PHYSICAL ACTIVITY AND EXERCISE IN THE ELDERLY AND CHRONICALLY ILL

Collection of research studies

Associate Professor Thesis

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by

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Foreword

This thesis is a collection of 12 studies focusing on physical activity and exercise in the elderly and chronically ill. All studies were published in the past five years as a paper in a journal indexed in the Web of Science (the only exception is Study 5, which is currently under review in the International Journal of Behavior Nutrition and Physical Activity). I am the first and corresponding author of all papers, except Study 7, where I am only the corresponding author.

Flanked by the short Introduction (Chapter 1) and Conclusions (Chapter 8), the main body of the thesis is formed by six interrelated chapters that progressively develop the topic of physical activity and exercise in the elderly and chronically ill.

Chapter 2 deals with the objective assessment of physical activity. Specifically, it sheds light on the current use of accelerometers and provides practical recommendations for researchers and clinicians (Study 1).[1] It also discusses the use of consumer-level activity monitors and reports on the results of our validation study of six monitors (Study 2).[2]

The next Chapter 3 summarises our research of interventions to increase habitual physical activity. This section features our study of a walking intervention delivered in primary care (Study 3)[3] and explores the experiences of patients participating in this intervention (Study 4).[4] Furthermore, this section also includes a systematic review and meta-analysis of studies of physical activity interventions combining self-monitoring with other intervention components (Study 5).[5]

Mental health benefits of physical activity are discussed in Chapter 4, which includes a study assessing the effect of a physical activity intervention on anxiety and depression symptoms (Study 6).[6] In addition, this section also explores the links between physical activity, physical fitness and mental health in a specific population of severely obese patients undergoing bariatric surgery (Study 7).[7]

Chapter 5 is dedicated to strength training in older adults. First, it summarises the effect of strength training on sarcopenia and frailty (Study 8).[8] Then, it focuses on the safety and efficacy of increasingly popular plyometric training (Study 9).[9] Finally, it reports the results of our training study of assisted training in older adults (Study 10).[10]

Findings from previous chapters are integrated with Chapter 6 that demonstrates how habitual physical activity and structured exercise training mutually interact. This chapter includes one study that investigated the effect of attending exercise sessions on the levels of habitual physical activity later that day and the following day (Study 11).[11]

Finally, Chapter 7 puts physical activity in the context of the ongoing COVID-19 pandemic and explores the effect of COVID-19 nationwide quarantine on accelerometer-assessed physical activity of heart failure patients (Study 12).[12]

All chapters start with a brief commentary to help readers follow the flow of the thesis. Then, within the chapters, the individual studies are reprinted in full (only in the printed version of the thesis) and introduced with several paragraphs covering background, methods and results, conclusions, and the impact of the study.

The studies included in the thesis are:

Study 1: Vetrovsky T, Clark CCT, Bisi MC, Siranec M, Linhart A, Tufano JJ, et al. Advances in accelerometry for cardiovascular patients: a systematic review with practical recommendations. Esc Hear Fail. 2020;7(5):2021–31.

Study 2: Vetrovsky T, Siranec M, Marencakova J, Tufano JJ, Capek V, Bunc V, et al. Validity of six consumer-level activity monitors for measuring steps in patients with chronic heart failure. Plos One. 2019;14(9):e0222569.

Study 3: Vetrovsky T, Cupka J, Dudek M, Kuthanova B, Vetrovska K, Capek V, et al. A pedometer-based walking intervention with and without email counseling in general practice: a pilot randomized controlled trial. Bmc Public Health. 2018;18(1):635.

Study 4: Vetrovsky T, Vetrovska K, Bunc V. A qualitative exploration of the experiences of primary care patients engaged in email counseling meant to increase *physical activity. Acta Gymnica. 2019;49(2):75–82.*

Study 5: Vetrovsky T, Borowiec A, Jurik R, Wahlich C, Smigielski W, Steffl M, et al. Do physical activity interventions combining self-monitoring with other components provide an additional benefit compared to self-monitoring alone? A systematic review and meta-analysis. Under review.

Study 6: Vetrovsky T, Cupka J, Dudek M, Kuthanova B, Vetrovska K, Capek V, et al. Mental health and quality of life benefits of a pedometer-based walking intervention delivered in a primary care setting. Acta Gymnica. 2017;47(3):138–43.

Study 7: Vetrovsky T, Fortova T, Conesa-Ros E, Steffl M, Heczkova J, Belohlavek J, et al. Increased Cardiopulmonary Fitness Is Associated with a Greater Reduction in Depression among People Who Underwent Bariatric Surgery. Int J Environ Res Public Health. 2021;18(5):2508.

Study 8: Talar K, Hernández-Belmonte A, Vetrovsky T, Steffl M, Kałamacka E, Courel-Ibáñez J. Benefits of Resistance Training in Early and Late Stages of Frailty and Sarcopenia: A Systematic Review and Meta-Analysis of Randomized Controlled Studies. J Clin Medicine. 2021;10(8):1630.

Study 9: Vetrovsky T, Steffl M, Stastny P, Tufano JJ. The Efficacy and Safety of Lower-Limb Plyometric Training in Older Adults: A Systematic Review. Sports Med. 2019;49(1):113–31.

Study 10: Vetrovsky T, Omcirk D, Malecek J, Stastny P, Steffl M, Tufano JJ. Overspeed Stimulus Provided by Assisted Jumping Encourages Rapid Increases in Strength and Power Performance of Older Adults. J Aging Phys Activ. 2020;29(2):259–66.

Study 11: Vetrovsky T, Omcirk D, Malecek J, Stastny P, Steffl M, Tufano JJ. Morning fatigue and structured exercise interact to affect non-exercise physical activity of fit and healthy older adults. Bmc Geriatr. 2021;21(1):179.

Study 12: Vetrovsky T, Frybova T, Gant I, Semerad M, Cimler R, Bunc V, et al. The detrimental effect of COVID-19 nationwide quarantine on accelerometer-assessed physical activity of heart failure patients. Esc Hear Fail. 2020;7(5):2093–7.

1. Introduction

Physical inactivity is responsible for up to 8% of non-communicable diseases and deaths across the world.[13] It is also associated with a higher risk for severe COVID-19 outcomes,[14] has a negative effect on mental health,[15] and results in decreased quality of life.[16] Thus, effective interventions to increase physical activity and reduce sedentary behaviour are urgently needed.[17]

The detrimental effects of physical inactivity are even more pronounced in older and chronically ill adults.[18,19] Unfortunately, these populations typically achieve below-average levels of physical activity, and they are also more resistant to interventions aimed at increasing physical activity.[20–22] Therefore, every effort must be made to find novel and effective approaches to increasing physical activity in the elderly and chronically ill.

This need has also been highlighted by the latest WHO Guidelines on Physical Activity and Sedentary Behaviour that dedicated specific sections to adults aged 65 years and older and adults with chronic conditions such as cardiovascular diseases, type 2 diabetes, and cancer.[23] The recommendations for both elderly and chronically ill are more or less the same: they should do at least 150 to 300 minutes of at least moderate-intensity aerobic activity AND muscle-strengthening exercises that involve all major muscle groups on at least two or more days a week. In addition, older adults should do varied multicomponent activities that emphasise functional balance and strength training on three or more days a week.[23]

When adhering to these guidelines, both older adults and adults with chronic conditions reap similar benefits: lower risk of all-cause and cause-specific mortality,[24,25] lower adiposity,[26] and better cognitive outcomes[27] are just a few examples. In addition, there are also some benefits of physical activity specifically related to either older adults (reduced rates of falls, reduced risk of age-related loss of physical function) or chronically ill (greater reduction in HbA1c and blood pressure, reduced risk of cancer recurrence).[28,29]

In summary, older adults and chronically ill are specific subgroups that have much in common and in which insufficient levels of physical activity lead to deterioration of their physical and mental health. At the same time, their limited functional abilities further reduce their physical activity levels, thus creating a vicious circle that is difficult to break. Therefore, the overarching aim of this thesis is to help the elderly and chronically ill live longer and healthier lives by engaging in regular physical activity and exercise.

2. Objective assessment of physical activity

Traditionally, physical activity has been assessed using questionnaires such as IPAQ.[30] However, questionnaires suffer from well-documented flaws, including recall bias, social desirability, etc., usually leading to overestimates of physical activity levels.[31] To overcome these drawbacks, researchers have long used objective measurement with accelerometers to increase the accuracy of physical activity assessment.[32] Unfortunately, accelerometers have their downsides, and their use creates new challenges to be resolved.[33]

Typically, researchers face many decisions such as the accelerometer placement (hip vs wrist), wear time (waking hours vs 24 h wear), choice of outcomes (minutes of moderate-to-vigorous physical activity vs average acceleration), choice of cut points, methods of dealing with non-wear time, etc.[34] Each of these decisions affects the results of a study and their interpretation and comparability with other studies. Therefore, it is paramount to reach a consensus about the appropriate accelerometry protocols and their proper reporting. Various research groups and consortia have already proposed their recommendations;[35] however, these are primarily focused on the general population and do not consider specific aspects of the elderly and chronically ill. Thus, in Study 1, we aimed to shed light on the current use of accelerometers for the assessment of physical activity in chronically ill, specifically in patients with heart failure, and provide practical recommendations for researchers and clinicians.[1]

Another downside of research-grade accelerometers (e.g., Actigraph, Axivity) is their high price which can be prohibitive, especially in large studies. As a result, researchers often resort to cheaper consumer-level activity monitors (e.g., Fitbit or Garmin) that offer seemingly same measurement capabilities as the research-grade accelerometers.[36] Indeed, in many validation studies, consumer-level devices have been shown as equivalent to research-grade accelerometers.[37] However, most of these studies have been conducted in the general population with a standard gait and movement patterns; thus, whether the consumer devices can be appropriately used in the elderly and chronically ill is less clear.[38] Therefore, in Study 2, we aimed to validate six consumer-level activity monitors in patients with heart failure.[2]

Study 1: Using accelerometers in the chronically ill

In the past decade, objective assessment of physical activity using accelerometers witnessed fast development, propelled mainly by advances in computational methods, including machine learning.[39] This field of research covers various topics such as the development of emerging metrics independent of population-specific cut points,[40] use of raw acceleration (usually expressed as Euclidean Norm Minus One, ENMO) instead of proprietary "counts",[41] detection of sitting as a posture (rather than just lack of physical activity),[42] or use of accelerometers to trigger context-aware Ecological Momentary Assessments.[43–45] However, these new emerging approaches are only slowly translated into practice, especially in clinical settings where relatively old-fashioned methods still prevail. In addition, the methods are often insufficiently and inappropriately reported, limiting the reproducibility of the findings.[46] Thus, we aimed to map the methods used to collect and process accelerometry data and examine the quality of reporting of these methods in chronically ill patients.

We chose heart failure as an example of chronic disease because of its increasing prevalence and economic burden and conducted a systematic review of all studies using accelerometers in heart failure patients. We identified 60 papers: 32 observational studies, 12 randomised controlled trials, 8 validation studies, 5 published study protocols, and 3 quasi-experimental studies. In total, 27 accelerometer brands and 46 models were used in the reviewed studies, with Actigraph and Fitbit being the most frequently used brands. The most often reported measure of physical activity was the daily number of steps (n = 20), followed by proprietary "counts" (n = 15), and time spent in physical activity intensity levels (n = 14). Only two studies used raw accelerometry data, and no study used machine learning or other emerging analytical techniques. To evaluate the quality of reporting, we adapted a tool developed by Montoye et al. that scores 12 items considered essential for complete reporting.[46] The reviewed studies failed to report between one and six (median 4) of these 12 items. The most underreported items included the criteria for defining non-wear time, the minimum number of minutes needed to be considered a valid day, and the number of valid days required for a patient to be included in the analysis.[1]

In summary, using the example of heart failure, we demonstrated considerable heterogeneity and a lack of consensus in the methods used for accelerometer data collection and processing in chronically ill. Furthermore, we found that despite their well-established limitations, traditional metrics such as steps, activity counts, and time spent in intensity levels still prevail. Thus, we have revealed an opportunistic gap in using metrics based on raw acceleration and machine learning techniques. Finally, we proposed practical recommendations for the use of accelerometers in patients with cardiovascular and other chronic diseases to encourage researchers and clinicians to improve the quality and transparency of their reporting.[1]

To ensure that this study will be of practical use to clinicians, it was conducted in close collaboration with cardiologists from the General University Hospital in Prague (Professor Belohlavek, Dr Siranec). In addition, to increase the international impact of our work, we invited distinguished researchers in the field of accelerometry from Coventry University, UK (Professor Duncan, Dr Clark), and the University of Bologna, Italy (Dr Bisi), as international collaborators on this review. This effort proved successful as our paper has been used and cited in the recent position paper on measuring physical activity with activity monitors in patients with heart failure published by the Committee on Exercise Physiology and Training of the Heart Failure Association of the European Society of Cardiology.[47]

Study 2: Consumer-level activity monitors

Consumer-level activity monitors are increasingly used in research, surveillance, and interventions for their widespread availability, low cost, and ease of use.[48,49] However, compared to research-grade accelerometers, consumer-level devices have some drawbacks: they use proprietary metrics that can be tweaked with new updates of their firmware; frequently launched new models are not necessarily compatible with older ones; or lower accuracy.[50] Despite these drawbacks, the advantages of consumer devices can still prevail in some circumstances, provided that their accuracy has been rigorously proven.[51] In the past decade, a plethora of validation studies demonstrated that various models of consumer-level activity monitors, mostly from Fitbit, are relatively accurate in healthy adults.[36,52,53] However, only a few studies validated consumer devices in the elderly and chronically ill.[54] For example, our systematic review found that none of the consumer-level activity monitor available on the market has been validated in heart failure patients.[1] Given that elderly and chronically ill usually have a slower gait that can hamper the accuracy of the accelerometers in detecting steps,[55,56], the lack of evidence of the validity of consumer-level activity monitors is of grave concern. Thus, we aimed to evaluate several consumer devices as measures of step count in patients with heart failure.

We evaluated six models of devices: Withings Go, Fitbit Charge 2, Garmin vívofit and vívofit 3, Omron HJ-322U-E, and SmartLAB walk+. We recruited a convenience sample of 15 patients with heart failure and 14 healthy individuals who wore all the devices concurrently with the criterion research-grade accelerometer Actigraph wGT3X-BT during three days under free-living conditions. In healthy individuals, all devices except Fitbit Charge 2 showed substantial correlation (Concordance Correlation Coefficient, CCC >0.95) with the criterion device and Mean Absolute Percentage Error, MAPE <10%, which is considered as a threshold for the validity of activity monitors. However, in patients with heart failure, none of the devices demonstrated substantial correlation, and only two devices (Garmin vívofit 3 and Withings

Go) showed at least moderate correlation (CCC >0.90). The MAPE was in the range of 12-18%, except for Fitbit Charge 2, with a high MAPE of 46%. The free-living testing was complemented with a lab-based study where 20 healthy participants walked at a treadmill at speeds of 2.4, 3.0, 3.6, and 4.2 km/h at 0% grade. It demonstrated that at slower speeds (3.0 km/h and lower), the accuracy of all devices substantially deteriorated.[2]

Thus, in heart failure patients and other chronically ill with impaired and slower gait, the accuracy of consumer-level activity monitors cannot be taken for granted, even though these devices have been validated in healthy adults with a normal gait. Still, most consumer-level monitors perform reasonably well enough to be valuable tools that clinicians can use for long-term self-monitoring to motivate their patients to walk more. However, for research purposes, research-grade accelerometers should be preferred for their greater accuracy and because they give researchers better control of the data collection and processing.[2]

Despite the plethora of studies validating consumer-level activity monitors in healthy adults,[50] only a few papers dealt with their accuracy in chronically ill.[1] Our study filled this gap and was the first study validating activity monitors in heart failure patients under free-living conditions. Consequently, the published paper has been frequently cited (7 citations in the Web of Science in the first two years since publication), reaching the 83rd citation percentile in the Web of Science impact beam plot. In addition, as a result of this paper, its first author has been invited to speak on activity monitoring devices at the ESC Preventive Cardiology 2021 congress.

3. Interventions to increase habitual physical activity

Despite the well-proven benefits of physical activity for healthy ageing and the prevention and treatment of various chronic diseases,[57] the majority of adults does not adhere to the physical activity recommendations.[58] Thus, effective interventions to increase habitual physical activity are critically needed.

Among various settings (in the community, at work), a healthcare setting seems to be especially suitable for delivering physical activity interventions, especially among the elderly and chronically ill.[59] Specifically, general practitioners are well situated to provide physical activity interventions to older adults and the chronically ill.[60–62] Thus, in Study 3, we aimed to evaluate the feasibility and potential efficacy of a physical activity intervention delivered in general practice.[3] Furthermore, in Study 4, we qualitatively explored the experiences of patients participating in this intervention and analysed what behaviour change techniques they used to increase their daily step count.[4]

One of the behaviour change techniques effectively used in our study was self-monitoring.[4] Indeed, self-monitoring with consumer-level activity monitors has been consistently shown as a powerful behaviour change technique [63,64]. However, given the positive impact of self-monitoring on physical activity levels, it is not clear if the effect of various complex physical activity interventions is primarily caused by self-monitoring alone or if additional components offer further benefits. Thus, in Study 5, we attempted to determine whether interventions that combine self-monitoring with other intervention components provide an additional benefit to self-monitoring alone.[5]

Study 3: Interventions in healthcare settings

General practitioners have great potential to advise their patients on recommended physical activity and shape their beliefs and attitudes towards physical activity.[60,65] In developed countries, the majority of adults visit their practitioner at least once a year, and general practitioners are viewed as credible sources of health information, particularly among the elderly and chronically ill.[66] Moreover, most practitioners believe that physical activity counselling is important and that they play a role in promoting physical activity among their patients.[61] Thus, it is not surprising that the National Institute for Health and Care Excellence in the UK recommends that general practitioners should identify inactive adults and advise them to increase their PA levels.[67] Unfortunately, practitioners often lack the time and appropriate training necessary to deliver physical activity interventions.[65] Thus, we conducted a pilot randomised controlled trial of a physical activity intervention to assess its feasibility and potential efficacy to support the development of future trials in a primary care setting.

We recruited physically inactive patients during preventive visits to their general practices and randomised them to a 12-week pedometer-based walking intervention with or without e-mail counselling. We found that the recruitment was feasible and acceptable but relatively slow and inefficient; moreover, general practitioners selectively recruited overweight and obese patients. Patients manifested high adherence, wearing the pedometer on 83% (± 20) of days. All patients from the counselling group actively participated in e-mail communication and responded to 46% (± 22) of the e-mails they received. Both groups significantly increased their daily step-count (pedometer-plus-email, + 2119, $p = 0.002$; pedometer-alone, + 1336, $p = 0.03$), but the difference between groups was not significant ($p = 0.18$). When analysing both groups combined, there was a significant decrease in body mass (− 0.68 kg, $p = 0.04$), waist circumference (− 1.73 cm, $p = 0.03$), and systolic blood pressure (− 3.48 mmHg, $p = 0.045$).[3]

Our study provided important information for conducting future randomised controlled trials of physical activity interventions delivered in general practice. Specifically, we found that patients recruited during preventive visits demonstrate excellent adherence to self-monitoring with an activity monitor and high levels of engagement with additional counselling. We also identified several issues that need to be addressed when designing future trials, namely the relatively slow and inefficient recruitment process, selective recruitment, and technical issues.[3]

The results of this study have been used to design a large randomised controlled trial of physical activity intervention in general practice (ENERGISED trial) in collaboration with the Institute of General Practice of the First Faculty of Medicine, Charles University (Professor Seifert). The trial has recently received funding (10 mil. CZK) from the Czech Health Research Council (Agentura pro zdravotnický výzkum České Republiky, AZV) of the Ministry of Health of the Czech Republic (Grant Number NU21-09-00007).

Study 4: Patients' experiences with physical activity interventions

Understanding beliefs, attitudes, and experiences of participants in physical activity interventions is critical for the successful implementation of these interventions.[68] Therefore, many studies conduct qualitative analyses of interviews with the study participants.[69–71] While this is a useful approach, it also has its limitations as the interviewees might be influenced by the interview situation. As such, they may not provide reliable information because of either an unconscious bias or even conscious and deliberate attempts to mislead the interviewer.[72] Thus, supplementing the interviews with the direct analysis of counselling content can yield additional insight. Unfortunately, papers that qualitatively analyse the content of physical activity counselling in primary care are rare, [73,74] which might be explained by the inconvenience of recording face-to-face or telephone counselling sessions. Our study described in the previous section[3] used e-mail counselling; thus, we had the convenience of access to the full content of e-mail communication with the study participants. Therefore, we explored the experiences of primary care patients participating in a physical activity intervention using the content of their e-mail messages.

We extracted, coded, and analysed 32 e-mail messages from 10 participants using thematic analysis. We identified 22 themes and grouped them into three categories: reflections on the pedometer-based intervention, use of behaviour change techniques, and barriers that affected participants' engagement in physical activity. Most participants well accepted the intervention: they enjoyed walking and appreciated the activity monitor. Action planning, goal setting and self-monitoring were the most prevalent behaviour change techniques implemented by the participants. Time constraints, weather conditions, and lack of motivation were the most common barriers that got in the way of increasing physical activity.[4]

In summary, using thematic analysis of the email messages written by participants in the course of physical activity counselling intervention, the study extended previous findings on the use of behaviour change techniques by intervention participants, documenting their perceptions and experiences with various techniques. The study also identified common barriers encountered by intervention participants in their effort to increase their level of physical activity.[4]

The results of this study significantly contributed to the design of the ongoing ENERGISED trial described in the previous section. Specifically, the behaviour change techniques identified in the study were built into the intervention. Furthermore, strategies to overcome various barriers to physical activity documented in the study were developed and included in the intervention.

Study 5: Self-monitoring as a powerful behaviour change technique

Self-monitoring using consumer-level activity monitors is a powerful behaviour change technique,[75–77] frequently used in physical activity interventions, as demonstrated in our previous study.[4] Considering the positive impact of self-monitoring on physical activity levels, it is worth questioning if the effect of various complex interventions is primarily caused by self-monitoring alone and if additional components further bolster the effects or have no effects. Thus, it seems pertinent to question the net effect of various intervention components above and beyond the self-monitoring effects, especially as some of these components (e.g., in-person counselling) are often resource-intensive compared with simple self-monitoring.[78] Therefore, our study aimed to determine whether complex physical activity interventions that combine self-monitoring using activity monitors with other intervention components provide an additional benefit to self-monitoring alone.

We systematically reviewed and meta-analysed randomised controlled trials that compared an intervention using self-monitoring with an activity monitor to increase physical activity (active control arm) with an intervention comprising precisely the same treatment PLUS any additional component intended to further increase physical activity (intervention arm). The search of five databases complemented by backward and forward citation searches yielded 65 eligible studies. At post-intervention, the mean difference between the intervention and active control arms was 947 steps/day; at follow-up, the mean difference was 439 steps/day. Meta-regressions suggested that interventions with a prescribed goal and added human counselling, particularly via phone/video calls, were associated with a greater mean difference in the daily step-count than interventions with added print materials, websites, smartphone apps, or incentives.[5]

We concluded that complex physical activity interventions that combine self-monitoring using activity monitors with other intervention components provide an additional benefit above and beyond self-monitoring alone. However, these interventions owe a substantial part of their overall effect to simple self-monitoring; thus, they should be assessed against active control arms comprised of self-monitoring and goal-setting to isolate the net effect of additional potentially resource-intensive components.[5]

This study resulted from international collaboration with the St George's University of London, UK (Professor Harris, Dr Wahlich) and the National Institute of Cardiology in Warsaw, Poland (Professor Malek, Professor Drygas). At the time of writing (September 2021), the manuscript of this study is under review in the International Journal of Behavior Nutrition and Physical Activity (impact factor 6.714). Moreover, the abstract of the study has been accepted for the Public Health Science 2021 conference. Consequently, it will be published as a meeting abstract in the special issue of The Lancet (impact factor 79.321). Thus, we assume that this study will gain high visibility and be adopted by the international community of researchers in the field of physical activity interventions.

4. Physical activity and mental health

The beneficial effects of physical activity on physical health have been long recognised.[79] More recently, researchers and clinicians realised the benefits of physical activity for mental health, both in patients diagnosed with anxiety and depression[15] and those without clinically diagnosed disorders.[80,81] As the elderly and chronically ill have an increased prevalence of anxiety and depression, the mental health benefits of physical activity in these populations are all the more important.

Despite decades of research on the effects of physical activity on mental health, there are still some knowledge gaps. Specifically, the body of evidence on mental health benefits of walking interventions in a primary care setting is contradictory and inconclusive.[68,82,83] Thus, in Study 6, we conducted a secondary analysis of our randomised controlled trial, described in the previous section, to explore the effect of the intervention on anxiety and depression symptoms and health-related quality of life.[6]

Similarly, evidence regarding the benefits of improved physical activity and fitness for the mental health and well-being of bariatric surgery patients is limited.[84–86] Thus, in Study 7, we aimed to determine the effect of changes in cardiopulmonary fitness on changes in mental health, fatigue, and health-related quality of life of patients with severe obesity who underwent gastric bypass surgery.[7]

Study 6: Mental health benefits of physical activity

Regular physical activity protects against the development of anxiety disorders and depression, reduces their symptoms, and increases the quality of life among patients with diagnosed anxiety disorders or depression.[15] Moreover, physical activity positively impacts symptoms of anxiety and depression even among people without clinically diagnosed anxiety or depression.[80,81] Walking is the most popular form of physical activity, especially among the elderly and chronically ill.[87] However, evidence regarding the positive effect of walking interventions on mental health among people without clinically diagnosed mental disorders is inconclusive.[68,82,83] Therefore, we aimed to assess whether a walking intervention delivered in primary care affects anxiety and depression symptoms and health-related quality of life in a general population of adults without clinical mental disorders.

We analysed data from our randomised controlled trial of the 3-month pedometer-based walking intervention described in the previous section. Study participants were administered the Hospital Anxiety and Depression Scale (HADS) and MOS 36-Item Short-Form Health Survey (SF-36) questionnaires before and after the intervention. Post-intervention, the average daily step count increased by 1,676 steps, representing an increase of 33% from baseline. Both the anxiety and depression subscales of HADS decreased, while the physical functioning, social functioning, mental health, vitality, and general health subscales of SF-36 increased.[6]

In conclusion, providing primary care patients with a pedometer and encouraging them to walk more in a primary care setting was associated with lower anxiety and depression scores and improved health-related quality of life. However, due to limitations of the quasi-experimental design of our study and the fact that recent large randomised controlled trials have failed to display similar findings, this conclusion should be viewed with caution and should be verified in future large randomised controlled trials.[6]

Study 7: Physical fitness and depression in bariatric patients

Physical activity, physical fitness, and obesity are mutually interconnected constructs affecting mental health.[84] In severely obese patients undergoing bariatric surgery, increased fitness improves the surgery process by greater post-surgery weight loss, improved body composition, and enhanced physical activity following surgery.[88,89] Conversely, lower levels of fitness have been associated with suboptimal weight loss and weight regain post-surgery[90]. However, evidence regarding the benefits of improved fitness for the mental health and well-being of bariatric surgery patients is limited.[85,86] Thus, the aim of this study was to determine the effect of changes in cardiopulmonary fitness on the mental health of patients with severe obesity who underwent gastric bypass surgery.

In this prospective observational study, we assessed cardiopulmonary fitness, physical activity, mental health, fatigue (Multidimensional Assessment of Fatigue questionnaire), and health-related quality of life (SF–36 questionnaire) of 26 patients prior to and 1, 3, and 6 months after bariatric surgery. Following the surgery, body weight and body fat percentage progressively improved. Mental health, fatigue, and quality of life also improved. Cardiopulmonary fitness operationalised as distance walked during the six-minute walk test increased by 36 m, and physical activity assessed with an accelerometer increased by 1260 steps/day. Improvements in the depression symptoms were significantly affected by changes in cardiopulmonary fitness: the greater the increase in cardiopulmonary fitness, the better the improvement in depression symptoms. In particular, increments of 10 m in the six-minute walk test led to the improvement of 0.5 points on the depression subscale of the Hospital Anxiety and Depression Scale (HADS) questionnaire (range 0 to 21). The results haven't changed after controlling for age, sex, change in weight, presence of comorbidities, and change in the daily number of steps.[7]

According to our findings, the observed increase of 36 m in 6MWT at three months post-surgery translates to a significant decrease of 1.8 points on the 21-point depression scale. As the minimal clinically important difference for depression score has been triangulated to be between 1.4 and 1.7, our finding represents a noticeable improvement, especially given the relatively low baseline values. These results suggest that patients should participate in exercise training programs to increase their fitness status for optimal physical and mental outcomes of bariatric surgery.[7]

5. Strength training in older adults

The majority of physical activity interventions in the elderly and chronically ill focus on steady-state aerobic physical activity. However, strength training is no less important for these populations as it increases physical performance and muscle strength which can help maintain independence and improve one's quality of life.[91–93] Indeed, recent WHO guidelines recommend that older adults and adults with chronic conditions should do muscle-strengthening activities that involve all major muscle groups on two or more days a week.[23]

Strength training is also an effective strategy to prevent and treat sarcopenia and frailty, syndromes that are highly prevalent among the elderly and negatively affect their quality of life.[92,94,95] However, there is a knowledge gap regarding the benefits of strength training at early (prevention) and late (treatment) stages in both syndromes combined. Thus, in Study 8, we aimed to synthesise current evidence regarding the effect of strength training interventions on muscular strength, physical function, and body composition in the elderly with both sarcopenia and frailty.[8]

Among various strength training modalities, plyometric training is a popular exercise technique that employs rapid eccentric motion followed immediately by a rapid concentric contraction.[96] Plyometric exercises were originally utilised in sports training to promote muscular power, agility, and rapid force production.[97,98] These same effects of plyometrics could be beneficial for older adults as they can help maintain independence and decrease the risk of falling.[99,100] However, whether plyometric training is a safe and efficacious training option in older adults is not known. Thus, in Study 9, we evaluated the safety and efficacy of plyometric training in older adults regarding various performance, functional, and health-related outcomes.[9]

A typical example of plyometric exercise is jump training.[96] However, in the elderly, jump training could be perceived as a dangerous and daunting task. Assisted jumping can serve as a low-impact alternative to traditional body-weight jumping, which might be more suitable for the population of older adults.[101] Assisted jumping has been often used in athletes but has never been tested in older adults.[102] Thus, in Study 10, we aimed to evaluate whether a 4-week training program including assisted jumping could improve jump performance, muscular strength, and balance in older adults.[10]

Study 8: Strength training as prevention of sarcopenia and frailty in older adults

Sarcopenia and frailty are debilitating syndromes with rapidly increasing prevalence among the elderly.[103] Both syndromes significantly increase the risk of falls, disability, dependence, hospitalisation, and mortality with an associated increase in public health costs.[104,105] Fortunately, sarcopenia and frailty can be prevented and even reversed with strength and resistance training.[92,95] However, little is known about the effect of resistance training in older adults with both syndromes combined. Furthermore, the effect of resistance training in the early stages of both syndromes (i.e., pre-sarcopenia and pre-frailty) has not been systematically evaluated. Therefore, we synthesised available evidence and conducted a meta-analysis of randomised controlled trials of resistance training in older adults with pre-/sarcopenia and pre-/frailty.

We identified 25 randomised controlled trials of resistance training interventions of at least eight weeks that recruited 2267 adults over 65 years of age with pre-/sarcopenia and pre-/frailty. Many of the included studies reported multiple outcomes (e.g., knee extension and knee flexion for lower-limb strength) with substantially varying intervention effects, sometimes even in the opposite direction. Using a standard meta-analytical approach would require choosing just one outcome and discarding the others, leading to a potential selection bias. Therefore, we used an innovative meta-regression technique named robust variance estimation (RVE) because it allows for the inclusion of the multiple dependent outcomes from the same study, thus avoiding the risk of bias.[106] Meta-analysis showed significant changes in favour of resistance training for handgrip and lower-limb strength, agility, gait speed, postural stability, functional performance, fat mass, and muscle mass. The positive effect of resistance training was also demonstrated during early stages, i.e., in the elderly with pre-sarcopenia and pre-frailty.[8]

In summary, we found that resistance training is a highly effective strategy to improve muscular strength, physical function, and body composition in older adults with pre-/sarcopenia and pre-/frailty. These findings reinforce the use of strength training interventions to delay and attenuate negative effects of sarcopenia and frailty in both early and late stages.

This study resulted from an international collaboration including the University of Murcia, Spain (Dr Courel-Ibanez, Dr Hernandez-Belmonte) and the University of Physical Education in Krakow, Poland (Dr Talar, Dr Kalamacka). The international research community on Twitter has greatly appreciated the study, where it was mentioned by 215 tweeters (Altmetric score of 137). Furthermore, in less than five months since publication, it collected 6 citations in the Web of Science.[8]

Study 9: Benefits of plyometric training in older adults

Various types of exercise can reverse or at least mitigate an age-related decline in health.[91] Among them, plyometric exercises, such as jumping, have a great potential to promote muscular power and rapid force production in the elderly.[96] Given that increased rapid force production and power output of the lower limbs can maintain independence and decrease the fear or risk of falling, plyometric training may help improve one's quality of life.[99,100,107] Despite these potentially beneficial effects, little research has been performed in older adults, and no review has explored whether plyometric training in older adults is a safe and efficacious training modality. Therefore, we conducted a systematic review to evaluate the safety and efficacy of plyometric training in older adults regarding various performance, functional, and health-related outcomes.

We identified 18 published papers reporting on 12 different studies of plyometric training in older adults (≥60 years). The studies were relatively small, with the largest one including only 36 subjects; the plyometric training lasted from 4 weeks to 12 months. The results of the studies indicated that plyometric exercises might have the potential for improving various performance (muscular strength, jump and physical performance), functional (postural stability, daily function), and health-related (bone health, body composition) outcomes in older persons. However, only in a few cases was plyometric training superior to another type of training with similar volume and intensity. In addition, no study reported an increased occurrence of injuries or other adverse events related to plyometric exercises.[9]

Thus, we concluded that plyometric training is a feasible and safe training option that positively affects muscular strength, jump performance, and physical performance in older adults. However, only limited evidence demonstrates the superiority of plyometric training over other types of training.[9]

Thanks to the novelty of the topic and the importance of the findings, this paper has been accepted to the prestigious Sports Medicine journal, which currently ranks 2nd in the Sport sciences category of the Web of Science (impact factor 11.136). Besides, it collected 14 citations in the Web of Science in less than three years since publication.

Study 10: Assisted jumping: a novel approach to strength training in older adults

Assisted jumping is a high-speed alternative to traditional body-weight jumping and is commonly used to introduce novel stimuli into athletes' training programs.[108] However, the same overspeed stimuli may also be effective in older adults who rarely move at fast velocities and do not sufficiently recruit high-threshold units in daily life.[101] Furthermore, as assisted jumping reduces impact forces, it could decrease the risk of an injury, thus being more suitable for the elderly.[109] Finally, assisted jumping is perceived to be easier than body-weight jumping, making it more enjoyable for older populations, potentially leading to higher adherence to the training program.[101] However, no study has yet explored the potential of assisted jumping in the elderly. Therefore, we aimed to determine whether assisted jumping could be safely and effectively implemented in older adults.

The study employed a single-group double-pretest posttest design and included a 4-week control period followed by a 4-week training period. The training program consisted of 11 supervised training sessions lasting up to 20 minutes, with the number of jumps per session starting at five jumps and progressing up to 24 jumps. The participants improved their performance in the CMJ as measured by flight time, but other jump characteristics did not change. Furthermore, the participants increased the eccentric strength of the quadriceps and improved their postural stability. Additionally, the participants reported increased enjoyment of jumping following the training period. Finally, we did not record any adverse events, injuries, or musculoskeletal problems during the training period.[10]

In conclusion, our study showed that combining assisted and body-weight jumping can improve various functional characteristics of older adults. It should be noted that the improvements were observed after just four weeks of training and with a relatively low number of jumps; thus, we can speculate that a longer program that progressively increases the number of jumps would result in even larger improvements.[10]

6. Interaction between habitual physical activity and structured exercise training

This thesis has shown that both habitual physical activity and strength exercise training are essential for the elderly and chronically ill. We have also demonstrated that habitual physical activity can be increased using behavioural interventions and that exercise training can positively affect muscular strength, body composition, and function of older adults. However, in real life, habitual physical activity and structured exercise can potentially interact.[110,111] For example, as people participate in structured exercise training, they tend to behaviourally compensate by decreasing their non-exercise physical activity. Furthermore, habitual physical activity is substantially influenced by physical feelings such as exercise-induced fatigue, especially in older adults and chronically ill with increased fatiguability.[112–114] Surprisingly, how older people react to day-to-day fatigue fluctuations and whether fatigue plays a role in non-exercise physical activity compensation is unknown. Thus, in Study 11, we aimed: (1) To explore whether the volume and intensity of habitual physical activity in older adults were affected by morning fatigue. (2) To investigate the effect of attending power and resistance exercise sessions on the levels of non-exercise physical activity later that day and the following day.

Study 11: The effect of structured exercise sessions on non-exercise physical activity

During the 4-week training program described in the previous section, participants wore an accelerometer attached to their right hip. In addition, during the same period, they were prompted every morning, using text messages, to rate their momentary fatigue on a scale from 0 to 10. We found that greater morning fatigue was associated with lower volume and intensity of daily physical activity. Specifically, one point greater on the fatigue scale was associated with 3.2 min less moderate-to-vigorous physical activity per day, which translates into 22 min less moderate-to-vigorous physical activity per week. It can be considered as a clinically significant effect, given that 22 min equates to roughly 15% of the recommended weekly minimum goal of 150 min of moderate-to-vigorous physical activity.[23] Furthermore, attending an exercise session was associated with less moderate-to-vigorous physical activity later that day by 3.7 min compared to days without an exercise session. However, the compensation was limited to the training day and did not impact the following days.[11]

In summary, following low-volume exercise sessions, fit and healthy older adults decreased their non-exercise physical activity later that day. Still, this compensation did not carry over into the next day. It might help to explain why so many previous studies failed to detect any compensation in habitual physical activity despite exposing the participants to a much greater training volume. As those studies compared physical activity before and after the entire training period rather than measuring its day-to-day fluctuations, they could have easily missed the same-day effect of compensation.[11]

The results of our study have important practical implications. As momentary morning fatigue negatively affects daily physical activity,[114] interventions with inappropriately high training volume leading to a substantial increase in state fatigue might result in a prolonged decrease of habitual physical activity, thus blunting the benefits of the training program. Consequently, we suggest that the state level of fatigue should be monitored during intensive interventions, especially in less fit older adults and those with chronic conditions associated with increased fatiguability.

7. Physical activity in times of pandemics

Despite the proven benefits of physical activity and exercise for the elderly and chronically ill, a substantial portion of this population remains physically inactive and refrain from exercise training.[13] This unfavourable situation has been recently worsened by the COVID-19 pandemics and associated measures, such as lockdowns and quarantines that have resulted in limited access to public gyms, swimming pools, etc., and overall reduction of physical activity.[14,115,116] Older adults and the chronically ill are especially vulnerable not only because they have a greater risk of developing severe illness but also because the reduction in physical activity can lead to a deterioration of their physical fitness and potentially result in a long-term worsening of their health status and prognosis.[117–121] Thus, in Study 12, we aimed to explore the effect of a nationwide quarantine in Czechia on accelerometer-assessed habitual physical activity of heart failure patients.

Study 12: Physical activity of heart failure patients during COVID-19 lockdown

We analysed the daily number of steps in heart failure patients during a 6-week period that included three weeks immediately preceding the onset of the quarantine (24 February to 15 March 2020) and the first three weeks of the quarantine (16 March to 5 April 2020). Compared with the three weeks before the onset of the quarantine, their step count was significantly lower during each of the first three weeks of the quarantine. When the daily step count was averaged across the three weeks before and during the quarantine, the decrease amounted to 1134 steps per day, which translated to a 16.2% decrease.[12]

In conclusion, the introduction of the nationwide quarantine due to COVID-19 had a detrimental effect on the level of habitual physical activity in heart failure patients, leading to an abrupt decrease of daily step count that lasted for at least the 3-week study period. Moreover, even after the end of the quarantine, we cannot be sure that patients' physical activity would return to their pre-quarantine levels because not engaging in regular physical activity could quickly become a new habit after three weeks of inactivity. Thus, staying active and maintaining sufficient levels of physical activity during the COVID-19 pandemic, for example, by participating in home-based training programmes, are essential despite the unfavourable circumstances of quarantine.[12]

This study was a collaborative effort of six university hospitals led by Professor Belohlavek from the General University Hospital in Prague. The study was published in the ESC Heart Failure journal and collected 12 citations during the first 12 months since publication.

8. Conclusions

Increasing physical activity in the elderly and chronically ill is a daunting task that requires a complex approach. First, physical activity levels need to be accurately assessed using objective methods, such as accelerometers. However, we found large heterogeneity and a lack of consensus in the methods used for accelerometer data collection, handling, and processing. To overcome this obstacle, we have proposed practical recommendations for using accelerometers in patients with cardiovascular and other chronic diseases to encourage researchers and clinicians to improve the quality and transparency of their reporting (Study 1).[1] Furthermore, we demonstrated that in adults with impaired and slower gait (typical for elderly and chronically ill), consumer-level activity monitors' accuracy deteriorates compared to research-grade accelerometers. Still, most consumer-level monitors perform reasonably well enough to be useful tools that clinicians can use for long-term self-monitoring to motivate their patients to walk more (Study 2).[2]

Second, effective interventions composed of various behaviour change techniques need to be developed based on understanding their target population's needs. We have developed a walking intervention to be delivered in a primary care setting and demonstrated that it is feasible and potentially effective (Study 3).[3] In addition, we identified behaviour change techniques preferred by the intervention participants (i.e., action planning, goal setting, self-monitoring) and common barriers (i.e., time constraints, weather conditions, lack of motivation) that got in the way of increasing their physical activity (Study 4).[4] Finally, we found that complex physical activity interventions that combine self-monitoring using activity monitors with other intervention components provide an additional benefit above and beyond self-monitoring alone (Study 5).[5] Together, these findings were used to design an mHealth intervention to be delivered in general practice to increase physical activity and reduce sedentary behaviour of patients with prediabetes and type 2 diabetes. A large randomised controlled trial assessing the efficacy of this intervention (ENERGISED trial) has recently received funding from the Czech Health Research Council of the Ministry of Health of the Czech Republic.

Third, apart from physical health benefits, increased physical activity can also improve mental health, even in populations without clinically diagnosed mental disorders. For example, we found that simply providing primary care patients with a pedometer and encouraging them to walk more is associated with lower anxiety and depression scores and improved health-related quality of life (Study 6).[6] Furthermore, using the example of severely obese patients undergoing bariatric surgery, we demonstrated that improvements in depressions symptoms are significantly affected by changes in physical fitness (Study 7).[7] Thus, our findings reinforce the importance of physical activity and physical fitness for optimal mental health outcomes.

Fourth, in addition to aerobic physical activity, strength training is an integral part of physical activity recommendations for older adults and adults with chronic conditions. We demonstrated that strength training is a highly effective strategy to improve muscular strength, physical function, and body composition in older adults with pre-/sarcopenia and pre-/frailty (Study 8).[8] Furthermore, we found that plyometric training, previously limited to athletes, is a feasible and safe training option that positively affects muscular strength, jump performance, and physical performance in older adults (Study 9).[9] Finally, we have adapted the method of assisted jumping for use in the elderly and demonstrated its potential to improve various functional characteristics of older adults after just four weeks of training. Besides, following the training period, participants reported increased enjoyment of exercise (Study 10).[10] Thus, we paved the way for future trials of assisted jumping as a novel exercise method that is safe and effective and enjoyable, making it a promising training modality for the elderly and chronically ill.

Fifth, habitual physical activity and structured exercise training can interact due to exercise-induced fatigue, especially in the elderly and chronically ill with increased fatiguability. Indeed, we demonstrated that greater morning fatigue is associated with lower levels of daily physical activity. Furthermore, we found that following low-volume exercise sessions, fit and healthy older adults decreased their non-exercise physical activity later that day (Study 11).[11] Though this compensation was limited to the same day and did not carry over into the next day, we might speculate that with higher training volume and less fit adults, the compensation could last longer, thus blunting the benefits of the training program. Therefore, we suggest that the state level of fatigue should be monitored during intensive interventions, especially in less fit older adults and those with chronic conditions associated with increased fatiguability.[11]

Finally, efforts to combat physical inactivity were recently hindered by the COVID-19 pandemics as the lockdowns and quarantines imposed by the governments further aggravated the lack of physical activity, especially in the most vulnerable populations of the elderly and chronically ill. For example, in Czechia, we found that introducing the nationwide quarantine due to COVID-19 had a detrimental effect on the level of habitual physical activity in heart failure patients, leading to an abrupt decrease of daily step count by approximately 16% (Study 12).[12] Given that physical inactivity is associated with a higher risk for severe COVID-19 outcomes [14], it is critical that every effort is made to support the elderly and chronically ill to stay active and maintain sufficient physical activity levels despite the unfavourable circumstances of COVID-19 pandemics.

References

1. Vetrovsky T, Clark CCT, Bisi MC, Siranec M, Linhart A, Tufano JJ, et al. Advances in accelerometry for cardiovascular patients: a systematic review with practical recommendations. Esc Heart Fail. 2020;7:2021–31.

2. Vetrovsky T, Siranec M, Marencakova J, Tufano JJ, Capek V, Bunc V, et al. Validity of six consumer-level activity monitors for measuring steps in patients with chronic heart failure. Plos One. 2019;14:e0222569.

3. Vetrovsky T, Cupka J, Dudek M, Kuthanova B, Vetrovska K, Capek V, et al. A pedometer-based walking intervention with and without email counseling in general practice: a pilot randomized controlled trial. Bmc Public Health. 2018;18:635.

4. Vetrovsky T, Vetrovska K, Bunc V. A qualitative exploration of the experiences of primary care patients engaged in email counseling meant to increase physical activity. Acta Gymnica. 2019;49:75–82.

5. Vetrovsky T, Borowiec A, Jurik R, Wahlich C, Smigielski W, Steffl Mi, et al. Do physical activity interventions combining self-monitoring with other components provide an additional benefit compared to self-monitoring alone? A systematic review and meta-analysis. Under review.

6. Vetrovsky T, Cupka J, Dudek M, Kuthanova B, Vetrovska K, Capek V, et al. Mental health and quality of life benefits of a pedometer-based walking intervention delivered in a primary care setting. Acta Gymnica. 2017;47:138–43.

7. Vetrovsky T, Fortova T, Conesa-Ros E, Steffl M, Heczkova J, Belohlavek J, et al. Increased Cardiopulmonary Fitness Is Associated with a Greater Reduction in Depression among People Who Underwent Bariatric Surgery. Int J Environ Res Public Health. 2021;18:2508.

8. Talar K, Hernández-Belmonte A, Vetrovsky T, Steffl M, Kałamacka E, Courel-Ibáñez J. Benefits of Resistance Training in Early and Late Stages of Frailty and Sarcopenia: A Systematic Review and Meta-Analysis of Randomized Controlled Studies. J Clin Med. 2021;10:1630.

9. Vetrovsky T, Steffl M, Stastny P, Tufano JJ. The Efficacy and Safety of Lower-Limb Plyometric Training in Older Adults: A Systematic Review. Sports Med. 2019;49:113–31.

10. Vetrovsky T, Omcirk D, Malecek J, Stastny P, Steffl M, Tufano JJ. Overspeed Stimulus Provided by Assisted Jumping Encourages Rapid Increases in Strength and Power Performance of Older Adults. J Aging Phys Activ. 2020;29:259–66.

11. Vetrovsky T, Omcirk D, Malecek J, Stastny P, Steffl M, Tufano JJ. Morning fatigue and structured exercise interact to affect non-exercise physical activity of fit and healthy older adults. Bmc Geriatr. 2021;21:179.

12. Vetrovsky T, Frybova T, Gant I, Semerad M, Cimler R, Bunc V, et al. The detrimental effect of COVID-19 nationwide quarantine on accelerometer-assessed physical activity of heart failure patients. Esc Heart Fail. 2020;7:2093–7.

13. Katzmarzyk PT, Friedenreich C, Shiroma EJ, Lee I-M. Physical inactivity and non-communicable disease burden in low-income, middle-income and high-income countries. Brit J Sport Med. 2021;Published Online First: 29 March 2021. doi: 10.1136/bjsports-2020-103640.

14. Sallis R, Young DR, Tartof SY, Sallis JF, Sall J, Li Q, et al. Physical inactivity is associated with a higher risk for severe COVID-19 outcomes: a study in 48 440 adult patients. Brit J Sport Med. 2021;bjsports-2021-104080.

15. Cooney GM, Dwan K, Greig CA, Lawlor DA, Rimer J, Waugh FR, et al. Exercise for depression. The Cochrane database of systematic reviews. 2013;CD004366.

16. Gillison FB, Skevington SM, Sato A, Standage M, Evangelidou S. The effects of exercise interventions on quality of life in clinical and healthy populations; a meta-analysis. Soc Sci Med. 2009;68:1700–10.

17. Reis RS, Salvo D, Ogilvie D, Lambert EV, Goenka S, Brownson RC. Scaling up physical activity interventions worldwide: stepping up to larger and smarter approaches to get people moving. Lancet. 2016;388:1337–48.

18. Walker RL, Greenwood-Hickman MA, Bellettiere J, LaCroix AZ, Wing D, Higgins M, et al. Associations between physical function and device-based

measures of physical activity and sedentary behavior patterns in older adults: moving beyond moderate-to-vigorous intensity physical activity. Bmc Geriatr. 2021;21:216.

19. Waring T, Gross K, Soucier R, ZuWallack R. Measured Physical Activity and 30-Day Rehospitalization in Heart Failure Patients. J Cardiopulm Rehabil. 2017;37:124–9.

20. GO Dibben, Hillsdon M, Dalal H, Metcalf B, P Doherty, HermannTang L, et al. Factors Associated with Objectively Assessed Physical Activity Levels of Heart Failure Patients. J Clin Exp Cardiol. 2020;

21. Giné-Garriga M, Sansano-Nadal O, Tully MA, Caserotti P, Coll-Planas L, Rothenbacher D, et al. Accelerometer-Measured Sedentary and Physical Activity Time and Their Correlates in European Older Adults: The SITLESS Study. J Gerontol A Biol Sci Med Sci. 2020;75:1754–62.

22. Shoemaker MJ, Tresh T, Hart J, Wood T. Objective Improvement in Daily Physical Activity in Heart Failure Remains Elusive. Cardiopulm Phys Ther J. 2018;29:63–80.

23. Bull FC, Al-Ansari SS, Biddle S, Borodulin K, Buman MP, Cardon G, et al. World Health Organization 2020 guidelines on physical activity and sedentary behaviour. Brit J Sport Med. 2020;54:1451–62.

24. Bellettiere J, Lamonte MJ, Evenson KR, Rillamas-Sun E, Kerr J, Lee I-M, et al. Sedentary Behavior and Cardiovascular Disease in Older Women. Circulation. 2019;139:1036–46.

25. Bellettiere J, Healy GN, LaMonte MJ, Kerr J, Evenson KR, Rillamas-Sun E, et al. Sedentary Behavior and Prevalent Diabetes in 6,166 Older Women: The Objective Physical Activity and Cardiovascular Health Study. J Gerontol A Biol Sci Med Sci. 2018;74:387–95.

26. Jakicic JM, Powell KE, Campbell WW, Dipietro L, Pate RR, Pescatello LS, et al. Physical Activity and the Prevention of Weight Gain in Adults: A Systematic Review. Med Sci Sports Exerc. 2019;51:1262–9.

27. Sink KM, Espeland MA, Castro CM, Church T, Cohen R, Dodson JA, et al. Effect of a 24-Month Physical Activity Intervention vs Health Education on Cognitive Outcomes in Sedentary Older Adults. Jama. 2015;314:781–10.

28. Dipietro L, Campbell WW, Buchner DM, Erickson KI, Powell KE, Bloodgood B, et al. Physical Activity, Injurious Falls, and Physical Function in Aging. Med Sci Sports Exerc. 2019;51:1303–13.

29. Pescatello LS, Buchner DM, Jakicic JM, Powell KE, Kraus WE, Bloodgood B, et al. Physical Activity to Prevent and Treat Hypertension: A Systematic Review. Med Sci Sports Exerc. 2019;51:1314–23.

30. Craig CL, Marshall AL, SJÖSTRÖM M, Bauman AE, Booth ML, Ainsworth BE, et al. International Physical Activity Questionnaire: 12-Country Reliability and Validity. Med Sci Sports Exerc. 2003;35:1381–95.

31. Limb ES, Ahmad S, Cook DG, Kerry SM, Ekelund U, Whincup PH, et al. Measuring change in trials of physical activity interventions: a comparison of self-report questionnaire and accelerometry within the PACE-UP trial. Int J Behav Nutr Phy. 2019;16:10.

32. Sasaki JE, John D, Freedson PS. Validation and comparison of ActiGraph activity monitors. J Sci Med Sport. 2011;14:411–6.

33. Migueles JH, Cadenas-Sanchez C, Tudor-Locke C, Löf M, Esteban-Cornejo I, Molina-Garcia P, et al. Comparability of published cut-points for the assessment of physical activity: Implications for data harmonization. Scand J Med Sci Spor. 2019;29:566–74.

34. Migueles JH, Cadenas-Sanchez C, Ekelund U, Nyström CD, Mora-Gonzalez J, Löf M, et al. Accelerometer Data Collection and Processing Criteria to Assess Physical Activity and Other Outcomes: A Systematic Review and Practical Considerations. Sports Med. 2017;47:1821–45.

35. Migueles JH, Aadland E, Andersen LB, Brønd JC, Chastin SF, Hansen BH, et al. GRANADA consensus on analytical approaches to assess associations with accelerometer-determined physical behaviours (physical activity, sedentary behaviour and sleep) in epidemiological studies. Brit J Sport Med. 2021;bjsports-2020-103604.

36. Reid RER, Insogna JA, Carver TE, Comptour AM, Bewski NA, Sciortino C, et al. Validity and reliability of Fitbit activity monitors compared to ActiGraph GT3X+ with female adults in a free-living environment. J Sci Med Sport. 2017;20:578–82.

37. Degroote L, Bourdeaudhuij ID, Verloigne M, Poppe L, Crombez G. The Accuracy of Smart Devices for Measuring Physical Activity in Daily Life: Validation Study. Jmir Mhealth Uhealth. 2018;6:e10972.

38. Welk GJ, Bai Y, Lee J-M, Godino J, Saint-Maurice PF, Carr L. Standardizing Analytic Methods and Reporting in Activity Monitor Validation Studies. Med Sci Sports Exerc. 2019;51:1767–80.

39. Clark CCT, Barnes CM, Stratton G, McNarry MA, Mackintosh KA, Summers HD. A Review of Emerging Analytical Techniques for Objective Physical Activity Measurement in Humans. Sports Med. 2017;47:439–47.

40. Rowlands AV, Edwardson CL, Davies MJ, Khunti K, Harrington DM, Yates T. Beyond Cut Points. Med Sci Sports Exerc. 2018;50:1323–32.

41. Migueles JH, Rowlands AV, Huber F, Sabia S, Hees VT van. GGIR: A Research Community–Driven Open Source R Package for Generating Physical Activity and Sleep Outcomes From Multi-Day Raw Accelerometer Data. J Meas Phys Behav. 2019;2:188–96.

42. Crowley P, Skotte J, Stamatakis E, Hamer M, Aadahl M, Stevens ML, et al. Comparison of physical behavior estimates from three different thigh-worn accelerometers brands: a proof-of-concept for the Prospective Physical Activity, Sitting, and Sleep consortium (ProPASS). Int J Behav Nutr Phy. 2019;16:65.

43. Maher JP, Rebar AL, Dunton GF. Ecological Momentary Assessment Is a Feasible and Valid Methodological Tool to Measure Older Adults' Physical Activity and Sedentary Behavior. Front Psychol. 2018;9:1485.

44. Degroote L, DeSmet A, Bourdeaudhuij ID, Dyck DV, Crombez G. Content validity and methodological considerations in ecological momentary assessment studies on physical activity and sedentary behaviour: a systematic review. Int J Behav Nutr Phy. 2020;17:35.

45. Giurgiu M, Niermann C, Ebner-Priemer U, Kanning M. Accuracy of Sedentary Behavior–Triggered Ecological Momentary Assessment for Collecting Contextual Information: Development and Feasibility Study. Jmir Mhealth Uhealth. 2020;8:e17852.

46. Montoye AHK, Moore RW, Bowles HR, Korycinski R, Pfeiffer KA. Reporting accelerometer methods in physical activity intervention studies: a systematic review and recommendations for authors. Brit J Sport Med. 2018;52:1507.

47. Klompstra L, Kyriakou M, Lambrinou E, Piepoli MF, Coats AJ, Cohen-Solal A, et al. Measuring physical activity with activity monitors in patients with heart failure. From literature to practice. A position paper from the Committee on Exercise Physiology and Training of the Heart Failure Association of the European Society of Cardiology. Eur J Heart Fail. 2020;

48. Farina N, Lowry RG. The Validity of Consumer-Level Activity Monitors in Healthy Older Adults in Free-Living Conditions. J Aging Phys Activ. 2018;26:128–35.

49. Simunek A, Dygryn J, Gaba A, Jakubec L, Stelzer J, Chmelik F. Validity of Garmin Vivofit and Polar Loop for measuring daily step counts in free-living conditions in adults. Acta Gymnica. 2016;46:129–35.

50. Evenson KR, Goto MM, Furberg RD. Systematic review of the validity and reliability of consumer-wearable activity trackers. Int J Behav Nutr Phy. 2015;12:159.

51. Evenson KR, Spade CL. Review of Validity and Reliability of Garmin Activity Trackers. J Meas Phys Behav. 2020;3:170–85.

52. Toth LP, Park S, Pittman WL, Sarisaltik D, Hibbing PR, Morton AL, et al. Validity of Activity Tracker Step Counts during Walking, Running, and Activities of Daily Living. Transl J Acsm. 2018;3:52–9.

53. Crouter SE, Schneider PL, Karabulut M, Bassett DR. Validity of 10 electronic pedometers for measuring steps, distance, and energy cost. Med Sci Sports Exerc. 2003;35:1455–60.

54. Straiton N, Alharbi M, Bauman A, Neubeck L, Gullick J, Bhindi R, et al. The validity and reliability of consumer-grade activity trackers in older, community-dwelling adults: a systematic review. Maturitas. 2018;112:85–93.

55. Panizzolo FA, Maiorana AJ, Naylor LH, Dembo L, Lloyd DG, Green DJ, et al. Gait analysis in chronic heart failure: The calf as a locus of impaired walking capacity. J Biomech. 2014;47:3719–25.

56. Fokkema T, Kooiman TJM, Krijnen WP, Schans CP van der, Groot MD. Reliability and validity of ten consumer activity trackers depend on walking speed. Med Sci Sports Exerc. 2017;49:793–800.

57. Pedersen BK, Saltin B. Exercise as medicine – evidence for prescribing exercise as therapy in 26 different chronic diseases. Scand J Med Sci Spor. 2015;25:1–72.

58. Bergman P, Grjibovski AM, Hagströmer M, Bauman A, Sjöström M. Adherence to physical activity recommendations and the influence of socio-demographic correlates – a population-based cross-sectional study. Bmc Public Health. 2008;8:367.

59. Lobelo F, Young DR, Sallis R, Garber MD, Billinger SA, Duperly J, et al. Routine Assessment and Promotion of Physical Activity in Healthcare Settings: A Scientific Statement From the American Heart Association. Circulation. 2018;137:e495–522.

60. Orrow G, Kinmonth A-L, Sanderson S, Sutton S. Effectiveness of physical activity promotion based in primary care: systematic review and meta-analysis of randomised controlled trials. BMJ. 2012;344:e1389–e1389.

61. Patel A, Kolt GS, Schofield GM, Keogh JW. General practitioners' views on the role of pedometers in health promotion. J Prim Health Care. 2014;6:152–6.

62. Poppe L, Plaete J, Huys N, Verloigne M, Deveugele M, Bourdeaudhuij ID, et al. Process Evaluation of an eHealth Intervention Implemented into General Practice: General Practitioners' and Patients' Views. Int J Environ Res Public Health. 2018;15:1475.

63. Chaudhry UAR, Wahlich C, Fortescue R, Cook DG, Knightly R, Harris T. The effects of step-count monitoring interventions on physical activity: systematic review and meta-analysis of community-based randomised controlled trials in adults. Int J Behav Nutr Phy. 2020;17:129.

64. Kanejima Y, Kitamura M, Izawa KP. Self-monitoring to increase physical activity in patients with cardiovascular disease: a systematic review and meta-analysis. Aging Clin Exp Res. 2018;31:163–73.

65. Hébert ET, Caughy MO, Shuval K. Primary care providers' perceptions of physical activity counselling in a clinical setting: a systematic review. Brit J Sport Med. 2012;46:625.

66. Schofield G, Croteau K, McLean G. Trust levels of physical activity information sources: a population study. Health Promot J Austr. 2005;16:221–4.

67. National Institute for Health and Care Excellence. Physical activity: brief advice for adults in primary care. NICE public health guidance 44 [Internet]. 2013. Available from: https://www.nice.org.uk/guidance/ph44

68. Normansell R, Smith J, Victor C, Cook DG, Kerry S, Iliffe S, et al. Numbers are not the whole story: a qualitative exploration of barriers and facilitators to increased physical activity in a primary care based walking intervention. BMC Public Health. 2014;14:1272.

69. Wahlich C, Beighton C, Victor C, Normansell R, Cook D, Kerry S, et al. 'You started something … then I continued by myself': a qualitative study of physical activity maintenance. Prim Health Care Res Dev. 2017;18:574–90.

70. Casey M, Hayes PS, Glynn F, ÓLaighin G, Heaney D, Murphy AW, et al. Patients' experiences of using a smartphone application to increase physical activity: the SMART MOVE qualitative study in primary care. Br J Gen Pract. 2014;64:e500–8.

71. Fortune J, Norris M, Stennett A, Kilbride C, Lavelle G, Victor C, et al. Pedometers, the frustrating motivators: a qualitative investigation of users' experiences of the Yamax SW-200 among people with multiple sclerosis. Disabil Rehabil. 2020;1–7.

72. Diefenbach T. Are case studies more than sophisticated storytelling?: Methodological problems of qualitative empirical research mainly based on semi-structured interviews. Quality & Quantity. 2008;43:875–94.

73. Bardach SH, Schoenberg NE. The content of diet and physical activity consultations with older adults in primary care. Patient Educ Couns. 2014;95:319–24.

74. Carroll JK, Antognoli E, Flocke SA. Evaluation of Physical Activity Counseling in Primary Care Using Direct Observation of the 5As. Ann Fam Medicine. 2011;9:416–22.

75. McEwan D, Beauchamp MR, Kouvousis C, Ray CM, Wyrough A, Rhodes RE. Examining the active ingredients of physical activity interventions underpinned by theory versus no stated theory: a meta-analysis. Health Psychol Rev. 2018;13:1–552.

76. Schroé H, Dyck DV, Paepe AD, Poppe L, Loh WW, Verloigne M, et al. Which behaviour change techniques are effective to promote physical activity and reduce sedentary behaviour in adults: a factorial randomized trial of an e- and m-health intervention. Int J Behav Nutr Phy. 2020;17:127.

77. Laranjo L, Ding D, Heleno B, Kocaballi B, Quiroz JC, Tong HL, et al. Do smartphone applications and activity trackers increase physical activity in adults? Systematic review, meta-analysis and metaregression. Brit J Sport Med. 2021;55:422–32.

78. Anokye NK, Lord J, Fox-Rushby J. Is brief advice in primary care a cost-effective way to promote physical activity? Brit J Sport Med. 2014;48:202.

79. Warburton DE, Charlesworth S, Ivey A, Nettlefold L, Bredin SS. A systematic review of the evidence for Canada's Physical Activity Guidelines for Adults. Int J Behav Nutr Phy. 2010;7:39.

80. Conn VS. Anxiety Outcomes After Physical Activity Interventions. Nurs Res. 2010;59:224–31.

81. Rebar AL, Stanton R, Geard D, Short C, Duncan MJ, Vandelanotte C. A meta-meta-analysis of the effect of physical activity on depression and anxiety in non-clinical adult populations. Health Psychol Rev. 2015;9:366–78.

82. Robertson R, Robertson A, Jepson R, Maxwell M. Walking for depression or depressive symptoms: A systematic review and meta-analysis. Ment Health Phys Act. 2012;5:66–75.

83. Harris T, Kerry SM, Limb ES, Victor CR, Iliffe S, Ussher M, et al. Effect of a Primary Care Walking Intervention with and without Nurse Support on Physical Activity Levels in 45- to 75-Year-Olds: The Pedometer And

Consultation Evaluation (PACE-UP) Cluster Randomised Clinical Trial. Plos Med. 2017;14:e1002210.

84. Luppino FS, Wit LM de, Bouvy PF, Stijnen T, Cuijpers P, Penninx BWJH, et al. Overweight, Obesity, and Depression: A Systematic Review and Meta-analysis of Longitudinal Studies. Arch Gen Psychiat. 2010;67:220–9.

85. Gill H, Kang S, Lee Y, Rosenblat JD, Brietzke E, Zuckerman H, et al. The Long-Term Effect of Bariatric Surgery on Depression and Anxiety. J Affect Disorders. 2018;246:886–94.

86. Szmulewicz A, Wanis KN, Gripper A, Angriman F, Hawel J, Elnahas A, et al. Mental health quality of life after bariatric surgery: A systematic review and meta-analysis of randomized clinical trials. Clin Obes. 2019;9:e12290.

87. Morris JN, Hardman AE. Walking to Health. Sports Med. 1997;23:306–32.

88. Moya M, Hernández A, Sarabia JM, Sánchez-Martos MA. Bariatric surgery, weight loss and the role of physical activity: a systematic review. Eur J Hum Mov. 2014;32:145–60.

89. Bellicha A, Ciangura C, Roda C, Torcivia A, Portero P, Oppert J-M. Changes in Cardiorespiratory Fitness After Gastric Bypass: Relations with Accelerometry-Assessed Physical Activity. Obes Surg. 2019;29:2936–41.

90. Amundsen T, Strømmen M, Martins C. Suboptimal Weight Loss and Weight Regain after Gastric Bypass Surgery—Postoperative Status of Energy Intake, Eating Behavior, Physical Activity, and Psychometrics. Obes Surg. 2017;27:1316–23.

91. Izquierdo M, Merchant RA, Morley JE, Anker SD, Aprahamian I, Arai H, et al. International Exercise Recommendations in Older Adults (ICFSR): Expert Consensus Guidelines. J Nutr Health Aging. 2021;25:824–53.

92. Lazarus NR, Izquierdo M, Higginson IJ, Harridge SDR. Exercise Deficiency Diseases of Ageing: The Primacy of Exercise and Muscle Strengthening as First-Line Therapeutic Agents to Combat Frailty. J Am Med Dir Assoc. 2018;19:741–3.

93. Giuliano C, Karahalios A, Neil C, Allen J, Levinger I. The effects of resistance training on muscle strength, quality of life and aerobic capacity in

patients with chronic heart failure — A meta-analysis. Int J Cardiol. 2017;227:413–23.

94. Steffl M, Bohannon RW, Sontakova L, Tufano JJ, Shiells K, Holmerova I. Relationship between sarcopenia and physical activity in older people: a systematic review and meta-analysis. Clin Interv Aging. 2017;12:835–45.

95. Coelho-Júnior HJ, Uchida MC, Picca A, Bernabei R, Landi F, Calvani R, et al. Evidence-based recommendations for resistance and power training to prevent frailty in community-dwellers. Aging Clin Exp Res. 2021;1–18.

96. Ramirez-Campillo R, Moran J, Chaabene H, Granacher U, Behm DG, García-Hermoso A, et al. Methodological characteristics and future directions for plyometric jump training research: A scoping review update. Scand J Med Sci Spor. 2020;

97. Grgic J, Schoenfeld BJ, Mikulic P. Effects of plyometric vs. resistance training on skeletal muscle hypertrophy: A review. J Sport Health Sci. 2020;

98. Eraslan L. Effect of Plyometric Training on Sport Performance in Adolescent Overhead Athletes: A Systematic Review. Sports Health. 2020;

99. Roie EV, Walker S, Driessche SV, Delabastita T, Vanwanseele B, Delecluse C. An age-adapted plyometric exercise program improves dynamic strength, jump performance and functional capacity in older men either similarly or more than traditional resistance training. Plos One. 2020;15:e0237921.

100. Zubac D, Paravlić A, Koren K, Felicita U, Šimunič B. Plyometric exercise improves jumping performance and skeletal muscle contractile properties in seniors. J Musculoskelet Neuronal Interact. 2019;19:38–49.

101. Tufano JJ. Assisted jumping: A possible method of incorporating high-velocity exercise in older populations. Med Hypotheses. 2019;126:131–4.

102. Tufano JJ, Amonette WE. Assisted Versus Resisted Training. Strength Cond J. 2018;40:106–10.

103. Ethgen O, Beaudart C, Buckinx F, Bruyère O, Reginster JY. The Future Prevalence of Sarcopenia in Europe: A Claim for Public Health Action. Calcified Tissue Int. 2017;100:229–34.

104. Xue Q-L. The Frailty Syndrome: Definition and Natural History. Clin Geriatr Med. 2011;27:1–15.

105. Bock J-O, König H-H, Brenner H, Haefeli WE, Quinzler R, Matschinger H, et al. Associations of frailty with health care costs – results of the ESTHER cohort study. Bmc Health Serv Res. 2016;16:128.

106. Hedges LV, Tipton E, Johnson MC. Robust variance estimation in meta-regression with dependent effect size estimates. Res Synth Methods. 2010;1:39–65.

107. Dobbs TJ, Simonson SR, Conger SA. Improving Power Output in Older Adults Using Plyometrics in a Body Mass–Supported Treadmill. J Strength Cond Res. 2018;32:2458–65.

108. Makaruk H, Starzak M, Suchecki B, Czaplicki M, Stojiljković N. The Effects of Assisted and Resisted Plyometric Training Programs on Vertical Jump Performance in Adults: A Systematic Review and Meta-Analysis. J Sports Sci Med. 2020;19:347–57.

109. Tufano JJ, Malecek J, Steffl M, Stastny P, Hojka V, Vetrovsky T. Field-Based and Lab-Based Assisted Jumping: Unveiling the Testing and Training Implications. Front Physiol. 2018;9:1284.

110. Drenowatz C, Grieve GL, DeMello MM. Change in energy expenditure and physical activity in response to aerobic and resistance exercise programs. Springerplus. 2015;4:798.

111. Silva AM, Júdice PB, Carraça EV, King N, Teixeira PJ, Sardinha LB. What is the effect of diet and/or exercise interventions on behavioural compensation in non-exercise physical activity and related energy expenditure of free-living adults? A systematic review. Brit J Nutr. 2018;119:1327–45.

112. Vestergaard S, Nayfield SG, Patel KV, Eldadah B, Cesari M, Ferrucci L, et al. Fatigue in a Representative Population of Older Persons and Its Association With Functional Impairment, Functional Limitation, and Disability. J Gerontol A Biol Sci Med Sci. 2009;64A:76–82.

113. Christie AD, Seery E, Kent JA. Physical activity, sleep quality, and self-reported fatigue across the adult lifespan. Exp Gerontol. 2016;77:7–11.

114. Egerton T, Chastin SFM, Stensvold D, Helbostad JL. Fatigue May Contribute to Reduced Physical Activity Among Older People: An Observational Study. J Gerontol A Biol Sci Med Sci. 2016;71:670–6.

115. Rowlands AV, Henson JJ, Coull NA, Edwardson CL, Brady E, Hall A, et al. The impact of COVID-19 restrictions on accelerometer-assessed physical activity and sleep in individuals with type 2 diabetes. Diabetic Med. 2021;e14549.

116. Caputo EL, Reichert FF. Studies of Physical Activity and COVID-19 During the Pandemic: A Scoping Review. J Phys Activ Health. 2020;17:1275–84.

117. Ahmadi MN, Huang B-H, Inan-Eroglu E, Hamer M, Stamatakis E. Lifestyle risk factors and infectious disease mortality, including COVID-19, among middle aged and older adults: Evidence from a community-based cohort study in the United Kingdom. Brain Behav Immun. 2021;

118. Burtscher J, Millet GP, Burtscher M. Low cardiorespiratory and mitochondrial fitness as risk factors in viral infections: implications for COVID-19. Brit J Sport Med. 2020;bjsports-2020-103572.

119. Courel-Ibáñez J, Pallarés JG, García-Conesa S, Buendía-Romero Á, Martínez-Cava A, Izquierdo M. Supervised Exercise (Vivifrail) Protects Institutionalized Older Adults Against Severe Functional Decline After 14 Weeks of COVID Confinement. J Am Med Dir Assoc. 2020;22:217-219.e2.

120. Lippi G, Henry BM, Sanchis-Gomar F. Physical inactivity and cardiovascular disease at the time of coronavirus disease 2019 (COVID-19). Eur J Prev Cardiol. 2020;204748732091682.

121. Yates T, Razieh C, Zaccardi F, Rowlands AV, Seidu S, Davies MJ, et al. Obesity, walking pace and risk of severe COVID-19 and mortality: analysis of UK Biobank. Int J Obesity. 2021;1–5.