were then included sequentially in the multilevel multivariate analysis. The variables were added to the null model one by one choosing/retaining those variable significant at $p<0.05$. The likelihood ratio test was used to compare the new model with the nested model. The final model estimated the adjusted coefficients and the corresponding 95% CI for all factors associated with the dependent variables. Predictors associated with the outcome variable with a probability < 0.05 were considered significant. Analyses were carried out using Stata® Version 16.1 (College Station, TX: StataCorp LP).

6.11.3 Results

A total of 104 participants were included. Main characteristics of participants are reported in Table 4. Mean age was 21 years and half of participants were males. Over half of the participants performed sports activities. Of these, the majority (68%) performed at an amateur level. Forty-three percent of participants were familiar with wearables and up to 45% used health Apps.

Table 4.

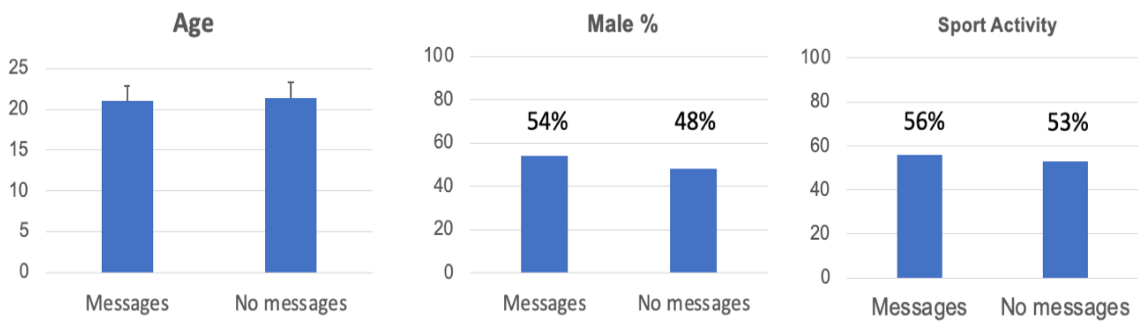
Participants' characteristics

Characteristics	**N=104 (%)**
Age (years) ± SD	21.2 ± 1.8
Male gender	52 (50)
Performing any sport activity	56 (54)
Sport level (%)	
Amateurs	38 (68)
Professionals	18 (32)
Familiar with wearables	43 (41)
Using any health App	47 (45)
Smoking (active)	29 (28)
Drinking frequency ≥ 2/week	37 (36)
BMI ± SD	22.0 ± 3.0
Vigorous activity at least 1/week	66 (63)
Moderate activity at least 1/week	49 (47)
Walking frequency ≥ 5/week	68 (65)

A total of 49 (47%) participants received persuasive messages on the importance of performing PA. No significant differences were detected according to gender, age, and sports activity between participants receiving and not receiving persuasive messages (Figure 5).

Figure 5.

Distribution of participants receiving and not receiving the intervention according to age, gender, and sports activity



Longitudinal assessment of SRS at T1, T2, and T3 showed no differences between the participants receiving and not receiving the messages (Table 5).

Table 5.

Comparison of self-reported stress between participants receiving and not receiving the messages at different study timepoints

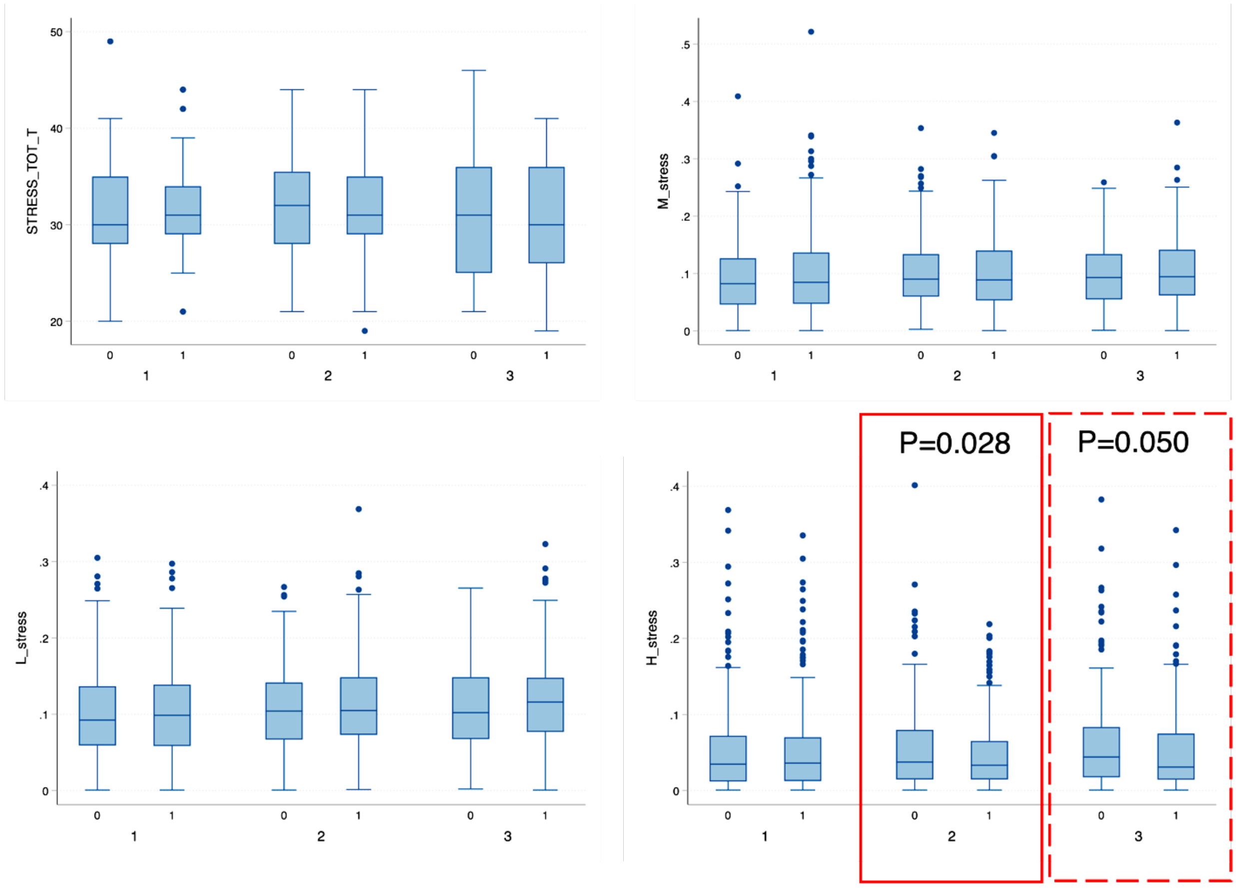
Characteristics	No Messages	Messages	P value
T1	31.6 ± 5.6	31.7 ± 4.7	NS
T2	31.7 ± 5.4	31.8 ± 5.3	NS
T3	31.0 ± 5.5	30.9 ± 6.0	NS

PSS measured on a 10 to 50 scale

When the 3 types of WAS measured were compared over time in the message and no message groups, a significant reduction in the high stress duration was noted in the intervention compared with the non-intervention group (Figure 6). However, the reduction was significant (P=0.03) only at T2 (after receiving the messages) and had borderline significance (P=0.05) at follow-up (T3), this probably indicating that the effect of the messages may be maximum if they are regularly received but may not have long-term effects. No differences were shown for moderate and low stress.

Figure 6.

Differences in wearable-measured stress at different timepoints in participants receiving and not receiving the intervention



Comparison of WAS (L= low, M= moderate, H= high) stress at different time points (1= T1, 2= T2, 3= T3) among participants receiving (1) or not receiving (1) the intervention.

To understand the association between the two methodologies for stress assessments among participants, SRS and WAS, multilevel multivariate linear regression with individuals as random effect level was used, including fundamental parameters that may have affected stress assessment such as gender and time. Smoking frequency, sport activity and sport level were not significant at bivariate analysis for low, moderate, and high stress duration and were not included in the model. Table 6 shows a correspondence between SRS and WAS for the assessment of high stress but not for the other stress forms.

Table 6.

Multilevel multivariate linear regression showing that self-reported stress (SRS) is correlated to high stress assessed by the wearables.

High stress (wearable)	Coefficient (95% CI)	P
Time T2 T3	 -0.00253 (-0.01673 - 0.00722) 0.003502 (-0.00323 – 0.01024)	 NS NS
Gender	- 0.00475 (- 0.01673 - 0.00722)	NS
Stress (self-reported)	0.00086 (0.00011- 0.00161)	**0.025**
Moderate stress (wearable)		
Time T2 T3	 0.00446 (-0.00220 – 0.01111) 0.00340 (-0.00428 – 0.01108)	 NS NS
Gender	- 0.00282 (- 0.01537 – 0.00973)	NS
Stress (self-reported)	0.00006 (- 0.00078 – 0.000895)	NS
Low stress (wearable)		
Time T2 T3	 0.00876 (0.00246 - 0.01506) 0.00986 (0.00253 – 0.01718)	 NS NS
Gender	0.00461 (-0.00639 - 0.01556)	NS
Stress (self-reported)	- 0.00019 (- 0.00096 - 0.00058)	NS

High stress was analysed further. Mean high stress for all participants over the 7-day period expressed in minutes per day at different study timepoints is reported in Table 7. The total number of observations decreased over time, indicating that there was less adherence to the wearable use toward the end of the experiment.

Table 7.

High, moderate, and low stress measured by the wearables over time

Study timepoint	High stress* (Q1-Q3)	Range	N
T1	74.66 (17-100)	1-531	663
T2	72.59 (21-102)	1-578	556
T3	83.41 (23-111)	1-551	360
Study timepoint	**Moderate stress* (Q1-Q3)**	**Range**	**N**
T1	134.77 (65-185)	1-751	745
T2	143.67 (83-193)	1-509	612
T3	142.91 (79-189)	1-523	387
Study timepoint	**Low stress* (Q1-Q3)**	**Range**	**N**
T1	143.39 (84-194)	1-439	746
T2	154.134 (99-202)	1-531	612
T3	159.01 (98-205)	1-465	380

*Mean minutes spent in the specific stress level per day. Since less than 3% of the subjects wore the tracker for < 24 hours during the observation, descriptive statistic included the raw measurements without adjusting for the time of monitoring.

None of the three stress levels showed significant differences over time.

For high stress, the analysis of variance between groups (SS 27382.58, df 2, MS 13691.29) and within groups (SS 9943067.75, df 1576, MS 6309.05) did not show significant differences (F 2.17, P=0.11) at different timepoints, and non-significance was confirmed also by Bonferroni analysis (T1-T2: -2.07, P=1.0; T1-T3: 8.74, P=0.28; T2-T3: 10.81, P=0.13).

For moderate stress, the analysis of variance between groups (SS 31742.48, df 2, MS 15871.24) and within groups (SS 14027510.5, df 1741, MS 8057.16) did not show significant differences (F 1.97, P=0.14) at different timepoints, and non-significance was confirmed also by Bonferroni analysis (T1-T2: 8.90, P=0.21; T1-T3: 8.15, P=0.44; T2-T3: -0.75, P=1.0).

For low stress, the analysis of variance between and within groups showed a significant difference (SS 73259.21, df 2, MS 36629.61 and SS 11926449.1, df 1735, MS 6874.03, respectively; F 5.33, P=0.005) confirmed by Bonferroni analysis between T1 and T3 (T1-T2: 10.74, P=0.053; T1-T3: 15.62, P=0.009; T2-T3: 4.88, P=1.0).

Another analysis regarded the inclusion in the multilevel model for low, moderate, and high stress, along with time and gender, of the 8 Stress Qualifiers (calm=1, calm-awake=2, balanced=3, balanced-awake=4, stressed=5, stressed-awake=6, very stressed=7, very stressed-awake=8). Time and gender were not significant, while significant correlations were consistently shown between “calm” versus other qualifiers with few exceptions for low stress (1: P=0.29; 2:

P<0.001; 3: P=0.0013; 4: P<0.001; 5: P=0.06; 6: P<0.001; 7: P=0.05), moderate stress (1: P=0.93; 2: P<0.001; 3: P<0.001; 4: P<0.001; 5: P<0.001; 6: P<0.001; 7: P<0.001), and high stress (1: P=0.74; 2: P<0.001; 3: P=11; 4: P<0.001; 5: P=0.006; 6: P<0.001; 7: P<0.001). The Garmin algorithm defining the qualifiers, however, remains unknown. For these reasons, as explained in the methods, the time spent in the high, moderate, and low stress levels was the chosen measure. To understand if PA, specifically the performance of vigorous activity (VA) could affect stress, the mean duration of VA (minutes per day over a 7-day period at each timepoint) was considered. Table 8 reports the mean duration of VA at different timepoints as it was measured by the wearables.

Table 8.

Vigorous activity measured by the wearables over time

Study timepoint	Vigorous activity*	Range	N
T1	3.66	0-221	705
T2	3.33	0-148	588
T3	4.15	0.144	390

*Mean minutes of vigorous activity unadjusted by the minutes of monitoring. Since less than 3% wore the tracker for less than 24 hours during the observation, descriptive statistic included the raw measurements without adjusting for the time of monitoring

Similar to high and moderate stress, the analysis of variance between groups (SS 158.85, df 2, MS 79.43) and within groups (SS 341991.38, df 1680, MS 203.57) did not show significant differences (F 0.39, P=0.68) at different timepoints, and non-significance was confirmed also by Bonferroni analysis (T1-T2: -33418, P=1; T1-T3: 0.488871, P=1; T2-T3: 0.823051, P=1). Interestingly, there was no association between the amount of self-reported VA by the participants and the one assessed by the wearables. This, however, is expected as being the majority of the subjects non athletes, the amount of activity can highly vary according to the period of the year, the academic commitments, and other environmental or unforeseen circumstances.

VA was included in the multilevel model used to study the correlation between SRS and WAS along with age and gender to adjust for potential confounders (Table 9). As expected, VA was significantly correlated with high stress, this potentially indicating that stress measures may be affected by physiological changes associated with PA. Other potential explanations are reported in the discussion. Table 9 reports the mixed-effect multilevel regression analysis for high stress duration including time, SRS, age, VA, and gender.

Table 9.

Multilevel multivariate linear regression showing predictors of high stress assessed by the wearables.

High stress*	Coefficient	P value	95% CI
Timepoint T1			
- T2	-3.59	0.39	-11.80 - 4.62
- T3	4.20	0.39	-5.31 - 13.70
SRS (PSS 10)	1.27	0.02	0.22 - 2.33
Vigorous activity	0.97	<0.001	0.72 - 1.22
Age	-3.63	0.13	-8.30 - 1.04
Male gender	-9.22	0.28	-26.09 - 7.66

*Expressed as duration (minutes per day of observation over a 7-day period of wearable measurement).
SRS= self-reported stress

6.11.4 Discussion and conclusions

The literature reveals different methods for stress detection using wearable physiological sensors and highlights that the study of stress is challenging due to the lack of a gold standard assessment methods, the difficulty in establishing a baseline “not-stressed” condition, and the multi-factorial nature of the physiological phenomenon “stress”, which can be affected by several factors such as age, gender, occupation, daily events, etc.

In the study presented, I have focused on the wearable-associated stress. This measure, when assessed by trackers, mainly focuses on the cardiovascular impact that stress may cause and that is shown through the heart rate variation analysis. The PPG is an easy-to-use, low-cost optical technique used to measure the changes in blood volume in the microvascular bed of tissue. As previously described, PPG signals are acquired non-invasively at the skin surface using a light source and a photodetector. This technique is promising as it may be used and optimized in the clinical setting for cardiovascular diseases (Castaneda et al., 2018; Bayoumy et al., 2021).

Overall, the results of his study showed that WAS can be compared favourably with a psychometric gold standard questionnaire, such as PSS-10.

The study was based on real world data received from university students dealing with real life stressors associated with studying at university at two different institutions. This is in contrasts to a laboratory setting whereby stressors are induced artificially to provide a stress response that are measured through physiological sensors inside a wearable device. In this respect the literature reveals studies whereby participants are exposed to stress including, but not limited, to problem solving with time pressure constraints (Setz et al., 2010), the Stroop Test (Zhai & Barreto 2006), pictures from the International Affective Picture System (IAPS) (Hosseini et al., 2016), or various sounds as stressors (Wijsman et al., 2013). Although these studies highlight a growing amount of evidence towards wearable devices being able to detect stress levels induced artificially, they have questionable validity outside the constraints of a laboratory. There is no existing literature reporting real-world data in a student population receiving an intervention (e.g., persuasive messages with the aim of increasing physical activity) that can reduce stress, taking comparable measurements from a PPG sensor within a wrist worn wearable device and a validated psychometric questionnaire (e.g., PSS-10). Although the PSS-10 is the most widely cited and used instrument to establish stress levels within individuals and different groups, it appears through a literature search that it has not been compared nor correlated with wearable devices to date. Many reviews and associated papers looking at wearable technology and the ability of electronic devices to detect stress cite the PSS-10 as a valid psychometric tool to measure stress but fail to discover correlations between the PSS-10 and the stress readings portrait by wearable devices. As an example, Samson & Koh (2020) in their review on photoplethysmography enabled wearable devices and stress detection mention and briefly describe the PSS as a measure for stress but fail to find inferences between the PSS and wearable devices. Hao et al. (2017) suggest in their study on stress detection using bio-signals from consumer wearables that their biomarker based on heart rate variability can be used as a valid objective tool to measure stress and look to make inferences to the PSS. The authors, however, did not use the PSS in their study but created their own stress scale by asking subjects to rate their current perceived stress level from 0 to 10 after each stress induced session and call it the perceived stress level (PSL). The authors did not find any significant correlations between their own stress scale and the physiological readings from the sensors. The type of wearable device used was not specified. Mocny-Pachońska et al., (2021) in their study on stress levels measured by a questionnaire in relation to stress measurements recorded by smart glasses and figure pulse oximeters refer to the PSS-10 in their related works section but then decide to create their own stress scale. Results showed no significant correlations between their perceived stress level questionnaire and linear acceleration, angular velocity of head registered from the smart glasses. Interestingly, the data received from the pulse oximeter (recording HR) when compared to the stress questionnaire, showed that the HR before and during the task was significantly higher than after the task ($p < 0.001$), while stress levels during the task were higher than before and after the task ($p < 0.001$). The Spearman's rank correlation between the perceived stress level and heart rate was 0.561 ($p = 0.005$), which portraits a borderline significant correlation between HR and the stress level questionnaire.

What is known, however, is that perceived stress levels and physiological signals are strongly correlated as shown by Meina et al., 2020. In this study, involving 26 male firefighters, the authors generated their own stress questionnaire and used sensor belts equipped with a dry-lead ECG and three-axial accelerometers to measure PA during fire incidents.

These examples highlight several issues, including missing evidence regarding comparison between the PSS-10 (considered to be a gold standard stress detection tool) and stress detection from wearable devices that use PPG detection methods. Moreover, evidence within the literature regarding the use of the validated tools is lacking, as authors usually build their own questionnaires.

This pose questions regarding representation, face, and content validity issues. Representation validity regards the question on "do the stress instruments portrait how well the construct under measurement is represented by the instrument?" (Trochim, 2000). Face validity questions if "the instrument appear to measure what it is meant to measure?" Trochim, (2000) and content validity asks to "what extent does the content within the instrument meet the intended concepts specified in the pre-study hypothesis?" (Guion, 1977). Hence, are these non-validated instruments' providing correct stress related data and if not are their inferences, correlations, and conclusions sound? (Pesudovs et al., 2007).

Moreover, the literature reveals that both real world and laboratory type experiments regarding the use of wearable devices are hampered by limitations when defining the ground truth (e.g., direct observation and measurement vs. information provided by inference) in the assessment of stressful events. To establish ground truth for wearable device readings, researcher can use three main solutions: firstly, physical response or physiological markers; secondly, additional validated sensors to verify the accuracy of certain signals such as those received to indicate stress; thirdly, employ validated psychometric tools such as PSS-10. Physical-response sampling includes testing for cortisol levels through blood, urine, saliva or leukocyte measurement as established biomarkers for physiological stress (Law et al., 2013; Vlenterie et al., 2016; Duthie & Reynolds, 2013; Łoś, & Waszkiewicz, 2021; McLaren et al., 2003). Nath, & Thapliyal, (2021) collected stress measurements from elderly undergoing speech and mental math task through a combination of Electrodermal Activity (EDA), PPG, and Skin Temperature (ST) sensors embedded in a smart wristband, in conjunction with salivary cortisol measures collected on cotton swabs. The authors found that, in comparison to salivary cortisol levels, the sensors could distinguish between stressed and not-stressed states with a high degree of accuracy using all four signals. In another study by Hong et al. (2010) stress was monitored using wearables that can send ECG signals through Bluetooth wireless communication. Stress administration (e.g., noxious physical and mental arithmetic stress) was given repeatedly to healthy adults while cortisol and catecholamines levels were measured from peripheral blood samples. The self-reported Visual Analogue Scale (VAS) was implemented to measure personal perceptions of stress. The authors showed that the VAS scale gradually increased as the level of stress increased and cortisol and catecholamine increase. HRV values taken from ECG signals showed a similar correlation with increased catecholamines over cortisol. Although the findings from Nath, & Thapliyal (2021); Hong et al., (2010) provide insights on the usefulness of physical-response measures for stress indication and their links with wearable devices data, there is still a lack of meaningful literature in this area. For example, in one systematic review by Hickey and Colleagues (2021) on wearable technology and stress, of the 21 included paper only 2 mentioned the use of physical-response type sampling. In a scoping review by Namvari et al. (2022) on PPG-enabled wearable devices used for stress detection, of the 23 included papers only one mentioned the use of physical-response type sampling as an establish biomarker to reference to test the accuracy of wearable devices. These elements may suggest that there is a limited strength of findings exhibited by existing studies into the accuracy and validity of wearable devices to detect stress.

The use of additional validated sensors (e.g., ECG) to verify signals, such as those received to indicate stress levels through HRV from PPG readings, can be a non-invasive and practical tool. ECG is considered the gold standard for reading HR and HRV. Correia et al. (2020) looked to validate a wireless earlobe Bluetooth PPG sensor to monitor HRV during stress (e.g., mental task exercise) using ECG chest strap as the ground truth standard. Their findings suggest that readings from the ECG and PGG sensor were relatively similar when participants were at rest, but that the HRV taken from the PGG sensor tended to overestimate its readings during the stress test in comparison to the ECG reading. They theorize that the variable breathing rates of participants may act as a confounding variable, as also highlighted by Schafer and Vagedes (2013) and Chen et al. (2015). These authors showed that different respiration levels provided different HRV readings with PGG overestimating them in comparison with ECG. In another study Baek, & Cho, (2019) compared PPG-measured HRV using wearable devices with a chest strap ECG. Results showed that the HRV readings were comparable with the ECG and provided significant correlations over a 24-hour recording period, while a significant reduction in HRV was measured during a socially evaluated speech aimed at creating a stress response. This is consistent with other studies by Grad (2015) and Shaffer, & Ginsberg, (2017) that highlight that HRV increases during relaxation and recovery periods. In contrast HRV typically provides low variability when the heart beats more rapidly. Heart rate and heartbeat have an inverse relationship with stress, in particular high stress generally predicting low HRV variability.

Examples of psychometric tools, surveys, instruments, and questionnaires that have been validated and used to compare WAS and related mental health outcomes such as anxiety and affect are few and include the Positive and Negative Affect Schedule test (PANAS), State-Trait Anxiety Inventory (STAI), Stress State Questionnaire (SSQ) and the PSS-10. Generally, participants undertaking such examinations are asked to respond to a series of questions rating their perceived experiences and feelings. Aristizabal et al. (2021) studied the feasibility of WAS and SRS detection measures in a semi-controlled lab environment. Psychological stress was induced using the Trier Social Stress Test Protocol for Inducing Psychological Stress (TSST) protocol, and a wrist-worn wearable device was used to collect skin temperature and HR through PGG and EDA, respectively. Psychometric behavioural questionaries included STAI, PSS-10, and an ad-hoc test based on a 7-point Likert scale from 1 ("Not at all stressed) to 7 ("Extremely stressed") at four different timepoints. Salivary cortisol levels were also measured. The PSS-10, however, was only used to gain a baseline measurement of stress and was not continued as a measure at the different timepoints throughout the experiment. Results concluded that EDA and HR values were on average 2.7 times and 16% higher, respectively, during the stress task while skin temperature did not significantly change between the different periods. The mean STAI (state) and "in the moment" stress scores were statistically significant and differed across the various stages of the experiment while cortisol levels were higher following the stress tasks. In another study by Reeves et al. (2019) on the application of wearable technology to quantify health and wellbeing in urban and natural environments they incorporated and compared both physiological data received from HRV readings and HR from Empatica E4 wristband with the Depression and Anxiety Stress Scale (DASS-21) and with PANAS. Participants with higher-than-average levels of stress in the week prior to the experiment had increased HR in the urban but not the natural setting. No significant correlations, however, were shown psychometric questionaries and HRV readings. One factor that may have affected this outcome was identified in the participants' pre-exposure stress levels.

Confounding factors that may impact on stress readings from wearable sensors include higher errors for males than females, darker skin tones, low quality readings from PPG sensors, little or no information regarding the algorithms used to process data, environmental factors such as temperature, humidity and participant sweat production. In a study by Shcherbina et al. (2017) results from testing a wide variety of different wrist worn wearable devices not including Garmin devices suggested that darker skin tone, larger wrist circumference, and BMI were all found to correlate positively with increased HR errors. In another study by Dooley et al. (2017) estimating exercise intensities using wearables, higher BMI was positively associated with larger error rates across multiple devices including the Garmin Forerunner 225. Interestingly, Garmin devices all use the same PPG sensors, the Garmin elevate optical heart rate sensor (Garmin elevate optical heart rate: Garmin 2022). Furthermore, Garmin suggests that it is easier to measure a person's HR at rest and acknowledges that changing environmental factors related to PA including movement, vibrations, sweating, temperature, and posture changes, as well as the distance between the PPG sensor and a person's skin, play into the ability to provide precise HRV readings (Garmin elevate optical heart rate: Garmin 2022). Garmin also mentions the use of selected algorithms used for their products that are produced by Firstbeat Analytics, a partner company of Garmin. Both companies, however, do not reveal any details for the algorithms they use. This fact alone provides an issue when trying to compare one Garmin device with another as the PPG sensor data may be interpreted differently by different algorithms (Mühlen et al., 2020). For example, in the case of Dooley et al. (2017) and their conclusions when using the Garmin Forerunner 225 it maybe too much to presume that the Vivosmart 5 would also find similar results simply because both devices use the same PPG technology, as they may run the PGG data through different algorithms which may interpret the data differently. Furthermore, Garmin highlights confounding variables that may affect their PPG sensors and associated readings they can also be supported within the literature. Claes et al. (2017) aimed to validate the Garmin Forerunner 225 PPG readings using ECG as a ground truth method. The authors found that overall readings were similar and that HR at rest was easier to predict than during medium to high intensity exercise. Moreover, they suggested that variability in their measurements were caused by a range of sensitivity issues including large movements (e.g., wide arm movements from inclined walking), perspiration, poor fitting of the device around the wrist, and BMI parameters, contributing to inconsistencies and outliners in their analysis. In two studies by Dooley et al. (2017) and Shcherbina et al. (2017), BMI was significantly correlated with device error readings across different wearable devices. In particular, miscalculations can occur with BMI and wrist circumference whereby the circumference of the wrist may underrepresent the device calculated BMI. Bent et al. (2020) specifically investigated the sources of inaccuracy in wearable PPG sensors, highlighting as confounding variables the PA type and intensity. Etiwy et al. (2019) in their study on the accuracy of wearable HR monitors in cardiac rehabilitation highlighted device error in association to darker skin tones assessed by the Fitzpatrick scale. Garmin Customer Support (2022) suggest that skin tone can have an effect on PPG sensors and battery life because different melanin levels associated with skin tone absorbs different levels of light (e.g., the higher the melanin level the lighter is absorbed). Furthermore, they mention that tattoos can block light from reaching the PPG sensor drastically affecting the devices readings. Salamone et al. (2021) in their review on the measurement of wearable devices in built up areas briefly mention humidity and temperature as potential confounders in sensor reading, although not statistical relationships are defined. Humidity and temperature are highlighted by Garmin Customer Support (2022) when referring to reasons for poor HR readings when swimming including large arm motions affecting blood volume in the wrist area, colder waters reducing blood to peripheral tissue at the wrist area and water drag pulling on the watch to create a gap between the PPG sensor and the skin. Garmin further mentions a range of activities that may impair PPG readings including and not limited to burpees, cycling when gripping the handlebars, push-ups, racket sports, weightlifting and yoga. Studies suggest that gender may also play a role in producing PGG sensor variability. In a study by Dehghanojamahalleh & Kaya, (2019), several males and females cardiovascular function differ; for example, pulse arrival time (PAT), pulse transit time (PTT), systolic pulse transit time (SPTT), and the ratio of areas under the PPG waveform from the onset to the inflection point and the inflection point to the end of the waveform are dependent on gender and are longer for men than for women. PPG waveform is dependent on the stiffness of the arteries that appeared higher in women compared with men (Russo et al., 2021). In another study by Firooz et al. (2017) on the influence of gender and age on the thickness and echo-density of skin, differences between males and females were reflected through PPG sensors because of a discrepancy in echo intensity and skin thickness.

Wearable technology continues to grow and advance, despite the devices that are currently available to the public are rarely validated for research. Because wearable technology is advancing so quickly the stakeholders may be sceptical in investing on a device that may be soon obsolete and replaced by the latest model. Economics is behind such a phenomenon as the wearable field is a multi-billion-dollar industry with more and more players entering the fray to gain a piece of the action. The companies involved in the industry are the drivers of wearable technology, innovation, and advancement and to stay ahead of competitors they are constantly upgrading devices and providing new models to the consumer market. Furthermore, in the majority of ambulatory trials, subjects' demographics and psychological baseline profiles (e.g., self- reported anxiety and depression levels) are either overlooked or not assessed and context information is often not measured (Muaremi, et al., 2013; Healey, 2005). Nevertheless, recent studies still highlight the fact that wearable devices in conjunction with validated psychological measures can predict stress, anxiety, and depression in different populations.

In the “Study and Exercise” substudy focused on stress, I opted for the analysis of WAS and SRS in a real-life environment, involving university students who received an intervention that can be useful for their mental and physical wellbeing. Half of the participants received messages on the importance of performing physical activity. The most important results that were shown included:

1. A correlation between WAS, measured as minutes per day recorded as “high stress” for the participants, and SRS measured with a validated questionnaire for stress, the PSS-10
2. A decrease in the WAS for the group receiving the intervention that was statistically significant at T2, after one month of message receipt, and significant (even if borderline) at T3, at one-month follow up after message discontinuation.

The first result highlights the promising use of WAS, however the fact that only high-stress and not moderate or low stress correlated with PSS-10 remain unclear. Furthermore, an increase in low stress over time was recorder in the whole group. One hypothesis is that high stress, measured by the wearable, represents a real and reliable stress measure deriving from daily stressors and stimuli, while moderate and low stress are part of regular life events that are not taken into account when self-reported by the participants. The fact that high stress remains constant over time (T1, T2, T3) increases the reliability of the study as it can be implied that no major confounders altered the measures, and no major changes were reported during this period.

The second result confirms the first, as only high stress appeared involved as determinant of stress affected by the intervention, and reinforces the concept that validated interventions, such as persuasive messages, can affect people’s behaviour and, in this case, reduce stress. The borderline significance at T2, however, may underline that long-term effects (> 30 days) of persuasive messages are limited and that repeated interventions, or continuous receipt of messages (e.g., constant intervention, but potentially with a lower frequency, for example periodical messages) may be more effective compared with one-time, high intensity interventions.

The substudy was characterized by several limitations and strengths, as reported below.

Study limitations included:

1. Sample size: although the overall sample size (around 500 students) was appropriate and a sample size was calculated of at least 200 subjects to assess the results of the intervention, further subgroup analysis and the application of strict inclusion criteria for selecting the subjects for the stress study reduced the sample size to 104, and only half of these subjects received the intervention

2. Absence of physiological data: cortisol levels were not measured; the main reason for not assessing these parameters was the historical period (end of 2021 – beginning of 2022) in which there were still COVID-19 restrictions in place for students' circulation and attendances in the academic setting
3. WAS measures: the Garmin wearables used algorithms that are not clearly disclosed and validated, therefore it is difficult to clearly define if stress measures were accurate and which ones were useful to be compared to SRS
4. Potential confounders: stressors such as academic stress (e.g., exams, assignments) were not measured; other elements such as BMI, wearable adherence to skin, type of activity, and skin tone were not used in the analysis or retrieved and may have affected the measurements
5. Follow-up time: the study last 9 weeks. A longer (> 1 month) follow-up could have been helpful in assessing longer term effects of the intervention or confirm the results obtained over time
6. Data analysis: only a substudy was presented, therefore data on PA or other results were not reported in detail.

Study strengths included:

1. Longitudinal multicentric study design
2. Use of a free, easy to use App (Psy-me) to collect data
3. Use of a validated questionnaire for SRS (PSS-10)
4. Use of a multilevel multiparametric analysis to assess and compare stress measures and their confounders over time, and the use of multiple (7-day) measures to record wearable activity.

Further analyses should include larger studies on students to measure stress levels and the reduction of stress using interventions, such as persuasive messages and PA. The type of response according to the type and timing of messages received should be explored. If possible, physiological tests measuring validated parameters (e.g., cortisol levels) should be included, and wearable-associated algorithms should be clarified to facilitate the dissemination of reliable results. The correspondence between SRS and WAS should be defined over time; the PSS-10 refers to the previous month data, therefore a 7-day WAS may not be enough to clearly represent a participant's stress behaviour in a certain period of life.

In conclusion, this substudy supports the use of quantitative, modern technology-based assessments in real life study assessing parameters that are relevant for people wellbeing. Gold standard measures remain pivotal to validate and explain these phenomena while progress move in the direction of digital health and wider metaverse.

6.12 References

Alberdi, A., Aztiria, A., & Basarab, A. (2016). Towards an automatic early stress recognition system for office environments based on multimodal measurements: A review. *Journal of biomedical informatics*, *59*, 49–75. https://doi.org/10.1016/j.jbi.2015.11.007

Aristizabal, S., Byun, K., Wood, N., Mullan, A.F., Porter, P., Campanella, C., Jamrozik, A., Nenadic, I.Z., & Bauer, B. (2021). The Feasibility of Wearable and Self-Report Stress Detection Measures in a Semi-Controlled Lab Environment. *IEEE Access, 9*, 102053-102068.

Allen J. (2007). Photoplethysmography and its application in clinical physiological measurement. *Physiological measurement*, *28*(3), R1–R39. https://doi.org/10.1088/0967-3334/28/3/R01

Among US Adults, NHANES 2007/2008-2017/2018. *Journal of physical activity & health*, *18*(S1), S74–S83. https://doi.org/10.1123/jpah.2021-0221

Banholzer, N., Feuerriegel, S., Fleisch, E., Bauer, G. F., & Kowatsch, T. (2021). Computer Mouse Movements as an Indicator of Work Stress: Longitudinal Observational Field Study. *Journal of medical Internet research*, *23*(4), e27121. https://doi.org/10.2196/27121

Baek, H. J., & Cho, J. (2019). Novel heart rate variability index for wrist-worn wearable devices subject to motion artifacts that complicate measurement of the continuous pulse interval. *Physiological measurement*, *40*(10), 105010. https://doi.org/10.1088/1361-6579/ab4c28

Batabyal, A., Bhattacharya, A., Thaker, M., & Mukherjee, S. (2021). A longitudinal study of perceived stress and cortisol responses in an undergraduate student population from India. *PloS one*, *16*(6), e0252579. https://doi.org/10.1371/journal.pone.0252579

Bayoumy, K., Gaber, M., Elshafeey, A., Mhaimeed, O., Dineen, E. H., Marvel, F. A., Martin, S. S., Muse, E. D., Turakhia, M. P., Tarakji, K. G., & Elshazly, M. B. (2021). Smart wearable devices in cardiovascular care: where we are and how to move forward. *Nature reviews. Cardiology*, *18*(8), 581–599. https://doi.org/10.1038/s41569-021-00522-7

Beauchaine, T. P., & Thayer, J. F. (2015). Heart rate variability as a transdiagnostic biomarker of psychopathology. *International journal of psychophysiology : official journal of the International Organization of Psychophysiology*, *98*(2 Pt 2), 338–350. https://doi.org/10.1016/j.ijpsycho.2015.08.004

Béjean, S., & Sultan-Taïeb, H. (2005). Modeling the economic burden of diseases imputable to stress at work. *The European journal of health economics : HEPAC : health economics in prevention and care*, *6*(1), 16–23. https://doi.org/10.1007/s10198-004-0251-4

Bent, B., Goldstein, B. A., Kibbe, W. A., & Dunn, J. P. (2020). Investigating sources of inaccuracy in wearable optical heart rate sensors. *NPJ digital medicine*, *3*, 18. https://doi.org/10.1038/s41746-020-0226-6

Bonde J. P. (2008). Psychosocial factors at work and risk of depression: a systematic review of the epidemiological evidence. *Occupational and environmental medicine*, *65*(7), 438–445. https://doi.org/10.1136/oem.2007.038430

Boudreaux, B. D., Hebert, E. P., Hollander, D. B., Williams, B. M., Cormier, C. L., Naquin, M. R., Gillan, W. W., Gusew, E. E., & Kraemer, R. R. (2018). Validity of Wearable Activity Monitors during Cycling and Resistance Exercise. *Medicine and science in sports and exercise*, *50*(3), 624–633. https://doi.org/10.1249/MSS.0000000000001471

Bremner J. D. (2006). Traumatic stress: effects on the brain. *Dialogues in clinical neuroscience*, *8*(4), 445–461. https://doi.org/10.31887/DCNS.2006.8.4/jbremner

Buckworth, J., & Nigg, C. (2004). Physical activity, exercise, and sedentary behavior in college students. *Journal of American college health : J of ACH*, *53*(1), 28–34. https://doi.org/10.3200/JACH.53.1.28-34

Calculating the cost of work-related stress and psychosocial risks. OSHA. (n.d.). Retrieved November 1, 2022, from https://osha.europa.eu/en/publications/calculating-cost-work-related-stress-and-psychosocial-risks

Carfora, V., Biella, M., & Catellani, P. (2022). Affective components in promoting physical activity: A randomized controlled trial of message framing. *Frontiers in Psychology*, 5073.

Carfora, V., De Dominicis, S., Brondino, M., Pasini, M., & Catellani, P. (2022, July 13). *Effects of Goal Setting and Vested Interest Messages Depends on Receivers' Body Mass Index*. FEPSAC. Retrieved November 27, 2022, from https://fepsac.com/events/16th-european-congress-of-sport-and-exercise-psychology/

Carfora V, Pastore M, Catellani P. A Cognitive-Emotional Model to Explain Message Framing Effects: Reducing Meat Consumption. Front Psychol. 2021 Mar 29;12:583209. doi: 10.3389/fpsyg.2021.583209. PMID: 33854457; PMCID: PMC8039126.

Castaneda, D., Esparza, A., Ghamari, M., Soltanpur, C., & Nazeran, H. (2018). A review on wearable photoplethysmography sensors and their potential future applications in health care. *International journal of biosensors & bioelectronics*, *4*(4), 195–202. https://doi.org/10.15406/ijbsbe.2018.04.00125

Cay, M., Ucar, C., Senol, D., Cevirgen, F., Ozbag, D., Altay, Z., & Yildiz, S. (2018). Effect of increase in cortisol level due to stress in healthy young individuals on dynamic and static balance scores. *Northern clinics of Istanbul*, *5*(4), 295–301. https://doi.org/10.14744/nci.2017.42103

Chandrasekaran, R., Katthula, V., & Moustakas, E. (2020). Patterns of Use and Key Predictors for the Use of Wearable Health Care Devices by US Adults: Insights from a National Survey. *Journal of medical Internet research*, *22*(10), e22443. https://doi.org/10.2196/22443

Chen, X., Huang, Y. Y., Yun, F., Chen, T. J., & Li, J. (2015). Effect of changes in sympathovagal balance on the accuracy of heart rate variability obtained from photoplethysmography. *Experimental and therapeutic medicine*, *10*(6), 2311–2318. https://doi.org/10.3892/etm.2015.2784

Childs, E., & de Wit, H. (2014). Regular exercise is associated with emotional resilience to acute stress in healthy adults. *Frontiers in physiology*, *5*, 161. https://doi.org/10.3389/fphys.2014.00161

Chow, H. W., & Yang, C. C. (2020). Accuracy of Optical Heart Rate Sensing Technology in Wearable Fitness Trackers for Young and Older Adults: Validation and Comparison Study. *JMIR mHealth and uHealth*, *8*(4), e14707. https://doi.org/10.2196/14707

Chowdhury, M. H., Shuzan, M. N. I., Chowdhury, M. E. H., Mahbub, Z. B., Uddin, M. M., Khandakar, A., & Reaz, M. B. I. (2020). Estimating Blood Pressure from the Photoplethysmogram Signal and Demographic Features Using Machine Learning Techniques. *Sensors (Basel, Switzerland)*, *20*(11), 3127. https://doi.org/10.3390/s20113127

Chyu, E. P. Y., & Chen, J. K. (2022). Associations Between Academic Stress, Mental Distress, Academic Self-Disclosure to Parents and School Engagement in Hong Kong. *Frontiers in psychiatry*, *13*, 911530. https://doi.org/10.3389/fpsyt.2022.911530

Chu, B., Marwaha, K., Sanvictores, T., & Ayers, D. (2022). Physiology, Stress Reaction. In *StatPearls*. StatPearls Publishing.

Carosella, K., Silamongkol, T., Basgoze, Z., Taraves, N., Wiglesworth, A., Cullen, K., & Klimes-Dougan, B. (2021). Amygdala Activation to Emotional Stimuli is Related to Perceived Stress and Difficulty Regulating Emotions in the Context of COVID-19 Pandemic. *Biological Psychiatry*, *89*(9), S109. https://doi.org/10.1016/j.biopsych.2021.02.281

Claes, J., Buys, R., Avila, A., Finlay, D., Kennedy, A., Guldenring, D., Budts, W., & Cornelissen, V. (2017). Validity of heart rate measurements by the Garmin Forerunner 225 at different walking intensities. *Journal of medical engineering & technology*, *41*(6), 480–485. https://doi.org/10.1080/03091902.2017.1333166

Coco, M., Buscemi, A., Pennisi, E., Cavallari, P., Papotto, G., Papotto, G. M. F., Perciavalle, V., Di Corrado, D., & Perciavalle, V. (2020). Postural Control and Stress Exposure in Young Men: Changes in Cortisol Awakening Response and Blood Lactate. *International journal of environmental research and public health*, *17*(19), 7222. https://doi.org/10.3390/ijerph17197222

Cohen, S., Kamarck, T., & Mermelstein, R. (1983). A global measure of perceived stress. *Journal of health and social behavior*, *24*(4), 385–396.

Cordeiro J. V. (2021). Digital Technologies and Data Science as Health Enablers: An Outline of Appealing Promises and Compelling Ethical, Legal, and Social Challenges. *Frontiers in medicine*, *8*, 647897. https://doi.org/10.3389/fmed.2021.647897

Correia, B., Dias, N., Costa, P., & Pêgo, J. M. (2020). Validation of a Wireless Bluetooth Photoplethysmography Sensor Used on the Earlobe for Monitoring Heart Rate Variability Features during a Stress-Inducing Mental Task in Healthy Individuals. *Sensors (Basel, Switzerland)*, *20*(14), 3905. https://doi.org/10.3390/s20143905

Dehghanojamahalleh, S., & Kaya, M. (2019). Sex-Related Differences in Photoplethysmography Signals Measured From Finger and Toe. *IEEE journal of translational engineering in health and medicine*, *7*, 1900607. https://doi.org/10.1109/JTEHM.2019.2938506

DeJonckheere, M., & Vaughn, L. M. (2019). Semistructured interviewing in primary care research: a balance of relationship and rigour. *Family medicine and community health*, *7*(2), e000057. https://doi.org/10.1136/fmch-2018-000057

de Witte, M., Kooijmans, R., Hermanns, M., van Hooren, S., Biesmans, K., Hermsen, M., Stams, G. J., & Moonen, X. (2021). Self-Report Stress Measures to Assess Stress in Adults With Mild Intellectual Disabilities-A Scoping Review. *Frontiers in psychology*, *12*, 742566. https://doi.org/10.3389/fpsyg.2021.742566

Dias, D., & Paulo Silva Cunha, J. (2018). Wearable Health Devices-Vital Sign Monitoring, Systems and Technologies. *Sensors (Basel, Switzerland)*, *18*(8), 2414. https://doi.org/10.3390/s18082414

Dooley, E. E., Golaszewski, N. M., & Bartholomew, J. B. (2017). Estimating Accuracy at Exercise Intensities: A Comparative Study of Self-Monitoring Heart Rate and Physical Activity Wearable Devices. *JMIR mHealth and uHealth*, *5*(3), e34. https://doi.org/10.2196/mhealth.7043

Duthie, L., & Reynolds, R. M. (2013). Changes in the maternal hypothalamic-pituitary-adrenal axis in pregnancy and postpartum: influences on maternal and fetal outcomes. *Neuroendocrinology*, *98*(2), 106–115. https://doi.org/10.1159/000354702

Paszkiel, S., Dobrakowski, P., & Łysiak, A. (2020). The Impact of Different Sounds on Stress Level in the Context of EEG, Cardiac Measures and Subjective Stress Level: A Pilot Study. *Brain sciences*, *10*(10), 728. https://doi.org/10.3390/brainsci10100728

De Dominicis, S., Dwyer, M., Ifversen, S., & Jorgensen, I. (2022, July 15). *Active breaks: a viable solution to reduce stress and improve wellbeing in office workers*. FEPSAC. Retrieved November 27, 2022, from https://fepsac.com/events/16th-european-congress-of-sport-and-exercise-psychology/

Ding, D., Lawson, K. D., Kolbe-Alexander, T. L., Finkelstein, E. A., Katzmarzyk, P. T., van Mechelen, W., Pratt, M., & Lancet Physical Activity Series 2 Executive Committee (2016). The economic burden of physical inactivity: a global analysis of major non-communicable diseases. *Lancet (London, England)*, *388*(10051), 1311–1324. https://doi.org/10.1016/S0140-6736(16)30383-X

European Agency for Safety and Health at Work - information, statistics, legislation, and risk assessment tools. European Agency for Safety & Health at Work - Information, statistics, legislation and risk assessment tools. (n.d.). Retrieved November 1, 2022, from https://osha.europa.eu/en

El-Farhan, N., Rees, D. A., & Evans, C. (2017). Measuring cortisol in serum, urine and saliva - are our assays good enough?. *Annals of clinical biochemistry*, *54*(3), 308–322. https://doi.org/10.1177/0004563216687335

Etiwy, M., Akhrass, Z., Gillinov, L., Alashi, A., Wang, R., Blackburn, G., Gillinov, S. M., Phelan, D., Gillinov, A. M., Houghtaling, P. L., Javadikasgari, H., & Desai, M. Y. (2019). Accuracy of wearable heart rate monitors in cardiac rehabilitation. *Cardiovascular diagnosis and therapy*, *9*(3), 262–271. https://doi.org/10.21037/cdt.2019.04.08

Evenson, K. R., & Spade, C. L. (2020). Review of Validity and Reliability of Garmin Activity Trackers. *Journal for the measurement of physical behaviour*, *3*(2), 170–185. https://doi.org/10.1123/jmpb.2019-0035

Franěk, M., Petružálek, J., & Šefara, D. (2022). Facial Expressions and Self-Reported Emotions When Viewing Nature Images. *International journal of environmental research and public health*, *19*(17), 10588. https://doi.org/10.3390/ijerph191710588

Financial costs of job stress: Total worker health for employers: CPH-New: Research. Total Worker Health for Employers | CPH-NEW | Research | UMass Lowell. (n.d.). Retrieved

November 30, 2022, from https://www.uml.edu/research/cph-new/worker/stress-at-work/financial-costs.aspx#burden

Fink, G. (2017). Stress: Concepts, definition and history. Reference Module in Neuroscience and Biobehavioral Psychology. https://doi.org/10.1016/b978-0-12-809324-5.02208-2

Firstbeat analytics: The strong partner that joined Garmin. Garmin Blog. (2020, September 15). Retrieved December 3, 2022, from https://www.garmin.com/en-SG/blog/firstbeat-analytics-the-strong-partner-that-joined-garmin/

Garmin, & subsidiaries, G. L. or its. (n.d.). *Garmin vivosmart® 5: Fitness activity tracker*. Garmin. Retrieved November 27, 2022, from https://www.garmin.com/en-US/p/782585

Gallè, F., Sabella, E. A., Ferracuti, S., De Giglio, O., Caggiano, G., Protano, C., Valeriani, F., Parisi, E. A., Valerio, G., Liguori, G., Montagna, M. T., Romano Spica, V., Da Molin, G., Orsi, G. B., & Napoli, C. (2020). Sedentary Behaviors and Physical Activity of Italian Undergraduate Students during Lockdown at the Time of CoViD-19 Pandemic. *International journal of environmental research and public health*, *17*(17), 6171. https://doi.org/10.3390/ijerph17176171

Garmin elevate optical heart rate: Garmin. Garmin Singapore. (n.d.). Retrieved November 25, 2022, from https://www.garmin.com.sg/minisite/garmin-technology/wearable-science/heart-rate/

Guion, R.M. (1977). Content Validity—The Source of My Discontent. *Applied Psychological Measurement, 1*, 1 - 10.

Godoy, L. D., Rossignoli, M. T., Delfino-Pereira, P., Garcia-Cairasco, N., & de Lima Umeoka, E. H. (2018). A Comprehensive Overview on Stress Neurobiology: Basic Concepts and Clinical Implications. *Frontiers in behavioral neuroscience*, *12*, 127. https://doi.org/10.3389/fnbeh.2018.00127

Goldstein D. S. (2010). Adrenal responses to stress. *Cellular and molecular neurobiology*, *30*(8), 1433–1440. https://doi.org/10.1007/s10571-010-9606-9

Gordan, R., Gwathmey, J. K., & Xie, L. H. (2015). Autonomic and endocrine control of cardiovascular function. *World journal of cardiology*, *7*(4), 204–214. https://doi.org/10.4330/wjc.v7.i4.204

Grad C. (2015). Heart rate variability and heart rate recovery as prognostic factors. *Clujul medical (1957)*, *88*(3), 304–309. https://doi.org/10.15386/cjmed-498

Guk, K., Han, G., Lim, J., Jeong, K., Kang, T., Lim, E. K., & Jung, J. (2019). Evolution of Wearable Devices with Real-Time Disease Monitoring for Personalized

Healthcare. *Nanomaterials (Basel, Switzerland)*, *9*(6), 813. https://doi.org/10.3390/nano9060813

Hanna, L. A., Wilson, M., Hall, M., & Hanna, A. (2018). A Questionnaire Study to Investigate Stress among Future Pharmacists by Gender and Year Group. *Pharmacy (Basel, Switzerland)*, *6*(3), 75. https://doi.org/10.3390/pharmacy6030075

Hao, T., Chang, H., Ball, M., Lin, K., & Zhu, X. (2017). cHRV Uncovering Daily Stress Dynamics Using Bio-Signal from Consumer Wearables. *Studies in health technology and informatics*, *245*, 98–102.

Hassard, J., Teoh, K., Visockaite, G., Dewe, P., & Cox, T. (2018). The cost of work-related stress to society: A systematic review. *Journal of occupational health psychology*, *23*(1), 1–17. https://doi.org/10.1037/ocp0000069

Herbert, C., Meixner, F., Wiebking, C., & Gilg, V. (2020). Regular Physical Activity, Short-Term Exercise, Mental Health, and Well-Being Among University Students: The Results of an Online and a Laboratory Study. *Frontiers in psychology*, *11*, 509. https://doi.org/10.3389/fpsyg.2020.00509

Herborn, K. A., Graves, J. L., Jerem, P., Evans, N. P., Nager, R., McCafferty, D. J., & McKeegan, D. E. (2015). Skin temperature reveals the intensity of acute stress. *Physiology & behavior*, *152*(Pt A), 225–230. https://doi.org/10.1016/j.physbeh.2015.09.032

Hinde, K., White, G., & Armstrong, N. (2021). Wearable Devices Suitable for Monitoring Twenty Four Hour Heart Rate Variability in Military Populations. *Sensors (Basel, Switzerland)*, *21*(4), 1061. https://doi.org/10.3390/s21041061

Hickey, B. A., Chalmers, T., Newton, P., Lin, C. T., Sibbritt, D., McLachlan, C. S., Clifton-Bligh, R., Morley, J., & Lal, S. (2021). Smart Devices and Wearable Technologies to Detect and Monitor Mental Health Conditions and Stress: A Systematic Review. *Sensors (Basel, Switzerland)*, *21*(10), 3461. https://doi.org/10.3390/s21103461

Herman, J. P., McKlveen, J. M., Ghosal, S., Kopp, B., Wulsin, A., Makinson, R., Scheimann, J., & Myers, B. (2016). Regulation of the Hypothalamic-Pituitary-Adrenocortical Stress Response. *Comprehensive Physiology*, *6*(2), 603–621. https://doi.org/10.1002/cphy.c150015

Hernando, D., Roca, S., Sancho, J., Alesanco, Á., & Bailón, R. (2018). Validation of the Apple Watch for Heart Rate Variability Measurements during Relax and Mental Stress in Healthy Subjects. *Sensors (Basel, Switzerland)*, *18*(8), 2619. https://doi.org/10.3390/s18082619

Höfling, T. T. A., Gerdes, A. B. M., Föhl, U., & Alpers, G. W. (2020). Read My Face: Automatic Facial Coding Versus Psychophysiological Indicators of Emotional Valence and Arousal. *Frontiers in psychology*, *11*, 1388. https://doi.org/10.3389/fpsyg.2020.01388

Hong, S., Yang, Y., Lee, J., Yang, H., Park, K., Lee, S., Lee, I., & Jang, Y. (2010). Ambulatory stress monitoring with a wearable bluetooth electrocardiographic device. *Studies in health technology and informatics*, *161*, 66–76.

Hosseini, S. A., Khalilzadeh, M. A., Naghibi-Sistani, M. B., & Homam, S. M. (2015). Emotional stress recognition using a new fusion link between electroencephalogram and peripheral signals. *Iranian journal of neurology*, *14*(3), 142–151.

Huang, C. J., Chan, H. L., Chang, Y. J., Chen, S. M., & Hsu, M. J. (2021). Validity of the Polar V800 Monitor for Assessing Heart Rate Variability in Elderly Adults under Mental Stress and Dual Task Conditions. *International journal of environmental research and public health*, *18*(3), 869. https://doi.org/10.3390/ijerph18030869

Hutmacher F. (2021). Putting Stress in Historical Context: Why It Is Important That Being Stressed Out Was Not a Way to Be a Person 2,000 Years Ago. *Frontiers in psychology*, *12*, 539799. https://doi.org/10.3389/fpsyg.2021.539799

Jia, S., Wang, S., Hu, C., Webster, P. J., & Li, X. (2021). Detection of Genuine and Posed Facial Expressions of Emotion: Databases and Methods. *Frontiers in psychology*, *11*, 580287. https://doi.org/10.3389/fpsyg.2020.580287

Kain, Z. N., Sevarino, F., Alexander, G. M., Pincus, S., & Mayes, L. C. (2000). Preoperative anxiety and postoperative pain in women undergoing hysterectomy. A repeated-measures design. *Journal of psychosomatic research*, *49*(6), 417–422. https://doi.org/10.1016/s0022-3999(00)00189-6

Kalia M. (2002). Assessing the economic impact of stress--the modern day hidden epidemic. *Metabolism: clinical and experimental, 51*(6 Suppl 1), 49–53. https://doi.org/10.1053/meta.2002.33193

Kamel Boulos, M. N., & Yang, S. P. (2021). Mobile physical activity planning and tracking: a brief overview of current options and desiderata for future solutions. *mHealth*, *7*, 13. https://doi.org/10.21037/mhealth.2020.01.01

Kawase, M., Komatsu, T., Nishiwaki, K., Kobayashi, M., Kimura, T., & Shimada, Y. (2002). Heart rate variability and arterial blood pressure variability show different characteristic changes during hemorrhage in isoflurane-anesthetized, mechanically ventilated dogs. *Anesthesia and analgesia*, *94*(1), . https://doi.org/10.1097/00000539-200201000-00004

Khan, I.A., Brinkman, W., Fine, N., & Hierons, R.M. (2008). Measuring personality from keyboard and mouse use. *ECCE '08*.

King, S. L., & Hegadoren, K. M. (2002). Stress hormones: how do they measure up?. *Biological research for nursing*, *4*(2), 92–103. https://doi.org/10.1177/1099800402238334

Kitsantas A., Winsler A., Huie F. Self-regulation and ability predictors of academic success during college: A predictive validity study. *J. Adv. Acad.* 2008;**20**:42–68. doi: 10.4219/jaa-2008-867.

Kivimäki, M., & Kawachi, I. (2015). Work Stress as a Risk Factor for Cardiovascular Disease. *Current cardiology reports*, *17*(9), 630. https://doi.org/10.1007/s11886-015-0630-8

Kraatz, S., Lang, J., Kraus, T., Münster, E., & Ochsmann, E. (2013). The incremental effect of psychosocial workplace factors on the development of neck and shoulder disorders: a systematic review of longitudinal studies. *International archives of occupational and environmental health*, *86*(4), 375–395. https://doi.org/10.1007/s00420-013-0848-y

Kołakowska, A., & Landowska, A. (2021). Keystroke Dynamics Patterns While Writing Positive and Negative Opinions. *Sensors (Basel, Switzerland)*, *21*(17), 5963. https://doi.org/10.3390/s21175963

König, A., Riviere, K., Linz, N., Lindsay, H., Elbaum, J., Fabre, R., Derreumaux, A., & Robert, P. (2021). Measuring Stress in Health Professionals Over the Phone Using Automatic Speech Analysis During the COVID-19 Pandemic: Observational Pilot Study. *Journal of medical Internet research*, *23*(4), e24191. https://doi.org/10.2196/24191

Kruk J. (2014). Health and economic costs of physical inactivity. *Asian Pacific journal of cancer prevention: APJCP*, *15*(18), 7499–7503. https://doi.org/10.7314/apjcp.2014.15.18.7499

Labott, S. M., Johnson, T. P., Fendrich, M., & Feeny, N. C. (2013). Emotional risks to respondents in survey research. *Journal of empirical research on human research ethics : JERHRE*, *8*(4), 53–66. https://doi.org/10.1525/jer.2013.8.4.53

Lamotte, G., Shouman, K., & Benarroch, E. E. (2021). Stress and central autonomic network. *Autonomic neuroscience: basic & clinical*, *235*, 102870. https://doi.org/10.1016/j.autneu.2021.102870

Law, R., Hucklebridge, F., Thorn, L., Evans, P., & Clow, A. (2013). State variation in the cortisol awakening response. *Stress (Amsterdam, Netherlands)*, *16*(5), 483–492. https://doi.org/10.3109/10253890.2013.817552

Lee, D. Y., Kim, E., & Choi, M. H. (2015). Technical and clinical aspects of cortisol as a biochemical marker of chronic stress. *BMB reports*, *48*(4), 209–216. https://doi.org/10.5483/bmbrep.2015.48.4.275

Lee, E., & Kim, Y. (2019). Effect of university students' sedentary behavior on stress, anxiety, and depression. *Perspectives in psychiatric care*, *55*(2), 164–169. https://doi.org/10.1111/ppc.12296

Li, Y., Zhang, B., Cao, Y., Zhao, S., Gao, Y., & Liu, J. (2011). Study on the BeiHang Keystroke Dynamics Database. *2011 International Joint Conference on Biometrics (IJCB)*, 1-5.

Lin, W., Orton, I., Li, Q., Pavarini, G., & Mahmoud, M.M. (2021). Looking At The Body: Automatic Analysis of Body Gestures and Self-Adaptors in Psychological Distress. *ArXiv, abs/2007.15815*.

Łoś, K., & Waszkiewicz, N. (2021). Biological Markers in Anxiety Disorders. *Journal of clinical medicine*, *10*(8), 1744. https://doi.org/10.3390/jcm10081744

Madsen, I., Nyberg, S. T., Magnusson Hanson, L. L., Ferrie, J. E., Ahola, K., Alfredsson, L., Batty, G. D., Bjorner, J. B., Borritz, M., Burr, H., Chastang, J. F., de Graaf, R., Dragano, N., Hamer, M., Jokela, M., Knutsson, A., Koskenvuo, M., Koskinen, A., Leineweber, C., Niedhammer, I., … IPD-Work Consortium (2017). Job strain as a risk factor for clinical depression: systematic review and meta-analysis with additional individual participant data. *Psychological medicine*, *47*(8), 1342–1356. https://doi.org/10.1017/S003329171600355X

Mariotti A. (2015). The effects of chronic stress on health: new insights into the molecular mechanisms of brain-body communication. *Future science OA*, *1*(3), FSO23. https://doi.org/10.4155/fso.15.21

Mathers, N. J., Fox, N. J., & Hunn, A. (1998). *Using interviews in a research project*. NHS Executive, Trent.

McLaren, G. W., Macdonald, D. W., Georgiou, C., Mathews, F., Newman, C., & Mian, R. (2003). Leukocyte coping capacity: a novel technique for measuring the stress response in vertebrates. *Experimental physiology*, *88*(4), 541–546. https://doi.org/10.1113/eph8802571

Mocny-Pachońska, K., Doniec, R. J., Sieciński, S., Piaseczna, N. J., Pachoński, M., Tkacz, E.J. (2021) The Relationship between Stress Levels Measured by a Questionnaire and the Data Obtained by Smart Glasses and Finger Pulse Oximeters among Polish Dental Students. *Applied Sciences*, 11(18):8648. https://doi.org/10.3390/app11188648

McInroy L. B. (2016). Pitfalls, Potentials, and Ethics of Online Survey Research: LGBTQ and Other Marginalized and Hard-to-Access Youths. *Social work research*, *40*(2), 83–94. https://doi.org/10.1093/swr/svw005

Mental health at work (no date) *World Health Organization*. World Health Organization. Available at: https://www.who.int/news-room/fact-sheets/detail/mental-health-at-work (Accessed: November 28, 2022).

MENTAL HEALTH: FACING THE CHALLENGES, BUILDING SOLUTIONS. (2006). *Addiction*, *101*(6), 901–902. https://doi.org/10.1111/j.1360-0443.2006.01524.x

Muaremi, A., Arnrich, B., & Tröster, G. (2013). Towards Measuring Stress with Smartphones and Wearable Devices During Workday and Sleep. *BioNanoScience*, *3*(2), 172–183. https://doi.org/10.1007/s12668-013-0089-2

Namvari, M., Lipoth, J., Knight, S., Jamali, A. A., Hedayati, M., Spiteri, R. J., & Syed-Abdul, S. (2022). Photoplethysmography Enabled Wearable Devices and Stress Detection: A Scoping Review. *Journal of Personalized Medicine*, *12*(11), 1792. MDPI AG. Retrieved from http://dx.doi.org/10.3390/jpm12111792

Nath, R.K., & Thapliyal, H. (2021). Wearable Health Monitoring System for Older Adults in a Smart Home Environment. *2021 IEEE Computer Society Annual Symposium on VLSI (ISVLSI)*, 390-395.

Nelson, B. W., & Allen, N. B. (2019). Accuracy of Consumer Wearable Heart Rate Measurement During an Ecologically Valid 24-Hour Period: Intraindividual Validation Study. *JMIR mHealth and uHealth*, *7*(3), e10828. https://doi.org/10.2196/10828

Newson, J. J., & Thiagarajan, T. C. (2019). EEG Frequency Bands in Psychiatric Disorders: A Review of Resting State Studies. *Frontiers in human neuroscience*, *12*, 521. https://doi.org/10.3389/fnhum.2018.00521

Out of the shadows: Making mental health a global priority. World Bank. (n.d.). Retrieved November 1, 2022, from https://www.worldbank.org/en/events/2016/03/09/out-of-the-shadows-making-mental-health-a-global-priority

Paulus, M., Kunkel, J., Schmidt, S., Bachert, P., Wäsche, H., Neumann, R., & Woll, A. (2021). Standing Breaks in Lectures Improve University Students' Self-Perceived Physical, Mental, and Cognitive Condition. *International journal of environmental research and public health*, *18*(8), 4204. https://doi.org/10.3390/ijerph18084204

Pascoe, M. C., Hetrick, S. E., & Parker, A. G. (2020). The impact of stress on students in secondary school and higher education. *International Journal of Adolescence and Youth, 25*(1), 104–112. https://doi.org/10.1080/02673843.2019.1596823

Peake, J. M., Kerr, G., & Sullivan, J. P. (2018). A Critical Review of Consumer Wearables, Mobile Applications, and Equipment for Providing Biofeedback, Monitoring Stress, and Sleep in Physically Active Populations. *Frontiers in physiology*, *9*, 743. https://doi.org/10.3389/fphys.2018.00743

Perming, C., Thurn, Å., Garmy, P., & Einberg, E. L. (2022). Adolescents' Experience of Stress: A Focus Group Interview Study with 16-19-Year-Old Students during the COVID-19 Pandemic. *International journal of environmental research and public health*, *19*(15), 9114. https://doi.org/10.3390/ijerph19159114

Pesudovs, K., Burr, J. M., Harley, C., & Elliott, D. B. (2007). The development, assessment, and selection of questionnaires. *Optometry and vision science : official publication of the American Academy of Optometry*, *84*(8), 663–674. https://doi.org/10.1097/OPX.0b013e318141fe75

Pribék, I. K., Szűcs, K. F., Süle, M., Grosz, G., Ducza, E., Vigh, D., Tóth, E., Janka, Z., Kálmán, J., Datki, Z. L., Gáspár, R., & Andó, B. (2021). Detection of acute stress by smooth muscle electromyography: A translational study on rat and human. *Life sciences*, *277*, 119492. https://doi.org/10.1016/j.lfs.2021.119492

Prieto-Avalos, G., Cruz-Ramos, N. A., Alor-Hernández, G., Sánchez-Cervantes, J. L., Rodríguez-Mazahua, L., & Guarneros-Nolasco, L. R. (2022). Wearable Devices for Physical Monitoring of Heart: A Review. *Biosensors*, *12*(5), 292. https://doi.org/10.3390/bios12050292

Public disclosure authorized - world bank (no date). Available at: https://documents1.worldbank.org/curated/en/270131468187759113/pdf/105052-WP-PUBLIC-wb-background-paper.pdf (Accessed: November 28, 2022).

Read, B. L. (2018). Serial Interviews: When and Why to Talk to Someone More Than Once. *International Journal of Qualitative Methods*, *17*(1). https://doi.org/10.1177/1609406918783452

Reeves, J. P., Knight, A. T., Strong, E. A., Heng, V., Neale, C., Cromie, R., & Vercammen, A. (2019). The Application of Wearable Technology to Quantify Health and Wellbeing Co-benefits From Urban Wetlands. *Frontiers in psychology*, *10*, 1840. https://doi.org/10.3389/fpsyg.2019.01840

Reddy, R. K., Pooni, R., Zaharieva, D. P., Senf, B., El Youssef, J., Dassau, E., Doyle Iii, F. J., Clements, M. A., Rickels, M. R., Patton, S. R., Castle, J. R., Riddell, M. C., & Jacobs, P. G. (2018). Accuracy of Wrist-Worn Activity Monitors During Common Daily Physical

Activities and Types of Structured Exercise: Evaluation Study. *JMIR mHealth and uHealth*, *6*(12), e10338. https://doi.org/10.2196/10338

Ressler K. J. (2010). Amygdala activity, fear, and anxiety: modulation by stress. *Biological psychiatry*, *67*(12), 1117–1119. https://doi.org/10.1016/j.biopsych.2010.04.027

Rodrigues, E., Lima, D., Barbosa, P., Gonzaga, K., Guerra, R. O., Pimentel, M., Barbosa, H., & Maciel, Á. (2022). HRV Monitoring Using Commercial Wearable Devices as a Health Indicator for Older Persons during the Pandemic. *Sensors (Basel, Switzerland)*, *22*(5), 2001. https://doi.org/10.3390/s22052001

Ros R.G., González F.P. Una aplicación web para la identificación de estudiantes de nuevo acceso a la Universitat en situación de riesgo académico (repertorios estratégicos y gestión del tiempo) @ *tic. Revista D'innovació Educativa.* 2009;**2**:10–17.

Russo, C., Jin, Z., Palmieri, V., Homma, S., Rundek, T., Elkind, M. S., Sacco, R. L., & Di Tullio, M. R. (2012). Arterial stiffness and wave reflection: sex differences and relationship with left ventricular diastolic function. *Hypertension (Dallas, Tex. : 1979)*, *60*(2), 362–368. https://doi.org/10.1161/HYPERTENSIONAHA.112.191148

Russo, S., Ronchetti, M., Di Tecco, C., Valenti, A., Jain, A., Mennini, F. S., Leka, S., & Iavicoli, S. (2021). Developing a cost-estimation model for work-related stress: An absence-based estimation using data from two Italian case studies. *Scandinavian journal of work, environment & health, 47*(4), 318–327. https://doi.org/10.5271/sjweh.3948

Rutakumwa, R., Mugisha, J. O., Bernays, S., Kabunga, E., Tumwekwase, G., Mbonye, M., & Seeley, J. (2020). Conducting in-depth interviews with and without voice recorders: a comparative analysis. *Qualitative Research*, *20*(5), 565–581. https://doi.org/10.1177/1468794119884806

Salamone, F., Masullo, M., & Sibilio, S. (2021). Wearable Devices for Environmental Monitoring in the Built Environment: A Systematic Review. *Sensors (Basel, Switzerland)*, *21*(14), 4727. https://doi.org/10.3390/s21144727

Samson, C., & Koh, A. (2020). Stress Monitoring and Recent Advancements in Wearable Biosensors. *Frontiers in bioengineering and biotechnology*, *8*, 1037. https://doi.org/10.3389/fbioe.2020.01037

Sanchez-Comas, A., Synnes, K., Molina-Estren, D., Troncoso-Palacio, A., & Comas-González, Z. (2021). Correlation Analysis of Different Measurement Places of Galvanic Skin Response in Test Groups Facing Pleasant and Unpleasant Stimuli. *Sensors (Basel, Switzerland)*, *21*(12), 4210. https://doi.org/10.3390/s21124210

Sato, W., Murata, K., Uraoka, Y., Shibata, K., Yoshikawa, S., & Furuta, M. (2021). Emotional valence sensing using a wearable facial EMG device. *Scientific reports*, *11*(1), 5757. https://doi.org/10.1038/s41598-021-85163-z

Scheid, J. L., & West, S. L. (2019). Opportunities of Wearable Technology to Increase Physical Activity in Individuals with Chronic Disease: An Editorial. *International journal of environmental research and public health*, *16*(17), 3124. https://doi.org/10.3390/ijerph16173124

Schneiderman, N., Ironson, G., & Siegel, S. D. (2005). Stress and health: psychological, behavioral, and biological determinants. *Annual review of clinical psychology*, *1*, 607–628. https://doi.org/10.1146/annurev.clinpsy.1.102803.144141

Setz, C., Arnrich, B., Schumm, J., La Marca, R., Tröster, G., & Ehlert, U. (2010). Discriminating stress from cognitive load using a wearable EDA device. *IEEE transactions on information technology in biomedicine : a publication of the IEEE Engineering in Medicine and Biology Society*, *14*(2), 410–417. https://doi.org/10.1109/TITB.2009.2036164

Shaffer, F., & Ginsberg, J. P. (2017). An Overview of Heart Rate Variability Metrics and Norms. *Frontiers in public health*, *5*, 258. https://doi.org/10.3389/fpubh.2017.00258

Smith, S. M., & Vale, W. W. (2006). The role of the hypothalamic-pituitary-adrenal axis in neuroendocrine responses to stress. *Dialogues in clinical neuroscience*, *8*(4), 383–395. https://doi.org/10.31887/DCNS.2006.8.4/ssmith

Stephens, M. A., & Wand, G. (2012). Stress and the HPA axis: role of glucocorticoids in alcohol dependence. *Alcohol research : current reviews*, *34*(4), 468–483.

St Quinton, T., Morris, B., Barwood, M. J., & Conner, M. (2021). Promoting physical activity through text messages: the impact of attitude and goal priority messages. *Health psychology and behavioral medicine*, *9*(1), 165–181. https://doi.org/10.1080/21642850.2021.1891073

Szakonyi, B., Vassányi, I., Schumacher, E., & Kósa, I. (2021). Efficient methods for acute stress detection using heart rate variability data from Ambient Assisted Living sensors. *Biomedical engineering online*, *20*(1), 73. https://doi.org/10.1186/s12938-021-00911-6

Taborsky, B., Kuijper, B., Fawcett, T. W., English, S., Leimar, O., McNamara, J. M., & Ruuskanen, S. (2022). An evolutionary perspective on stress responses, damage and repair. *Hormones and behavior*, *142*, 105180. https://doi.org/10.1016/j.yhbeh.2022.105180

toi, K., Jiang, Y. Q., Iwasaki, Y., & Watson, S. J. (2004). Regulatory mechanisms of corticotropin-releasing hormone and vasopressin gene expression in the hypothalamus. *Journal of neuroendocrinology*, *16*(4), 348–355. https://doi.org/10.1111/j.0953-8194.2004.01172.x

The heart rate sensor on my Garmin watch is not accurate: Garmin Customer Support. The Heart Rate Sensor on My Garmin Watch Is Not Accurate | Garmin Customer Support. (n.d.). Retrieved November 26, 2022, from https://support.garmin.com/en-US/?faq=xQwjQjzUew4BF1GYcusE59

Trochim, W. (2000) The Research Method Knowledge Base. 2nd Edition, Atomic Dog Publishing, Cincinnati.

Tosato, J.deP., Caria, P. H., Gomes, C. A., Berzin, F., Politti, F., Gonzalez, T.deO., & Biasotto-Gonzalez, D. A. (2015). Correlation of stress and muscle activity of patients with different degrees of temporomandibular disorder. *Journal of physical therapy science*, *27*(4), 1227–1231. https://doi.org/10.1589/jpts.27.1227

Ussery, E. N., Whitfield, G. P., Fulton, J. E., Galuska, D. A., Matthews, C. E., Katzmarzyk, P. T., & Carlson, S. A. (2021). Trends in Self-Reported Sitting Time by Physical Activity Levels Among US Adults, NHANES 2007/2008-2017/2018. *Journal of physical activity & health*, *18*(S1), S74–S83. https://doi.org/10.1123/jpah.2021-0221

Valenza, G., Garcia, R. G., Citi, L., Scilingo, E. P., Tomaz, C. A., & Barbieri, R. (2015). Nonlinear digital signal processing in mental health: characterization of major depression using instantaneous entropy measures of heartbeat dynamics. *Frontiers in physiology*, *6*, 74. https://doi.org/10.3389/fphys.2015.00074

Van Puyvelde, M., Neyt, X., McGlone, F., & Pattyn, N. (2018). Voice Stress Analysis: A New Framework for Voice and Effort in Human Performance. *Frontiers in psychology*, *9*, 1994. https://doi.org/10.3389/fpsyg.2018.01994

Vinkers, C. H., Penning, R., Hellhammer, J., Verster, J. C., Klaessens, J. H., Olivier, B., & Kalkman, C. J. (2013). The effect of stress on core and peripheral body temperature in humans. *Stress (Amsterdam, Netherlands)*, *16*(5), 520–530. https://doi.org/10.3109/10253890.2013.807243

Vijayan, V., Connolly, J. P., Condell, J., McKelvey, N., & Gardiner, P. (2021). Review of Wearable Devices and Data Collection Considerations for Connected Health. *Sensors (Basel, Switzerland)*, *21*(16), 5589. https://doi.org/10.3390/s21165589

Vizer, L. M., Zhou, L., & Sears, A. (2009). Automated stress detection using keystroke and linguistic features: An exploratory study. *International Journal of Human-Computer Studies, 67*(10), 870–886. https://doi.org/10.1016/j.ijhcs.2009.07.005

Vlenterie, R., Roeleveld, N., & van Gelder, M. M. (2016). Single awakening salivary measurements provide reliable estimates of morning cortisol levels in pregnant women. *Psychoneuroendocrinology*, *74*, 295–301. https://doi.org/10.1016/j.psyneuen.2016.09.009

Waxenbaum, J. A., Reddy, V., & Varacallo, M. (2022). Anatomy, Autonomic Nervous System. In *StatPearls*. StatPearls Publishing.

Wikimedia Foundation. (2022, June 12). *Ground truth*. Wikipedia. Retrieved December 3, 2022, from https://en.wikipedia.org/wiki/Ground_truth

Wijsman, J., Grundlehner, B., Liu, H., Penders, J., & Hermens, H.J. (2013). Wearable Physiological Sensors Reflect Mental Stress State in Office-Like Situations. *2013 Humaine Association Conference on Affective Computing and Intelligent Interaction*, 600-605.

World Health Organization. (n.d.). Stress. World Health Organization. Retrieved November 1, 2022, from https://www.who.int/news-room/questions-and-answers/item/stress

World Health Organization. (2022, October 5). *Physical activity*. Who.int; World Health Organization: WHO. https://www.who.int/news-room/fact-sheets/detail/physical-activity

World Health Organization. (n.d.). *Out of the shadows: Making mental health a global priority*. World Health Organization. Retrieved November 1, 2022, from https://www.who.int/director-general/speeches/detail/out-of-the-shadows-making-mental-health-a-global-priority

World Health Organization. (n.d.). *Stress*. World Health Organization. Retrieved November 28, 2022, from https://www.who.int/news-room/questions-and-answers/item/stress

Yang, H., Liu, B., & Fang, J. (2021). Stress and Problematic Smartphone Use Severity: Smartphone Use Frequency and Fear of Missing Out as Mediators. *Frontiers in psychiatry*, *12*, 659288. https://doi.org/10.3389/fpsyt.2021.659288

Yang, Y., & Yang, P. (2022). Effect of College Students' Academic Stress on Anxiety Under the Background of the Normalization of COVID-19 Pandemic: The Mediating and Moderating Effects of Psychological Capital. *Frontiers in psychology*, *13*, 880179. https://doi.org/10.3389/fpsyg.2022.880179

Zhai, J., & Barreto, A.B. (2006). Stress Recognition Using Non-invasive Technology. *The Florida AI Research Society*.

Zhang, H., Feng, L., Li, N., Jin, Z., & Cao, L. (2020). Video-Based Stress Detection through Deep Learning. *Sensors (Basel, Switzerland)*, *20*(19), 5552. https://doi.org/10.3390/s20195552

7. Dissertation conclusions and future work

Due to my background in physical activity as a coach and as a researcher in sport psychology, I have been lucky to be able to continue my research in this field. Specifically, during my last year I have focused my research on the use of wearable technology to analyse the interplay between physical activity levels and psychological variables such as stress and wellbeing.

The PhD path is ultimately about learning and like the ability of research to push the boundaries of scientific discovery and understanding one is expanding along the learning within the PhD. Underpinning the PhD journey is the scientific method that accompanies aspiring students like an experienced guide beating a track up a mountain side. Like the start of a mountain ascent whereby there are many routes to choose from, at the beginning the PhD path seems broad with many different options or possibilities.

The pinnacle of my ascent was to use wearable technology to measure psychological variables in exercisers, and initially the topic was broad. I wanted to refine and lay a base to launch my PhD journey from hence I conducted a systematic review of the literature to explore the most common psychological variables that had been correlated with physical exercise. Like the journey up the mountain the path is not always clear but guided by the scientific method and following a systematic approach I directed my attention towards “simple” correlations and was able to find statistically significant inferences between commonly studied psychological variables such as self-efficacy and exercise. Moreover, like discovering a diamond shaped crystal amongst shingle scree on the mountain side along the journey, I was able to meta analyse many of these psychological variables to highlight the bilateral and positive relationship between self-efficacy, self-regulation, and exercise. Importantly along this section of the journey through an extended literature search I also discovered that stress, anxiety, and even depression were relevant psychological variables being currently studied in relationship with wearable devices which take physiological readings from the body, often using PPG to gather HRV readings. Hence, I was able to narrow my focus and start on the next section of my ascent with a more refined outlook. Life and from experience the mountain can be unpredictable and perilous providing for a plethora of hazards. Like the mountain and incredibly this hazardous unpredictability reared within the PhD course in the form of the COVID-19 pandemic. Cascading downwards like an avalanche on the mountain it descended cutting its own track through an unexpecting populace in the form of morbidity, university closures and lockdown measures. Moreover, it cut ties to research populations such as sports teams and heightened physical inactivity and increased stress levels. During an event like this, one must first gather their senses to acknowledge and accept the situation, then re-evaluate, and look for alternative measures. This can be likened to the stress response since although it provides us with an innate mechanism to help with our survival in the face of impending danger it can also override our ability to make sound decisions that invariably may lead to a perilous conclusion. Constructive appraisal and initiative ensured that in our case it eventualised that the problem of the COVID-19 pandemic could also be the answer. Hence our research team set about the construction of three separate studies that would allow for in depth learning and analysis and included: The Sport Motivation Scale use in a cohort of Italian rugby players: a comprehensive analysis; COVID-19 pandemic: Benefits and challenges for physical activity and psychological consequences; and Active breaks at the office: a viable solution to reduce stress and improve wellbeing. The pandemic put stop to an ongoing longitudinal study using rugby players, measuring their perceptions of motivation is their rugby specific sports teams. Like an event on the mountain one can stop and reflect on where they are and where they have come from to provide motivation and direction to continue along the journey. "The Sport Motivation Scale (SMS) in a cohort of Italian rugby players" involved gathering previously recorded data over consecutive seasons and highlighted in depth psychometric research to further validate the SMS as a valid statistical tool for use in Italy.

The COVID-19 lockdown provided for a decrease from "traditional" working methods and psychometric measurement processes such as face to face interviews or questionnaire-based assessments. Moreover, it increased sedentary behaviour and its negative physiological and psychological health-related issues. Although, and on the other hand, it provided for an increase in remote working and digital, technology-based communications and interactions. This scenario and these consequences insured for a curiosity into the paper "Benefits and challenges for physical activity and psychological consequences" which required an in-depth investigation into the resources and assets available for home-based inquiry about exercise, stress and wellbeing that was provided by academic institutions and government bodies at both local and international levels. Findings were important and highlighted a lack of resources and preparation for a pandemic type of catastrophe.

In Denmark, and with the intended research population of rugby specific sports teams now closed to us, an alternative and important population to study were office workers. Furthermore, we networked and establishing a vested relationship with a newly formed Danish start up called Pleaz, whereby we set about implementing a digitally based exercise intervention to increase exercise in office work environments while looking to decrease stress and increase overall wellbeing. This paper established a direct and progressive path with the use of wearable devices. Moreover, it helped us to explore better their capability for measuring psychological variables such as stress through physiological readings. Furthermore, it set a base of experience in wearable research that led directly to the incorporation of wearable devices in our latest longitudinal research study entitled "Studying and exercising: the use of wearables in university students". Post-COVID-19 restrictions saw a relative return to normal life as communities looked to manage the virus. Moreover, it provided our research group with access to greater populations, including students who - like office workers - are at risk from sedentary behaviour. Following positive results from our active breaks paper we were curious to see if vested messages alone could predict an increase in physical activity and whether readings of stress from wearable devices would correlate with measurement of perceived stress using a validated self-assessment tool (Perceived Stress Scale, PPS-10). Again, results were positive as we used a multilevel multivariate model to incorporate predictors and timepoints in the analysis. The study found that messages alone did correlate with an increase in PA and, from the substudy analysis, that the PSS-10 did correlate with the measurements for high stress from the wearable devices. This study was novel and encouraging and provided greater in depth learning and understanding of the relationships between physiological readings from wearables and psychological variables and statistical analysis.

Moreover, the use of wearable devices in research is in its infancy and endeavours to provide a profound effect for users regarding their ability to self-manage and diagnose potentially harmful events such as high stress or even clinical events. Furthermore, the ability to self-diagnose and manage stress through the prescription of PA via messages through wearable devices and associated technology could ensure for a reduction of pressure currently placed on healthcare systems across the globe that have proven to be overloaded.

The knowledge and experience gained from the PhD path has provided a sound understanding of the systematic nature of the scientific method as well as insights into the continued expansion of data analysis. The PhD journey is not a means to an end, but rather looks to lay a foundation of experience and knowledge to refine a path and specialise in a particular area. Moreover, for learning to be a lifelong endeavour from a PhD perspective one must continue to push the boundaries of scientific knowledge. Thus, with the knowledge and experience gained through the PhD, I first intend to undertake another systematic review looking at the relationships between stress, anxiety and depression and the ability of wearable devices to predict the three. Secondly, I intend to implement a study using wearable devices within specific populations, such as athletes, or looking at collaborations to investigate clinical populations to predict stress, anxiety and depression and implement a non-invasive intervention based on vested messages and a relaxing breathing technique as a form of low intensity exercise.

Ultimately, I would like to keep the direction of my research in sports-related wellbeing in a changing digital world.