Determinants of Physical Activity in Cardiovascular Disease Secondary Prevention and the Potential for Digital Health Interventions

A global perspective with a particular focus on the Austrian healthcare context

Hannah McGowan

Propositions

Belonging to the dissertation

Determinants of Physical Activity in Cardiovascular Disease Secondary Prevention and the Potential for Digital Health Interventions
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Hannah Christine McGowan

1. Physical activity interventions for individuals with cardiovascular disease that ignore mental health aspects are inadequate in supporting physical activity behaviour *(this dissertation)*.

2. Cardiac rehabilitation needs to shift from time-limited programmes to continuous life-long support *(this dissertation)*.

3. Equitable digital inclusion depends more on societal and systemic factors than individual technical efforts *(this dissertation)*.

4. The design of digital health interventions is not of greater importance than insight into its implementation setting *(this dissertation)*.

5. Measurable behavioural and clinical outcomes require pairing with qualitative, patient-reported findings to paint a complete picture of the effects of health interventions.

6. There is a challenge between creating personalised health promotional interventions and ones that are standardized for use by many people.

7. Regardless of qualitative or quantitative research, a level of reflexivity in terms of the role the researcher plays in their research is crucial.

8. Digital health should target a problem in which technical solutions offer a concrete advantage rather than a re-invention of existing solutions.

9. The future of cardiovascular disease care will be primarily driven by demands for improved advancements in the chronic, long-term support and management of the disease *(impact paragraph)*.

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The research presented in this thesis was conducted at the Ludwig Boltzmann Institute for Digital Health and Prevention and CAPHRI Care and Public Health Research Institute, Department of Health Promotion, of Maastricht University. CAPHRI participates in the Netherlands School of Public Health and Care Research CaRe.

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DETERMINANTS OF PHYSICAL ACTIVITY IN CARDIOVASCULAR DISEASE SECONDARY PREVENTION AND THE POTENTIAL FOR DIGITAL HEALTH INTERVENTIONS

A global perspective with a particular focus on the Austrian healthcare context

DISSERTATION

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CHAPTER 1

General Introduction

1. Introduction

The development and implementation of evidence-based physical activity interventions that target the most common barriers and facilitators to physical activity engagement among individuals with cardiovascular disease is critical in reducing the adverse outcomes of cardiovascular disease. This introductory chapter begins by describing the concern of cardiovascular disease worldwide and the growing need to increase evidence-based modifiable lifestyle interventions. Physical activity is one of the main modifiable behavioural factors for improved cardiovascular health and this chapter provides insight into the determinants (i.e., influencing factors) and motivation of physical activity engagement.

First, chapter one begins by addressing the determinants of physical activity reported within the general population, as this has been extensively explored and provides a foundation to this dissertation. Second, this chapter addresses more recent findings specific to the population of individuals with cardiovascular disease, framing the perspective central to this dissertation. Third, this chapter addresses the increased development of digital health technologies for improved health and behavioural change, such as physical activity promotion and medication management, and the benefits these could serve for individuals with cardiovascular disease. Fourth, this chapter touches on the current challenges regarding the uptake of digital health technologies among patients and healthcare professionals and provides suggestions for encouraging acceptability based on reported facilitators and barriers. Last, this chapter describes the context and outline of this dissertation.

1.1 Definition of terms

This dissertation focuses on the determinants (i.e., factors) that relate to physical activity engagement in the cardiovascular disease population and the potential for digital health technologies to support in the prevention of cardiovascular disease. In this dissertation, determinants refer to factors presenting associations with physical activity and the focus is not on presenting evidence of causality. While this analysis of factors relating to physical activity is guided by an underlying logic of causal relationships in accordance with Bauman et al. (2002) [1], the use of observational data in this dissertation limits the conclusions drawn of a cause-and-effect relationship. Thus, these findings serve as an initial exploration of potentially relevant determinants, which will require further evaluation in different study types (e.g., experimental studies or studies with a temporal sequence, such as longitudinal designs] [1,2]) to better determine their causal relationships with physical activity.

This dissertation includes both *modifiable determinants*—factors that can be changed or controlled at the individual-, social and community-, and regional-, national- and international-level—such as access to healthcare services, the physical and living environment, social networks, individual behaviours, income level, education level, as well as *non-modifiable determinants*—factors that cannot be changed in a behavioural change context, such as age, gender, family history [3]. In this dissertation, the outcome is physical activity engagement and the determinants investigated are those associated with this behaviour. The main determinants addressed in this dissertation are modifiable ones, in which one can intervene upon by means of behavioural change interventions. For non-modifiable determinants, suggestions are provided regarding how behavioural change interventions may best be tailored or situated to support various demographic groups (e.g., older age).

In this dissertation, digital health technologies refer to the range of digital tools (e.g., smartphones, mobile apps, wearables, web-based solutions) used for clinical care in cardiovascular disease. Here the focus is on patient-facing tools (i.e., tools involving direct or indirect patient interaction) rather than tools for use solely between different healthcare providers (e.g., management tool for data-sharing between healthcare professionals). The digital health technologies addressed in this dissertation include those that facilitate communication and engagement with patients; collect and transmit patient-level clinical data; enable sharing and access to electronic clinical data, guided by the American Medical Association definition of digital health [4].

> "Digital health encompasses a broad scope of tools that engage patients for clinical purposes; collect, organize, interpret and use clinical data; and manage outcomes and other measures of care quality. This includes, but is not limited to, digital solutions involving telemedicine and telehealth, mobile health (mHealth), wearables (e.g., Fitbit), remote monitoring, apps, and others"

Additionally, this dissertation situates itself in the secondary prevention of cardiovascular disease due to its focus of individuals with an established cardiovascular disease or following an acute cardiac event (e.g., myocardial infarction). Here, this dissertation follows the clinical definition of secondary prevention defined by the World Heart Federation:

> "**Secondary prevention** targets people with established cardiovascular disease…secondary cardiovascular prevention can be defined as any strategy aimed to reduce the probability of a recurrent cardiovascular event in patients…"[5].

Thus, the impact of this dissertation is principally for individuals in secondary prevention, in particular the self-management phase of cardiovascular disease. Nevertheless, some of the findings of this dissertation may also be relevant for primary prevention (i.e., before a developed cardiovascular condition), particularly chapter five, as it addresses the uptake of evidence-based digital health interventions generally in the cardiovascular clinical context.

1.2 Cardiovascular disease and its growing burden

Cardiovascular disease remains the leading cause of death globally before cancer and respiratory disease [6,7]. It refers to health problems found within the cardiovascular health system, concerning the heart and blood vessels [8]. There are four main categories of cardiovascular disease: coronary artery disease, cerebrovascular disease (incl. stroke), peripheral artery disease and aortic atherosclerosis (incl. aneurysms) [8]. The most common form is coronary artery disease (sometimes called coronary heart disease or ischaemic heart disease), which refers to the narrowing or blockage of the coronary arteries, blood vessels to the heart, often as a result of atherosclerosis, the build-up of fatty material and plaque [8,9]. It accounts for one-third to one-half of all cases of cardiovascular disease and can lead to worsening health outcomes such as myocardial infarction (heart attack) and heart failure [8]. In 2021, it was the largest contributor to cardiovascular disease mortality globally and across European Society of Cardiology (ESC) member states reported in the ESC atlas of cardiology *cardiovascular realities 2024* [7,10].

Despite advancements in medicine and treatment of cardiovascular disease, leading to falls in age-standardized cardiovascular mortality, crude cardiovascular mortality is expected to rise due to a growing prevalence of cardiovascular disease driven mostly by an ageing global population [11]. From

1990 to 2019, cases of total cardiovascular disease nearly doubled from 271 million to 523 million, and number of cardiovascular disease deaths rose from 12.1 million to 18.6 million [12]. Projections from 2025 to 2050 predict an expected 90% increase in cardiovascular disease prevalence, and an expected 35.6 million cardiovascular deaths in 2050 [11]. Moreover, the growing burden of cardiovascular disease on quality of life and physical functioning is evident with global trends reporting years lived with disability doubling from 1990 to 2019 and a 54.7% increase in crude disability-adjusted life years (DALYs) projected between 2025 and 2050 [11,12].

The economic burden of cardiovascular disease is also apparent. Cardiovascular disease is estimated to have cost the European Union 282 billion euros in 2021 with over half of the costs focused on health and long-term care [13]. These costs estimates were predicated based on hospital care (e.g., visits, hospitalisations), medications, social care, informal care, and productivity loss [13]. Many factors are contributing to the rising burden of cardiovascular disease. Besides an ageing population, social-environmental reasons, such as an increase in sedentary jobs relating to longer sitting hours, longer commutes and less leisure time activities are contributing factors to the rising trends of cardiovascular disease [8].

1.3 Global effort to reduce cardiovascular disease mortality and morbidity

Given the predicted increase of cardiovascular disease in the next years, there is an urgent need to reduce the burden of cardiovascular disease. This is reflected in the development of sustainable development goal (SDG) 3.4 by the United Nations (UN) in 2015 in alignment with the 2030 Agenda for Sustainable Development:

> "By 2030, reduce by one third premature mortality from non-communicable diseases through prevention and treatment and promote mental health and well-being" [14].

Despite this agenda, efforts to reduce premature mortality of non-communicable diseases are lagging. A 2025 report of the SDG goals status stated that although premature death due to non-communicable diseases has declined over the years, neither the world nor its regions are on track to meet the sustainable development goal 3.4 of reducing premature non-communicable disease mortality by one third by 2030 [15]. A contributor to this slowing of global health progress was the COVID-19 pandemic, which shortened life expectancy and caused other adverse outcomes [15]. This calls for an even greater need to intensity efforts to address equitable access to care for all individuals to reach this target by 2030 [15].

The European Research Area Network on Cardiovascular disease (ERA-CVD) developed a Strategic Research Agenda (SRA) in 2019 as a call to action to enhance cardiovascular research and implementation of its findings in Europe [16,17]. This call addresses how cardiovascular disease has changed over time and the need to shift attention to match these changes. Specifically, in the last decades, significant improvements in the initial survival of heart attacks or stroke have led to a growing population of patients with chronic cardiovascular disease [16]. Thus, a large focus must shift to improving care of chronic cardiovascular disease and secondary prevention strategies. The SRA suggests key areas of cardiovascular research to advance progress: better prevention and risk detection, new concepts for better treatment and personalised medicine, addressing health care costs through better management, early disease detection, better treatment and care through efforts such as 'Big Data' and e-health technology (e.g., non-invasive simple wearable devices) [16]. In terms of

improved management of cardiovascular disease, the SRA calls for implementation research for the delivery of best practices into clinical care [16].

The European Cardiovascular Health Plan released in 2022 constitutes a development at the European level to reduce premature and preventable deaths in Europe and improve access to high-quality cardiovascular risk assessment and care. Here its emphasis is placed on equitable access, increase in rehabilitation, patient-centred healthcare, and improvement in primary and secondary prevention [18]. The proposed key components include the creation of a European cardiovascular health data knowledge centre, a European Cardiovascular Health Observatory, national action plans, and an incubator and progressive policy environment for digital transformation across Europe [18].

Moreover, the World Heart Federation released a 2023 update describing a roadmap for secondary prevention of cardiovascular disease globally [19]. Here they outlined current roadblocks to secondary prevention at the individual-, healthcare- and policy-level and what actions can be implemented to counteract them. Here, key implementation strategies were suggested that focus on health literacy interventions and supporting self-management (lifestyle behaviour change and medication adherence) at the individual-level; strategies to improve primary health care and hospitals, and strategies to empower healthcare professionals to carry out service delivery at the healthcare-level; accessibility of medication, national policies for secondary prevention and enabling fiscal policies and healthy settings/environments (e.g., community action) at the policy-level [19]. They also mentioned newer implementation strategies, such as digital health interventions for risk factor management, healthcare providers, and cardiac rehabilitation [19].

Furthermore, just newly released by the European Commission as of December 2025, is a European Union published cardiovascular health plan: *the Safe Hearts Plan* [20]. This constitutes a landmark achievement in health policy denoting a strategic response to the European Union's leading health challenge. The plan is centred on three pillars: (1) prevention, (2) early detection and screening, and (3) treatment and care (including rehabilitation) [20]. It aims to support these through the themes of digital innovation, research and knowledge, and confronting inequalities. To do so, it outlines specific initiatives, including increased funding, advancing and promoting research, legislation framework revisions, the launch of European Union protocols and awareness campaigns, and supporting digital health deployment and application [20].

Taken together, these initiatives demonstrate both a global and European effort to reduce the mortality and morbidity of cardiovascular disease. They highlight the need for improved prevention and treatment of cardiovascular disease, and an increasing urgency to support chronic cardiovascular disease care driven by a growing aging population and advancements in acute care.

1.4 Lifestyle modification as primary and secondary prevention of cardiovascular disease

For cardiovascular disease prevention, engagement in healthy lifestyles is crucial. This is due to the nature of cardiovascular disease, which is contributed primarily out of modifiable risk factors. In a large prospective cohort study across 21 countries, modifiable risk factors were found to contribute to over 70% of cardiovascular disease-related cases and deaths [21]. This included behavioural factors (e.g., smoking, diet, physical activity), metabolic factors (e.g., hypertension, diabetes), psychosocial factors (e.g., education and depression symptoms), and environmental factors [21]. Although some of these encompass more traditionally well-established risk factors (e.g., hypertension, diabetes, poor

diet), emerging evidence is underlining the impactful role of environmental exposures, particularly air pollution, on cardiovascular health [22].

The importance of healthy lifestyle behaviours can be depicted in a 2024 systematic review and meta-analysis [23]. Here, it was reported that individuals of the general population with the healthiest combination of lifestyle behaviours—such as exercise engagement, healthy diet, quality sleep, and other health-related habits—had a significant risk reduction of cardiovascular disease and cardiovascular disease mortality by 58% and 55%, respectively [23]. Additionally, those with a cardiovascular disease who adhered to the healthiest combination of lifestyle behaviours showed a significant risk reduction of 62% for cardiovascular disease recurrence and 67% for all-cause mortality, when compared to those with the least healthy combination of lifestyle behaviours [23].

These findings underscore that engagement in healthy lifestyle behaviours are related to improved cardiovascular disease outcome and reduced mortality [23]. As such, lifestyle interventions that target modifiable risk factors may be beneficial in supporting individuals in adopting a healthier lifestyle at both the general population level (primary prevention) and individuals with a diagnosed cardiovascular disease (secondary prevention). This is supported by the notion that engagement of healthy lifestyle behaviours is appropriate and beneficial at any stage of the patient journey and across the lifespan [24].

1.5 Physical activity as a key modifiable behavioural factor

Among modifiable risk factors, physical inactivity plays a particular threat to cardiovascular health. In 2021, 397,000 cardiovascular deaths and 686,000 deaths overall were estimated to be attributable to physical inactivity [25]. Although other risk factors, such as high systolic blood pressure, dietary risks, high low-density lipoprotein cholesterol, air pollution, and smoking rank higher in the attributed burden of cardiovascular disease, low physical activity still plays a critical role [25]. In the aforementioned cohort study of 21 countries, it was found that among behavioural risk factors, physical activity was the second highest risk factor associated with cardiovascular disease, after tobacco use [21]. Moreover, adequate physical activity can positively influence the other highly correlated risk factors of cardiovascular disease, such as high blood pressure, high cholesterol, diabetes, obesity and depression. Two systematic reviews demonstrate that physical activity reduces blood pressure and improves lipid outcomes (e.g., total cholesterol, high-density lipoprotein cholesterol) [26,27]. Here, the greatest reduction in systolic and diastolic blood pressure was found at 150 minutes of aerobic exercise per week [26]. Additionally, exercise shows moderate to large effects on reducing depressive symptoms supporting its beneficial role in improved psychological health [28].

Given the benefits of physical activity for primary and secondary prevention, the World Health Organization (WHO) and the European Society of Cardiology (ESC) recommend the following for good health: 150-300 minutes/week of moderate intensity, or 75-150 minutes/week of vigorous intensity aerobic physical activity (or an equivalent combination of both) and a minimum of twice a week of muscle-strengthening exercise involving all major muscle groups at moderate intensity or greater [24,29]. Moreover, the 2025 ESC Clinical Consensus Statement on mental health and cardiovascular disease underscores the importance of healthy lifestyle changes, including regular physical activity for improving mental health, cardiovascular well-being, risk factors and cardiovascular outcomes [30].

Despite the benefits and health recommendations for physical activity, we currently face a global physical inactivity concern. The WHO global status report on physical activity in 2022 estimated that

80% of adolescents and 27% of the world's adult population do not meet the WHO's recommended levels of physical activity [31]. Additionally, through a pooled analysis of population-based surveys with 5.7 million participants across 163 countries and territories, it was reported that physical inactivity is rising, as observed through an increase in global age-standardised prevalence of insufficient physical activity from 23.4% in 2000 to 31.3% in 2022 [32]. If this trend continues, the global target of a 15% relative reduction between 2018 and 2030 set by the global action plan [33] will not be met for adults [31,32].

Among individuals with cardiovascular disease, for whom physical activity is a recommended secondary prevention measure for the reduction of recurrent events [34], trends of physical inactivity are also concerning. A cross-sectional study in 2016-2017 across 27 countries found that two-thirds (66%) of coronary patients did not achieve their physical activity targets after six months of a coronary artery event or intervention [35]. This represents alarming findings that current lifestyle behaviour guidelines are not met in the general population nor among individuals with a diagnosed cardiovascular condition.

1.6 Challenges of physical activity adherence in the general population

Determinants of physical activity in the general population have been explored extensively over the past 40 years [36–39]. Efforts to understand why some individuals engage in physical activity and others do not has been of high importance for the public health domain and findings have revealed that multiple factors contribute to physical inactivity. These include factors related to the individual- (e.g., psychological), interpersonal- (e.g., social), environment- (e.g., facilities), region or national policy- (e.g., urban planning) and global-level (e.g., economic development) [37].

Although multiple factors contribute to physical inactivity, there are some consistencies found across studies to suggest that certain factors are particularly relevant to physical activity behaviour. A 2012 narrative review of systematic reviews (including reviews from 1999 – 2012) found that self-efficacy and health status were the factors with the strongest evidence influencing physical activity in adults (based on consistent evidence across reviews) [37]. Following that, other consistent factors (based on evidence across at least two reviews) were: age (inversely), male sex, higher income and socioeconomic status, higher intention to exercise, later stages of change (transtheoretical model), perceived effort (inversely), and a higher personal history of physical activity during adulthood [37]. In terms of environmental variables, the main factors related to total physical outcome were proximity to recreation facilities and locations, transportation environments (e.g., pavement and safety of crossings) and aesthetics (e.g., greenness and attractiveness) [37]. Other factors such as policy, societal factors and social norms have shown to contribute to physical activity engagement, but warrant further investigation. Additionally, genetics (including genetic profiles) and evolutionary factors could affect physical activity, but have been less studied [37].

Furthermore, an updated systematic review of reviews from 2017 explored the most relevant personal and environmental factors associated with physical activity [38]. In terms of personal factors, they also reported that self-efficacy had the strongest association with participation in physical activity (in terms of consistent evidence across reviews). Other consistent positive factors were intention to exercise, outcome expectations, perceived behavioural control, and perceived good fitness [38]. Whereas age, bad health and fitness status were consistent negative associations with physical activity participation.

In terms of environmental factors, accessibility to facilities, presence of sidewalks, and aesthetics were consistent positive associations with physical activity participation [38].

Moreover, in an extensive systematic review of systematic reviews funded by the Dutch Ministry of Health, Welfare and Sport, published reviews from 1960-2014 were systematically searched and assessed to provide a synthesis of evidence concerning determinants of physical activity [39]. Among adults, they found positive associations of physical activity for the following factors: general health, goal setting/intention/commitment to planning, self-efficacy/perceived behavioural control, degree of urbanization and urban planning [39]. However, in contrast to findings of the previous reviews, they found null associations with perceived negative consequences/outcome expectancy, and aesthetics. They also noted some determinants specific to different age groups. For example, they reported that among older adults, positive associations were found for employment status, affective judgement/attitudes/beliefs about physical activity and access to recreation and sport facilities, and a negative association found for symptoms/illness/(chronic) conditions [39]. This suggests that some determinants may also be related to the age group of individuals and might call for differences in intervention strategies.

Overall, although many factors contribute to physical activity engagement or disengagement, there are some consistent patterns of key determinants of physical activity across reviews, such as self-efficacy, intention, health status and access/proximity to facilities. These provide good evidence for these determinants as important factors for physical activity and suggest interventions that focus on these constructs, alongside targeting especially vulnerable groups for physical inactivity, may lead to improved physical activity outcomes in the general population.

1.7 Challenges of physical activity adherence among individuals with cardiovascular disease

Although determinants of physical activity have been an area of high exploration in the general population, research into determinants of physical activity in the cardiac population (i.e., individuals with an established cardiovascular disease) are rather limited. As people with cardiovascular disease may have specific needs related to their medical condition, unique factors may affect their engagement in physical activity that are particularly relevant or different to those present in the general public.

One such factor may be the phenomenon known as kinesiophobia - an excessive and irrational fear that physical movement and activity will cause (re)injury or health worsening [40,41]. This phenomenon is highly prevalent among individuals with cardiac conditions. A 2024 meta-analysis and systematic review of 14 studies across six countries found an overall prevalence of 61% among patients with heart disease, with a higher prevalence found in upper-middle income countries compared to high-income countries by 71.8% and 49.9%, respectively [42]. Many risk factors may contribute to kinesiophobia in patients with the most recognized being lower education level, lower monthly income, and anxiety [42]. As long-term disease management can contribute to a greater financial or economic burden (although highly dependent on the country*)* [43], and lower mental health because of negative emotional responses [30], kinesiophobia may serve as a strong barrier to physical activity for individuals with cardiovascular disease, but less so for the general population.

Additionally, unique safety concerns might exist for individuals with cardiovascular disease that could influence their participation in physical activities. For instance, the low availability and accessibility of

automated external defibrillators in public or green spaces [44]. It has been reported that public access automated external defibrillators are in poorly accessible areas between 18-59% of cases or not always available [44]. For someone with an out-of-hospital cardiac arrest, slow access to an automated external defibrillator is life-threatening. This can make it unsafe for someone of high risk for a cardiac arrest to engage in exercise alone outdoors. Furthermore, it may exacerbate fear of exercising and a low sense of safety for high-risk individuals.

Building off these prior points, Fraser et al. (2022) conducted a cross-sectional study of 567 patients with cardiac conditions and reported mental barriers to physical activity engagement including a lack of confidence and anxiety while exercising [45]. Furthermore, health state, such as symptoms (e.g., fluid retention) affected the ability to engage in physical activity. Other barriers such as age and accessibility/cost of facilities were similar barriers to the general population, but with an additional financial barrier noted regarding the need to obtain medical notes to gain access to gyms [45]. On the other side, facilitators of physical activity were related to observed health benefits, both in general health, mental health and specific to cardiovascular components e.g., maintaining weight, improving breathing, and managing comorbidities, such as diabetes [45].

Another cross-sectional survey of 154 patients with heart failure found that higher education, self-efficacy, and motivation were significantly associated with a higher amount of physical activity [46]. In contrast, commonly reported barriers to exercise (as expressed by more than 80% of patients) were: 'suffering from minor injuries', 'other responsibilities', 'family responsibilities', 'feeling physically tired' and 'working long hours' [46]. Socioenvironmental factors related to 'family not interested in exercise' and kinesiophobia referring to 'being afraid of getting hurt through exercise' were expressed less, but still by 69% and 68%, respectively. However, symptoms or severity of disease were not significantly related to physical activity [46].

Overall, there appears to be overlap in the factors relating to physical activity in the general population with people with cardiovascular disease, such as in age, facility accessibility, and self-efficacy. However, certain factors may be unique (or more relevant) to the cardiac population, as for instance kinesiophobia, public availability of automated external defibrillators, sense of safety and reassurance, and additional costs related to the medical condition. As intervention developers rely on identified factors that influence physical activity behaviour in order to develop evidence-based and tailored behavioural change interventions, this warrants further exploration of more systematically synthesised findings and an assessment of their relative importance in this specific population of individuals with cardiovascular disease.

1.8 Motivation for maintenance of physical activity: self-determination theory

The maintenance of heart-healthy physical activity habits is critical for individuals with cardiovascular disease as it may lower mortality risk and reduce hospitalization [47,48]. Motivation plays a key role in physical activity engagement and maintenance, and refers to the energization and direction of behaviour [49]. This definition derives from Deci and Ryan's self-determination theory [49], a well-established theory of human behaviour, that will serve as the theoretical basis for defining and exploring motivation for physical activity in this section, given its extensive application to the field of physical activity behaviour [50–52].

Briefly, self-determination theory is based on the inherent idea that people are naturally intrinsically motivated and orientated towards development and growth [53]. However, in order for healthy development to take place and to be driven to behaviour three basic needs must be met: autonomy (feeling in control), competence (feeling capable), and relatedness (feeling connected to others or having a sense of belonging) [53].

Self-determination theory further stipulates that motivation exists on a spectrum rather than a binary stance of 'exhibiting' or 'lacking' motivation. According to the sub-theory organismic integration theory (OIT), motivation ranges from 'amotivation' (no motivation) to the highest state of self-determined behaviour: 'intrinsic motivation' (engaging in something out of an inherent joy). In between these two end-points lie four different forms of extrinsic motivation varying based on how strongly the behaviour is controlled by external factors (e.g., social approval, punishments, praise) versus internalized factors. Two of these are controlled principally from external factors and thus categorized as *controlled motivation.* These include 'external regulation' and 'introjected regulation'. External regulation is the most-controlled form and refers to engaging in behaviour out of other people's demands, requests, rewards, punishments. Introjected regulation is the second-most controlled form and denotes engaging in a behaviour out of guilt, pressure or contingencies [53]. In contrast, the two remaining forms of extrinsic motivation reflect motivation that is more internalised and thus (together with intrinsic motivation) are categorised under *autonomous motivation* reflecting self-determined forms of motivation. 'Identified regulation', the first one, refers to engaging in a behaviour out of perceived valued benefit of the outcome (e.g., "I eat healthy because it's important to me"). Next, 'integrated regulation', the most autonomously extrinsically-motivated one, stems out of reasons due to the behaviour aligning with an individuals' sense of self or goals (e.g., "a healthy lifestyle is a part of who I am"). Finally, intrinsic motivation is the most autonomous (or self-determined) form of motivation and aligned with an individuals' sense of happiness and satisfaction (e.g., "I eat healthily because I enjoy it") [53]. According to self-determination theory, those individuals exhibiting autonomous motivation (identified, integrated, or intrinsic) and having one's basic psychological needs met are more likely to sustain a behaviour [53].

Self-determination theory has been extensively applied to the study of exercise motivation to understand the role motivation plays in exercise. Overall, consistent evidence supports the role of autonomous motivation and exercise participation. For example, in a longitudinal study that followed individuals from their adolescence to adulthood over six years found autonomous motivation to be positively associated with physical activity at each measured time point over time. In contrast, controlled motivation was only positively associated with physical activity at one time point during late adolescence [50].

Similarly, a systematic review of 66 empirical studies found consistent support of a positive relation between more autonomous forms of motivation and exercise, with controlled forms of motivation showing mixed and inconsistent results [51]. The mixed results of controlled motivation mostly stemmed from the subcategory 'introjected regulation' with results split between positive and null relations with exercise. In terms of overall controlled motivation, no study found a positive association with exercise. Although autonomous motivation in general was positively linked with exercise, for its subtypes (identified, integrated, or intrinsic) it can be difficult to determine the most important one for promoting exercise behaviour, based on mixed findings and likely shared variance between the constructs. However, presently, there is a trend towards identified regulation being more predictive of initial or short-term adoption, and intrinsic motivation more predictive of long-term exercise adherence [51]. Overall, this suggests the importance of autonomous motivation on exercise.

Consistent with the prior findings, a recent systematic review of reviews reported that 80% of articles showed a consistent strong positive relationship between physical activity and autonomous motivation, whereas controlled motivation showed either no or a negative association to physical activity [52]. Here, they found that intrinsic and identified regulation were consistently positively associated with physical activity and regarded as determinants of physical activity (based on strong evidence and consistency across reviews), whereas integrated regulation may be a potential predictor of physical activity (based on current level of evidence) [52].

Overall, these findings demonstrate the importance of the role of autonomous motivation and physical activity maintenance. There are some inconsistencies regarding which subtypes of autonomous motivation are most predictive of physical activity and at what stage of change these are most relevant, which calls for further investigation. However, overall, there is a strong indication that behavioural change interventions should focus on ensuring that individuals identify, resonate and feel in control of the behaviour rather than providing external rewards, punishment, or expectations. Thus, for the target group of an intervention, it is necessary to understand individual values, expectations and interests to ensure that behavioural change interventions align to these, thereby promoting autonomous motivation and in turn sustained behaviour.

1.9 Motivation for physical activity among individuals with cardiovascular disease

Similarly, to the general population, autonomous motivation plays an important role in higher physical activity maintenance for individuals with cardiovascular disease. In a longitudinal study that investigated the roles of self-efficacy and motivation in exercise adherence among 801 patients with coronary heart disease found that autonomous motivation remained a significant predictor of long-term exercise behaviour regulation (one year after hospital discharge), whereas self-efficacy was only a significant predictor for short-term behaviour (six months after discharge) [54]. Self-efficacy also partially mediated the relationship between motivation for exercise and six-month exercise behaviour. Additionally in alignment with prior findings, controlled motivation did not play role in exercise engagement. It was unrelated to exercise behaviour at either timepoint suggesting that autonomous motivation drove exercise behaviour [54].

Similarly, autonomous motivation at the end of cardiac rehabilitation was positively correlated with exercise behaviour at 3- and 6-week follow-ups after the program [55]. Moreover, autonomous motivation predicted exercise behaviour at the 6-week follow-up, although it did not significantly predict behaviour at the 3-week follow-up [55]. This suggests that measuring autonomous motivation may be beneficial in predicting later exercise maintenance and that regular assessments could be performed throughout an intervention or in healthcare to keep track of those patients that may be vulnerable to non-adherence to physical activity engagement. Moreover, it suggests that physical activity interventions or cardiac rehabilitation programs that foster autonomous motivation may encourage maintenance of exercise in the long-term.

Given patients' heart condition, their reasons or motives for engaging in physical activity may differ from those of the general population. For instance, the aforementioned cross-sectional study by Fraser et. al (2022) reported that many patients had goals and aspirations relating to the future after overcoming the event or goals, such as regaining the independence they had before the cardiac event [45]. This type of motivation may be very different to that of a healthy individual who has never

experienced a sudden loss in health quality or physical ability. In such a case, focused interventions which highlight small steps to individuals' regained independence may thus naturally align to a more autonomous type of motivation. Furthermore, goals of prolonging life, living better mentally and physically, and retaining the ability to see friends and family [45] may reflect specific health or age-specific motivations for physical activity. Lastly, reported preferences for participating in physical activity outdoors [45] may suggest priorities of exercising for being in nature or feeling good, rather than simply exercising for the goal of body toning or appearance.

In general, along with tackling the main determinants of physical activity reported in the aforementioned sections, focusing on autonomous motivation in cardiac rehabilitation programs or behavioural change interventions may be important for promoting long-term physical activity engagement. Currently, there is a large focus on increasing self-efficacy for exercise behaviour in cardiac rehabilitation programs, which is important for encouraging adherence, however, future efforts integrating more autonomous motivation strategies may be one avenue to promote maintenance of exercise [54]. To achieve this, it is therefore necessary to understand what topics are relevant to patients with cardiovascular disease, what activities align directly to their autonomous motivational drives, or what intervention strategies may increase autonomous motivation.

1.10 The emergence of digital health technologies for behavioural change

Digital health technologies have increasingly been developed as a potential strategy for supporting individuals in their behavioural change. With the surge of technology in the past two decades, the number of publications relating to technologies for behavioural change has risen drastically and offered new avenues of behavioural change interventions [56]. In terms of trends, mobile apps have been by far the most utilized platform and physical activity, followed by healthy eating, the most targeted lifestyle [56]. So far, goal setting has been the most frequently applied behavioural change technique, followed by self-monitoring, motivation, and feedback to encourage behavioural change [56]. The ability of daily technologies to support such information, communication and feedback structures have changed the way individuals have access to behavioural change interventions and provided new avenues of support.

These digital features can aide individuals in staying on track of lifestyle behaviours, with evidence supporting their positive effect. A 2021 meta-analysis of 28 randomised controlled trial studies found small-to-moderate positive effects on physical activity measures using a mobile app or activity tracker compared to an alternative tracking method [57]. The features that were more effective on physical activity (with moderate effect sizes) were text-messaging and personalisation features [57], suggesting that digital tools can help with reminding individuals of their intended goals and providing tailored feedback to their individual needs and targets.

1.11 Digital health technologies for primary and secondary prevention of cardiovascular disease

In the context of cardiovascular disease where lifestyle behaviour modification plays an important role, digital health technologies hold great potential in improving behavioural adherence and management of risk factors and health condition. Prior evidence suggests that digital health

interventions are effective in improving clinical and behavioural outcomes in primary and secondary prevention, along with health-related behaviours (e.g., physical activity, sedentary behaviour, diet, weight management, medication adherence) [58–60].

A quantitative systematic review that assessed how efficacious mobile phone interventions (text messaging, mobile app and telemonitoring via mobile phones) were on improving clinical outcomes and behaviour in secondary prevention of cardiovascular disease found that the large majority of included studies (79%, 22 of 28) reported improved outcomes [59]. These included aspects of improved overall physical activity (MET-minutes/week), medication adherence, cardiovascular risk factor profile, blood pressure, cholesterol, exercise capacity and quality of life. As such, mobile health (m-health) may be beneficial in providing monitoring and support for patients managing their cardiovascular disease [59]. However, in this review, no significant differences were found between the experimental and control groups in terms of major clinical outcomes, namely, mortality, number of hospitalisations or days in hospital. Thus, the efficacy of m-health interventions on these major clinical outcomes requires further exploration.

Another systematic review and meta-analysis that encompassed a broader range of digital tools – telemedicine, web-based strategies, email, mobile phones, apps, text messaging, and monitoring sensors – reported benefits of digital health interventions on cardiovascular disease outcomes [60]. Here it was found that digital health interventions significantly reduced cardiovascular outcomes (which included events of myocardial infarction, stroke, revascularization, hospitalisations, and all-cause mortality) [60].

Besides the behavioural and clinical outcomes, digital health interventions may present financial benefits for the health system. In a systematic review of 14 studies, all included studies found the digital health interventions to be cost-effective, either in terms of gained quality-adjusted life years with cost savings *or* gained quality-adjusted life years at a higher cost, but at an acceptable incremental cost-effectiveness ratio [61].

Reasons behind the effectiveness of digital health interventions may be due to the support and guidance they can provide to individuals over the patient journey. This is reflected by findings reporting that the digital features most associated with positive health outcomes are higher frequency of messages, two-way communication, tailored advice, and use of multiple modalities [59]. The features that tend to keep individuals engaged and active in their disease management related to better health outcomes. Moreover, given the time constraints of healthcare professionals, it is often difficult to achieve this level of consistent, tailored and attentive care in the acute or out-patient setting, which is why evidence-based digital health interventions may serve great potential for healthcare.

Overall, these findings show support for the utilization of digital health technologies in cardiovascular prevention. It may help to alleviate the burden of adverse outcomes, improve quality of life and reduce the financial strain of cardiovascular disease on the healthcare system.

1.12 Challenges to digital health technology uptake for cardiovascular disease

Despite the potential for digital health technologies to aide patients in the prevention and management of cardiovascular disease, digital health remains slow to uptake. Reasons for low

implementation in clinical care are multifaceted. In 2019, the European Society of Cardiology (ESC) published a position paper addressing the barriers to the implementation of digital health in cardiovascular medicine [62]. Broadly, the main barriers to implementation encompassed stakeholder resistance (including patient and provider barriers), legal, ethical and technical barriers (e.g., privacy, security, liability concerns and lack of interoperability), as well as other barriers relating to lack of digital health-based care economical evaluations and reimbursement [62].

Subsequently, in 2022, the World Heart Federation released a roadmap for Digital Health in Cardiology [63]. They outlined the most prevalent roadblocks towards the implementation of digital health intervention across four specific domains: the health system, the health workforce, patient level, and the technological side of the digital health intervention [63]. These spanned areas of lack of national guidelines (e.g., on eHealth and data security), evaluation standards, unclear reimbursement pathways, poor infrastructure at the health system level to individual barriers of digital (il)literacy and low acceptability (including trust and safety perception) at the patient and health workforce level to poor design, usability, interoperability and contextualisation at the technological level [63].

Furthermore, the American Heart Association released a scientific statement in 2025 calling for technologies promoting heart healthy behaviour change to be implemented with an equitable lens to ensure beneficial outcomes across diverse populations [64]. In this context, it outlined specific considerations for promoting equity across multiple levels of influence, namely, the individual, interpersonal, community and societal level. It stressed that technologies need to be perceived as acceptable, appropriate and usable by groups, and that engaging the targeted communities that the technology should support is essential throughout the development and testing process [64].

These statements highlight that the implementation of digital health interventions occurs at varying levels of influence and depicts the complexity towards the adoption of digital health interventions in cardiovascular care. Furthermore, they mirror the complexity depicted in technology implementation frameworks in healthcare, such as Greenhalgh's NASSS framework for studying non-adoption of promising technologies [65]. Here, the NASSS framework explores this through seven domains: (1) the health condition; (2) the technology; (3) the value proposition; (4) the individuals intended to adopt the technology; (5) the healthcare organization; (6) the wider system (incl. political, sociocultural); (7) adaptation over time – how each of the previous six domains evolve over time [65].

Overall, further research calls for exploration into these different levels of influence and insight into what steps can be done to optimize and ensure evidence-based digital health interventions are integrated properly into cardiovascular care. The sub-sections below address the challenges for uptake related to two main stakeholder groups, namely patients and healthcare providers.

1.12.1 Challenges related to patients

As addressed before, patient level barriers to digital health interventions pose a great problem to their success. As patients are among the main stakeholders that will use and engage with digital health, their perspectives and views are critical to ensure the potential and effectiveness of digital health interventions for improved patient care [66].

However, as aforementioned, patient acceptability is low and suboptimal. This is especially true for vulnerable populations, who have often been underrepresented in digital health solutions (e.g., older adults, people with disabilities, people from cultural and linguistic minorities) [66]. A reason for this phenomenon may be that digital health is often developed from a technological side and designed

without the perceptions and needs of patients, especially those of vulnerable groups, in the development process [66,67]. This can be reflected by the main patient barriers towards uptake of digital health technology in cardiovascular care presented in a systematic scoping review [68]. In this review, they reported that among the most frequent barriers to uptake were difficulty using technology, fear of technology, feeling that care through digital health technology was impersonal, older age and lack of interest, followed by cognitive impairment, technical problems and feeling it as time consuming [68]. These reflect that digital health technologies are not well-aligned to patient interests and needs, nor is trust ensured in the technology. Additionally, another main barrier to uptake reported in the review was a poor internet connection [68] reflecting infrastructure barriers and a need to either ensure that the digital health technology is accessible to all or additional resources are provided to patients.

In the domain of cardiovascular disease, where individuals are often older-aged and present multiple morbidities, the understanding of patient needs is critical. In the context of digital health this is of utmost importance because of a concerned digital divide, i.e., the concern that older patients may be left behind in the advancements of newer technologies and thus not receive equitable care [69,70]. As such, it is essential that interventions are designed appropriately for this population and strategies are in place to improve the digital inclusion of older adults [69]. Furthermore, in terms of lifestyle behaviours, such as physical activity, where individuals with cardiac conditions may present specific fears [42], tailored digital features are crucial to promote their adoption.

1.12.2 Challenges related to healthcare professionals

Similar to patients, healthcare providers are key stakeholders of digital health interventions, but serve different roles. They often fulfil the role of gatekeepers and implementers of digital health interventions for patient care meaning they play an important role for either the adoption or rejection of digital health interventions [71]. Given their low acceptability of digital health technologies, this similarly reflects a misalignment in the development and implementation process where their perceptions and needs are not well integrated. Generally, healthcare providers are understudied in their role as stakeholders in digital health technologies [71].

A recent umbrella review explored healthcare professional barriers and facilitators to digital health technology use across various health conditions and reported key barriers to use [72]. These included infrastructure and technical barriers, psychological and personal issues, and concerns of increasing working hours or workload [72]. Among the personal and psychological barriers, this encompassed resistance to change, negative perceptions of technology (e.g., fear of technology, scepticism), challenges with usability (e.g., difficultly understanding technology, low literacy), perception of less human interaction, and demographic factors, such as age, education levels, and professional experience [72].

Similarly, in another review, focused specifically on cardiovascular care, the most frequent barriers reported by clinicians were increased work and responsibilities, unreliable technologies/lack of evidence supporting them, lack of integration with electronic medical records, data privacy and security concerns, financial concerns, and feeling that digital health technology-delivered care was impersonal [68]. Interestingly, in this review, in comparison to 25 studies reporting patient-level barriers, only six studies reported clinical-level barriers [68]. This may reflect in the cardiovascular care domain that clinician-level barriers to digital health technology are less explored or developed, thus requiring further investigation.

Nevertheless, these findings suggest that digital health technologies are often not developed in the correct context that healthcare providers work in, nor is their evidence and components well understood by healthcare providers. This calls for better investigation into the needs and perspectives of healthcare providers. Specifically in the domain of cardiovascular disease, with the rapid expansion of digital health technologies focused on prevention and management of cardiac conditions, there is a great need to further explore healthcare provider perceptions within this specific clinical context.

1.13 Aim of this dissertation

This dissertation has two main aims: to (1) identify the main determinants (i.e., influencing factors) and motivating reasons for physical activity behaviour among individuals with cardiovascular disease (2) explore patient and healthcare provider needs and perspectives of digital health technologies to understand their potential and role in secondary prevention of cardiovascular disease, as well as the factors influencing uptake and implementation in the cardiovascular clinical context. Together these two aims provide suggestions for the design and implementation of (digital) physical activity interventions targeted at the cardiac population (i.e., individuals with cardiovascular disease).

1.14 Context of this dissertation

The publications that make up the scope of this dissertation stem out of my employment at the Ludwig Boltzmann Institute of Digital Health and Prevention (LBI-DHP) in Salzburg, Austria. The LBI-DHP is a research institute funded by the Ludwig Boltzmann Gesellschaft (LBG) that was tasked to tackle the growing concern of cardiovascular disease in Austria, as well as worldwide. It has a seven-year funding plan (2019-2026) to investigate how digital technologies can support heart-healthy physical activity in individuals with cardiovascular disease, high-risk individuals and the general population [73]. With its specific mission to develop, evaluate and implement digital health interventions [74], much of the research has been focused on the Austrian healthcare context.

For context of secondary prevention of cardiovascular disease in the Austrian healthcare context, cardiac rehabilitation consists of concrete phases: (phase I) early in-hospital mobilization after an acute event; (phase II) four-to-six weeks of in- or out-patient rehabilitation; (phase III) 6-12 months of out-patient rehabilitation to assure sustainability of the results achieved during phase II; (phase IV) lifelong adherence to lifestyle behaviours lying in the responsibility of the patient [75,76].

Thus, the context of this dissertation falls into this clinical landscape with two of the four studies in this dissertation reflective of the Austrian healthcare system—consisting of study participants who had completed phase II of cardiac rehabilitation in Austria—, and the other two studies relating to the international level.

1.15 Outline of this dissertation

This general introduction chapter brought attention to the global crisis of cardiovascular disease and the importance of physical activity adherence as a key modifiable behavioural factor for individuals with cardiovascular disease. It provided an introduction into the challenges of adhering to physical

activity and highlighted the need to identify the factors influencing physical activity specifically in the cardiac population, as individuals with cardiovascular disease might present unique challenges to physical activity engagement that are less relevant or different to those of the general public. Furthermore, this introduction presented the potential of digital health interventions to support cardiovascular disease prevention. It highlighted the current state of evidence in terms of its benefits, as well as the current challenges of low acceptability of evidence-based digital health interventions by healthcare providers and patients hindering its potential. Lastly, the introduction provided initial reasons for the low acceptability based on reported barriers in literature and emphasised that to move forward it is paramount to understand patient and healthcare provider needs, perceptions and views of digital health interventions.

The following (four) chapters each present a study that was conducted to address the two main aims of this dissertation. Chapter two introduces a systematic review that identifies and reports the associated strength of determinants of physical activity among individuals with cardiovascular disease at an international level. Chapter three presents a primary study using a cross-sectional study design to explore physical activity behaviours, preferences and motivation in long-term secondary prevention among former cardiac rehabilitation participants in the Austrian healthcare context. Chapter four further presents a similar cross-sectional study, but investigates digital technology perceptions and usage in daily life and physical activity among a different sample of former cardiac rehabilitation participants in the Austrian healthcare context. Chapter five concludes with a systematic review that identifies the most prevalent factors influencing the uptake of digital health interventions in the cardiovascular clinical context from the perspectives of healthcare providers across primary studies at a global level.

Lastly, chapter six provides a general discussion of the main findings and implications of each chapter and how they relate to the overall aim of this dissertation.

Presented below is a brief description of each upcoming chapter.

Chapter 2: Determinants of physical activity behaviour among individuals with cardiovascular disease: a systematic review

Individuals with cardiovascular disease often have difficulty adhering to the physical activity guidelines in secondary prevention, even among those that participated in cardiac rehabilitation programs, where they learned about the importance of physical activity. It is therefore warranted to gain insight into the determinants i.e., factors that influence their engagement in physical activity in secondary prevention, which could aide with developing interventions targeted for this stage of the patient journey.

This chapter provides a broad overview of the determinants of physical activity among cardiovascular patients across a wide range of samples. Here, the application of a systematic review allows for a comprehensive and systematic synthesis of determinants of physical activity engagement in secondary prevention of cardiovascular disease that reflects samples across different countries and over years.

The aim of this chapter is to identify and collate determinants of physical activity among individuals with cardiovascular disease and to determine their relative importance based on quantifiable measures of association. Here, included primary studies were those focused on the secondary prevention (specifically self-sustained, maintenance stage) including former cardiac rehabilitation, post-acute event or general samples of individuals with cardiovascular disease. By including studies reporting bivariate association statistics, this review could synthesis the quantifiable strength of the

associations (determinants and physical activity engagement) and the frequency of reported determinants across all included studies. As such, this review highlights the determinants that emerge consistently associated to physical activity engagement in the cardiac population. These provide evidence of the most relevant determinants of physical activity for this population and provides suggestions for what factors interventions should focus on based on these identified determinants.

Chapter 3: Exploring physical activity preferences and motivation in long-term cardiac prevention: An Austrian cross-sectional study

The focus of this chapter is to gain insight into the determinants, motivating reasons and preferences of physical activity engagement in an Austrian sample of individuals with cardiovascular disease. Former phase II cardiac rehabilitation participants were recruited from five centres to participate in this cross-sectional study. The aims of this study were to (1) understand the main determinants of physical activity engagement among this sample (2) gain insight into their preferences for type and preferred location of physical activity (3) understand the role motivation plays in long-term maintenance using the self-determination theory as a framework (4) highlight the most frequently reported motivating factors. These collected aims are geared towards providing recommendations for physical activity interventions for such a sample. This adds to the above-mentioned systematic review by providing perspectives from the Austrian context, as no published studies from Austria had been identified in the literature search for the systematic review.

Chapter 4: Use and perceptions of digital technology for daily life, physical activity and health information among former cardiac rehabilitation patients in Austria: A cross-sectional study

Digital health technologies, such as apps and wearables hold great promise for improving the adherence of lifestyle modification behaviours, such as physical activity in cardiovascular disease secondary prevention. However, their potential is only relevant based on their use and perceived benefit by individuals with cardiovascular disease.

This chapter explores the usage and patient-reported perceptions of digital technologies among a sample of former cardiac rehabilitation participants in Austria. Using a cross-sectional design, this exploratory study provides insight into technology behaviours, and barriers and facilitators to technology use in a primarily older-aged sample of individuals with cardiovascular disease. The main aims of this study were to (1) gain insight into the use (frequency and type) of digital technology in the daily lives, physical activity engagement and health information habits of former cardiac rehabilitation participants (2) compare these patterns with those of the general Austrian population to highlight similarities and differences (2) explore patient understanding of data privacy regulations (3) highlight the main reasons why patients do or do not use digital technology in their maintenance of physical activity. Overall, this chapter provides insight into patient needs and preferences for digital health technologies in secondary prevention, which constitute important points of reference for technology design.

Chapter 5: Factors influencing the uptake of digital health interventions for cardiovascular disease prevention among healthcare providers: a systematic review

Besides patients, healthcare providers are key stakeholders for digital health interventions through their position to introduce, recommend and support patients in using digital health technologies. Their insights are valuable to understanding what factors facilitate or hinder a successful uptake of digital health interventions in clinical practice.

This chapter explores this on a global scale through a systematic review approach. Here, the main aims are to (1) understand barriers and facilitators of digital health intervention adoption from the perspectives of healthcare providers (2) provide a comprehensive collection of perspectives by including a wide breath of evidence, namely, qualitative, quantitative and mixed method studies (3) identify the most important barriers and facilitators by presenting their frequency across the number of included studies (4) compare these factors across income level of country to assess if barriers and facilitators differ based on country income level (5) recommend strategies for implementation in clinical practice based on these collated findings.

Chapter 6: Discussion

This chapter provides a general discussion reflecting on the results of the prior chapters. It reports on the main findings and implications from these studies. Based on these findings and extant literature, it provides recommendations for the design and implementation of (digital) health interventions for encouraging physical activity behaviour in cardiovascular disease secondary prevention. Lastly, it reports on the limitations of these studies and future directions for research.

CHAPTER 2

Determinants of physical activity among individuals with cardiovascular disease: a systematic review

Chapter 2: Determinants of physical activity behaviour among individuals with cardiovascular disease: a systematic review

This chapter is currently under review at the European Journal of Cardiovascular Nursing:

McGowan, H., Gutenberg, J., Mayr, B., Sareban, M., Niebauer, J., Crutzen, R., Kulnik, S.T (2025). Determinants of physical activity among individuals with cardiovascular disease: a systematic review. ***Under review*** at the European Journal of Cardiovascular Nursing.

Abstract

Aim: Despite the well-established benefits of physical activity (PA) for individuals with cardiovascular disease (CVD), adherence to PA is challenging after completing a cardiac rehabilitation programme. This study aimed to synthesise observational data on the determinants for PA in individuals with CVD, to inform behaviour change research and intervention development in CVD secondary prevention.

Methods and results: This systematic review included studies published from 2005 to 2025, reporting bivariate association statistics for determinants of PA in adults fulfilling the medical indications for cardiac rehabilitation. Five electronic databases (CINAHL, Embase, MEDLINE/PubMed, PsycINFO, Web of Science Core Collection) were searched. Risk of bias was assessed using the National Heart, Lung, and Blood Institute's Study Quality Assessment Tool for Observational Studies. Data were analysed using descriptive analysis and narrative synthesis. Seventy studies from 29 countries were included. Forty-one studies were rated good quality, and 29 fair. Evidence for 56 determinants and their associations with PA was synthesised. Self-efficacy, life attitude, intention for PA, exercise belief, education level, adaptation to weather, (prior) exercise behaviour, habit formation, knowledge/information, social support, psychological wellbeing, and employment showed positive associations. New York Heart Association class, history of heart disease, comorbidity, age, alcohol consumption, arterial hypertension, fatigue, pain, frailty, loneliness, emotion (including kinesiophobia), depression, and family (responsibility) circumstances showed negative associations.

Conclusion: Developers of behaviour change interventions may draw on these identified determinants for PA in individuals with CVD. Further research in underrepresented geographic regions, and studies into underrepresented determinants and dynamic changes of PA behaviours over time are warranted.

Registration: International Prospective Register of Systematic Reviews (PROSPERO) CRD42020206637

Background

Cardiovascular disease (CVD) is the leading cause of premature death and disability worldwide, accounting for approximately 19.8 million deaths in 2022 [77]. Disability-adjusted life years of ischaemic heart disease have declined over the past three decades, but remains the leading cause of disease burden in over 50-year-olds [78], and the global prevalence of CVD and its associated burden, in terms of health and socio-economically, are currently rising due to aging populations [79,80]. Various modifiable risk factors (e.g., smoking, physical inactivity) are linked to an unhealthy lifestyle and contribute to CVD. A recent epidemiological study including 155,000 participants across 21 high-, middle-, and low-income countries found that modifiable risk factors account for approximately 70% of CVD-related cases and deaths [21].

Physical inactivity is one of the most detrimental modifiable cardiovascular risk factors, yet heart-healthy physical activity (PA) levels remain considerably lower than recommended [81,82]. The World Health Organization and international medical guidelines currently recommend 150-300 minutes of moderate-intensity or 75-150 minutes of vigorous-intensity PA (or an equivalent combination of both) per week for the prevention and treatment of CVD [24,29].

Exercise-based cardiac rehabilitation programmes educate and guide individuals with CVD to be physically active as part of secondary prevention. The concept of cardiac rehabilitation refers to interventions that mitigate the impact of underlying cardiac diseases (i.e., minimise morbidity and mortality risk) and restore physiological, psychological, and societal functioning [83–85]. The well-established health benefits of PA in individuals with CVD underline the importance of PA among this population [86]. For instance, total mortality reduction, fewer event incidences, and reduced rehospitalizations were reported clinical endpoints of exercise among individuals with coronary artery disease [86]. Moreover, improvements in cardiopulmonary fitness and quality of life have been found with exercise training among patients with heart failure with preserved ejection fraction (HFpEF), as well as on the combined outcome of all-cause mortality or all-cause hospitalization after adjusting for relevant predictors among patients with heart failure with reduced ejection fraction (HFrEF) [86].

Despite these reported improvements, challenges remain in maintaining heart-healthy PA behaviour after completing a cardiac rehabilitation programme [34,87]. A survey including 8,261 patients with coronary artery disease from 27 European countries found that 6-24 months after a cardiac event, only 35% of the respondents engaged in ≥150 minutes per week, whilst only 16% of the respondents performed vigorous PA for ≥60 minutes per week [35]. This reflects a general and urgent need for effective measures to increase PA levels in the long-run and thereby reduce the risk of recurring cardiovascular events and premature death in individuals with CVD.

Exploration into the determinants of PA behaviour has been observed extensively in the general population. Although many factors contribute to PA behaviour, reviews of reviews have identified several consistent determinants of PA, including self-efficacy, intention to exercise, health status and access to facilities [37,38].

Reasons for low levels of PA after cardiac events are also diverse. Previous studies suggest that determinants such as health beliefs [88–90], health conditions and comorbidities [91–93], health literacy [94,95], illness cognition [96–98], and socio-demographic characteristics [45,99,100] impact PA behaviour in the CVD population. However, the lack of a collated synthesis of determinants through a formal review has made it difficult to determine the key determinants for PA in this cohort.

Intervention developers rely on identified factors that influence PA behaviour in order to develop evidence-based and tailored behaviour change interventions. Many previous studies have collected

quantitative data on various determinants of PA in the CVD population. Yet, no systematic reviews and meta-analyses have been performed to provide collated insights on the quantified associations between determinants and PA behaviour. Therefore, this systematic review aimed to collect and analyse observational data on the relative importance of determinants for heart-healthy PA levels in individuals with CVD, to inform behaviour change research and intervention development in long-term secondary CVD prevention.

Methods

This systematic review aimed to identify and report on studies that collected observational data quantifying the associations between determinants and PA behaviour among individuals with cardiovascular disease. The objectives were to (1) identify relevant determinants of PA behaviour among individuals with cardiovascular disease; and (2) to describe the strength of the associations between the identified determinants and PA behaviour. Taken together, these findings inform behaviour change research and the development of interventions that promote heart-healthy PA behaviour among individuals with cardiovascular disease in long-term secondary prevention.

This article follows the Preferred Reporting Items of Systematic Reviews and Meta-analysis (PRISMA) statement [101]. The PRISMA checklist is appended in Additional File 1.

Protocol and registration

The full protocol for this systematic review has been published elsewhere [102]. The review was registered with the International Prospective Register of Systematic Reviews (PROSPERO, registration number CRD42020206637).

Eligibility Criteria

Search domains

The search domains comprised of population, determinants of PA, and outcome behaviour (PA).

Population

This systematic review included adults aged 18 years or over, fulfilling the medical indications for cardiac rehabilitation [24,76,81,103,104] (e.g., acute coronary syndrome, bypass surgery, heart failure etc). The rationale for defining the population description by these medical indications for cardiac rehabilitation is that those imply an evidence-based recommendation for individuals with CVD to carry out heart-healthy PA as part of their lifelong secondary CVD risk prevention. As we were interested in this general self-sustained, maintenance stage of secondary prevention, we deliberately did not include studies which assessed PA behaviour during or immediately after a formal cardiac rehabilitation programme or intervention (i.e., PA behaviours pre and post cardiac rehabilitation). Instead, we focused on studies which assessed PA behaviours weeks or years after a cardiac rehabilitation programme or an acute cardiac event. Despite this, the findings may also offer insights relevant to formal cardiac rehabilitation programmes or the immediate post-acute phase.

Determinants

Determinants of PA behaviour include non-modifiable (e.g., demographics, comorbidity) and modifiable (e.g., cognitive, health behaviour) aspects. Authors use various terminology to describe such determinants, e.g., barriers, causes, contributors, determinants, facilitators, factors, mediators, predictors. This broad range of terms was included in the search strategy to account for authors' differing terminology.

Outcome behaviour

Outcome data regarding PA behaviour included both self-reported (subjective) and tracked (objective) PA data. Self-reported data refers to information provided by self-completion of a questionnaire or by answering questions posed by a researcher or healthcare professional. Tracked data refers to data collected through sensor devices, e.g., acelerometers, pedometers, smartphones.

Different outcomes describing individuals' average or regular levels of PA (e.g., daily/weekly minutes of moderate and vigorous PA) were considered as well as descriptions of dynamic subbehaviours of PA over time (e.g., increasing, reducing type of PA). Outcomes describing attendance at, or completion of cardiac rehabilitation programmes were excluded, as these are not representative of ongoing, habitual and independent heart-healthy PA behaviour.

Additional criteria

This review included only studies that either reported bivariate associations statistics and their 95% confidence intervals, or that presented data which allowed the calculation of such association statistics and their 95% confidence intervals. For instance, the calculation of Cohen's d and its 95% confidence interval was performed in R studio (R 4.2.1) using the function cohen.d.ci() from the R package psych [105] with the point estimate following the standard definition from Cohen [106], and the confidence interval based on the usual variance approximation [107]. The 95% confidence interval for correlation coefficients was computed using the Fisher z-transformation [108] for Pearson's correlation, and following Bonnett and Wright (2000)'s approach for Spearman's correlation [109]. Odds ratio was calculated by dividing the odds of the event in the exposed group by the odds of the event in the unexposed group and its 95% CI was computed using a standard error and confidence interval formula for odds ratios [110,111].

Cross-sectional and longitudinal observation studies were included. 'Usual care' control groups from experimental studies were also eligible. Included were peer-reviewed journal articles published in English, Dutch, or German (representing the languages spoken by the author group) since 2005. The publication data for included studies was set from 2005 onwards, to reflect more up-to-date care approaches in the secondary prevention of cardiovascular disease, and subsequently the healthcare and socio-cultural contexts of more recent care pathways.

Information sources

Five bibliographic databases were used: Cumulative Index to Nursing and Allied Health Literature (CINAHL), Excerpta Medica dataBASE (Embase), Medical Literature Analysis and Retrieval System Online (MEDLINE via PubMed), PsycINFO, and Web of Science Core Collection.

Search strategy

The search strategy is provided in the Additional File 2. The search was first conducted in August 2020 (last date of search 20.08.2020) and subsequently updated in April 2023 (last date of update search 27.04.2023) and in March 2025 (last date of update search 26.03.2025).

Study selection process

The search strategy is provided in the Additional File 2. The search was first conducted in August 2020 (last date of search 20.08.2020) and subsequently updated in April 2023 (last date of update search 27.04.2023) and in March 2025 (last date of update search 26.03.2025).

Data extraction

Data extraction was conducted in parallel and independently by pairs of reviewers (RC, JG, STK, HM, BM, MS) to ensure high accuracy. The following data were extracted: authors, journal, study title, language, year of publication, study aim, study design, sample description (characteristics and size), setting and study country, determinants, method(s) of assessing determinants (e.g., validated questionnaire), type of PA behaviour, PA behaviour assessment method(s), timepoint or follow-up period since hospitalisation or cardiac rehabilitation, effect sizes for associations between determinants and PA behaviour, i.e., correlation coefficient (r), odds ratio (OR), and Cohens'd (d), as well as their 95% confidence interval. When no bivariate effect size and/or 95% confidence interval was reported, it was calculated from the available data whenever possible using RStudio (2022.07.2).

Quality assessment

Pairs of reviewers (RC, JG, STK, HM, BM, MS) independently rated the methodological quality of all included studies using the National Heart, Lung, and Blood Institute's (NHLBI) Study Quality Assessment Tool for Observational Studies [112] (Additional File 3). Disagreements between two reviewers were discussed and, if necessary, resolved by a third reviewer.

Data synthesis

Descriptive analysis and narrative synthesis were conducted. Due to the heterogeneity of included studies with regard to participant characteristics a quantitative synthesis (meta-analysis) was not performed.

The descriptive analysis was conducted using text and tables to present for each individual determinant, the corresponding study, sample size, PA outcome, timepoint or follow-up period since hospitalisation or cardiac rehabilitation, and the effect size and 95% confidence interval concerning the associations between the determinant and PA behaviour. To structure the descriptive analysis, determinants were categorised according to the OPTImAL ontology [113], a system with 320 interrelated predictors that may determine PA in the CVD population.

For ease of interpretation, the directions of association statistics were aligned across all determinant categories, so that positive associations (+) indicate that a higher value of the determinant is associated with more PA and negative associations (-) express that higher value of the determinant is associated with less PA. The strength of association statistics was classified as *none*, *weak*, *moderate*, *strong*, or *very strong* according to the qualitative descriptors and cut-points described by Rosenthal [114] (table 1). Vote counting was used to summarise the number of statistics expressing positive, negative or no associations [115].

To support the narrative synthesis, data were visualised in a global heat map (RStudio 2022.07.2) and in a diverging stacked bar chart (Microsoft Excel Version 2307, 2019).

Table 1. Qualitative descriptors for strength of associations according to Rosenthal [114].

Association statistic	None	Weak	Moderate	Strong	Very strong
Correlation coefficient (r)	-0.10 < r <0.10	0.10 ≤ r < 0.30 -0.30 < r ≤ -0.10	0.30 ≤ r < 0.50 -0.50 < r ≤ -0.30	0.50 ≤ r < 0.70 -0.70 < r ≤ -0.50	0.70 ≤ r r ≤ -0.70
Odds ratio (OR)	0.67 < OR < 1.50	1.50 ≤ OR < 2.50 0.40 < OR ≤ 0.67	2.50 ≤ OR < 4.00 0.25 < OR ≤ 0.40	4.00 ≤ OR < 10.00 0.10 < OR ≤ 0.25	10.00 ≤ OR OR ≤ 0.10
Cohen's d (d)	-0.20 < d < 0.20	0.20 ≤ d < 0.50 -0.50 < d ≤ -0.20	0.50 ≤ d < 0.80 -0.80 < d ≤ -0.50	0.80 ≤ d < 1.30 -1.30 < d ≤ -0.80	1.30 ≤ d d ≤ -1.30

Results

The literature searches (first search and two update searches) yielded a total of 17,377 search results. After de-duplication, 12,539 search results remained for title and abstract screening. Three hundred thirty-eight articles were retrieved for full-text assessment, of which 264 were excluded. Reasons for exclusion are given in the PRISMA flow diagramme (figure 1), with the main reason for exclusion being that studies reported adjusted and multivariate statistical models but not their underlying bivariate associations (n=101). Finally included were 74 articles reporting on 70 primary studies (figure 1).

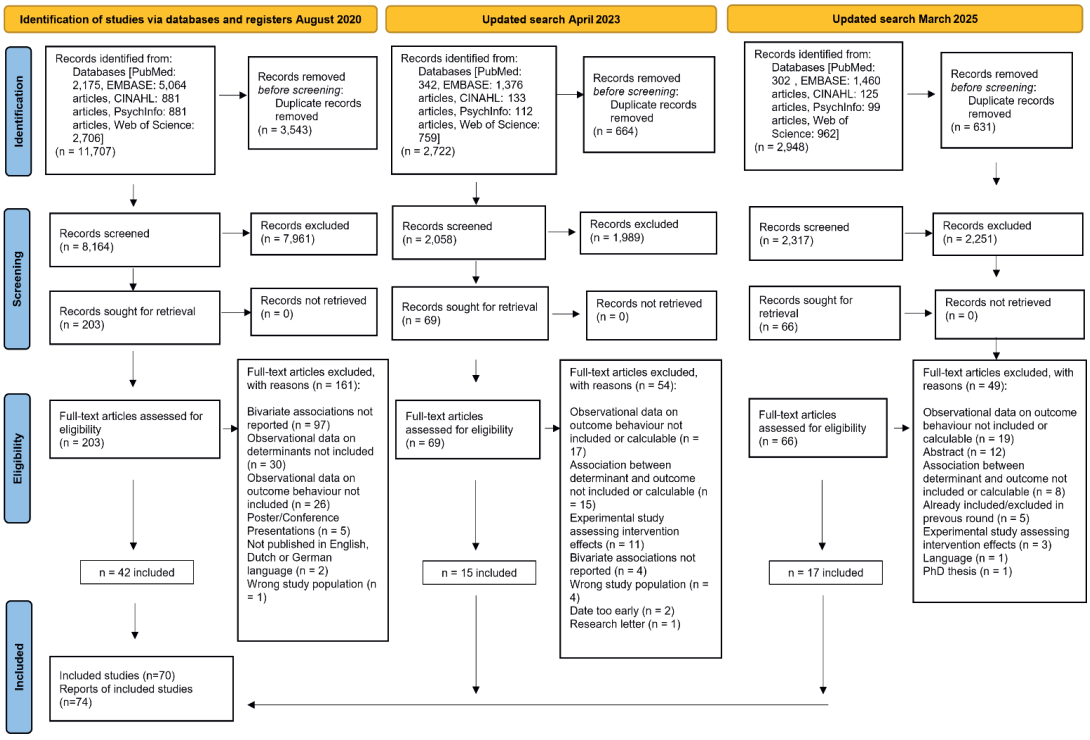


Figure 1. PRISMA flow diagram for new systematic reviews, including searches of databases and registers only. From: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al.

The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71 [101]. For more information, visit: http://www.prisma-statement.org/

Study characteristics

Study characteristics are summarised in table 2. The 70 included studies [54,55,116–187] were conducted in 29 countries. Individual study sample sizes ranged from 25 to 15,613, with 39,101 study participants included in total. The global distribution of study participants is shown in figure 2.

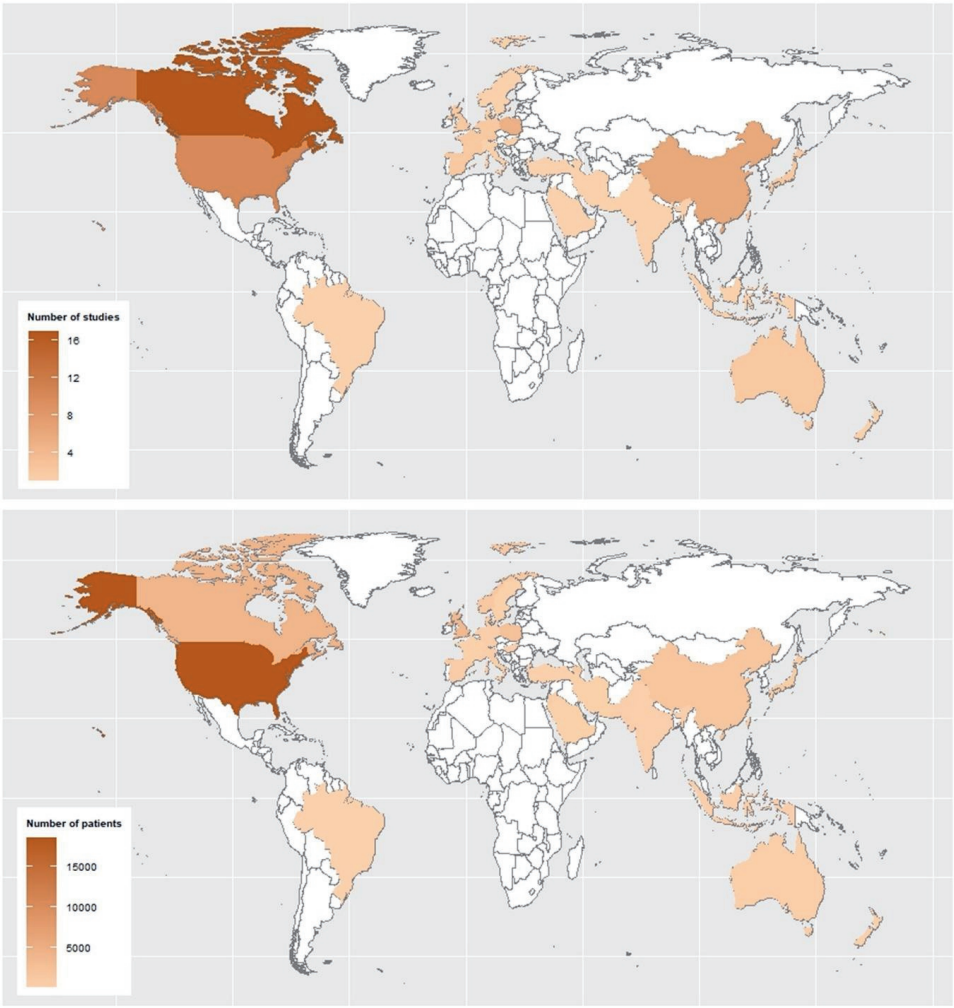


Figure 2. Global distribution of study participants

The majority of study participants were male (53% to 100% male in 66 studies). The mean age of study samples ranged from 54 to 87 years (besides one study focused on congenital heart disease with a mean age of 29 years). With regard to cardiac diagnoses, study samples represented either coronary

heart disease across various degrees of severity (descriptors *coronary heart disease*, *myocardial infarction, percutaneous coronary intervention, coronary artery bypass grafting*, n=37), a mix of cardiac conditions (descriptors *cardiac rehabilitation* and *mixed cardiac diagnoses*, n=22), or specific groups such as *heart failure*, *heart valve surgery*, or *heart transplantation* (n=11). The time point of data collection in relation to an acute cardiac event or in relation to a cardiac rehabilitation programme was up to 3 months in 21 studies, 3-6 months in 9 studies, 6-12 months in 9 studies, 12-24 months in 7 studies, over 24 months in 12 studies, and not reported in 12 studies (table 2).

Table 2. Study characteristics

Author	Country	Study design	Study population	N	Gender (% male)	Age (mean ± SD)	Time-point/follow-up[j]
Ali 2017 [116]	Pakistan	Cross-sectional	Bypass surgery	265	59.2	67.2 ± 13.4	Mean 5.7 (SD 1.3) weeks post surgery
Ali 2017 [117] Ali 2018 [118]	Canada	Longitudinal	Cardiac rehabilitation	411	70.1	65.0 ± 10.4	2 years after CR start
Almoghairi 2024 [187]	Saudi Arabia	Cross-sectional	Coronary heart disease with recent PCI	104	81.7	59.5 ± 13.0	1 month after PCI
Alsaleh 2023 [159]	Jordan	Cross-sectional	Coronary heart disease[b]	400	64.7	54.3 ± 8.9	≥4 months after diagnosis
Arthur 2013 [155]	Canada	Longitudinal	Cardiac rehabilitation	203	0.0	63.1 ± 11.0	12 months after CR completion
Bermudez 2023 [186] Bierbauer 2023 [185]	Switzerland	Longitudinal	Cardiac rehabilitation	137	84.7	62.30 ± 11.2	Approx. 7 days before CR to 3 weeks after discharge from CR
Bernardo 2013 [119]	Brazil	Cross-sectional	Cardiac rehabilitation	69	71.0	67.2 ± 9.2	At CR start
Blanchard 2008 [120] Blanchard 2009 [121]	Canada	Longitudinal	Coronary heart disease and post-acute event	76	76.0	63.0 ± 11.0	6 months after CR start
Blanchard 2010 [122] Blanchard 2011 [123]	Canada	Longitudinal	Coronary heart disease and post-acute event	280	72.5	63.0 ± 11.5	3 months after CR start
Bray 2006 [124]	Canada	Longitudinal	Cardiac rehabilitation	44	63.6	59.4 ± 13.5	6 weeks after CR completion
Chien 2014 [125]	Taiwan	Longitudinal	Heart failure	111	62.2	63.2 ± 11.5	1 month after hospital discharge

Crane 2005 [126]	USA	Cross-sectional	Myocardial infarction[a]	84	0.0	75.0 ± 5.8	6-12 months after MI
Dąbek 2020 [127]	Poland	Cross-sectional	Coronary heart disease[b]	217	56.7	67.4 ± 8.5[d]	During hospitalisation
de Melo Ghisi 2015 [128]	Canada	Experimental	Cardiac rehabilitation	146	78.8	64.3 ± 12.0	22-24 weeks after CR start
de Melo Ghisi 2015 [129]	Canada	Longitudinal	Cardiac rehabilitation	214	67.2	66.1 ± 9.3	6 months after CR start
Dhillon 2023 [184]	India	Cross-sectional	Mixed cardiac diagnoses[c]	196	53.6	n.r.	Between 1-6 years of heart disease
Dontje 2014 [130]	Netherlands	Cross-sectional	Heart failure	68	71.0	62.0 ± 14	Stable outpatients recruited from HF clinics[k]
Dunn 2018 [131]	USA	Longitudinal	Coronary heart disease[b]	122	65.6	65.0 ± 9.1	During hospitalisation
Esnaasharieh 2022 [160]	Iran	Cross-sectional	Heart Failure	103	59.2	55.9 ± 11.4	Mean 7.2 (SD 5.0) years disease duration
Fahmi 2022 [161]	Indonesia	Cross-sectional	Post-treatment AMI	150	78.8	n.r.	Patients recruited from a cardiac clinic[k]
Feng 2023 [183]	China	Cross-sectional	Post-PCI	226	83.6	58.6 ± 7.6	Median 1.8 (IQR 0.6 – 4.0) years after PCI
Foster 2021 [162]	Scotland	Cross-sectional	Cardiac rehabilitation	285	75.9	68.7 ± 10.5	Patients referred to CR[k]
Funaki 2023 [163]	Japan	Longitudinal	Post-PCI	577	86.5	64 (58 - 68)[g]	1 month after PCI
Gabulova 2023 [182]	Azerbaijan	Cross-sectional	Coronary heart disease	687	75.1	59.6 ± 9.6	Routine outpatient visits[k]
Goo 2024 [181]	South Korea	Cross-sectional	Coronary heart disease	1083	63.6	68.9 ± 8.9	Previous diagnosis of angina or MI[k]
Goodwin 2019 [132]	USA	Cross-sectional	Acute coronary syndrome	151	69.5	64.0 ± 11.4	35 days after hospital discharge
Graham 2024 [180]	USA	Cross-sectional	Post-MI or angina	582	72.5	67 ± 9.8	Mean 1.8 (SD 1.3) years after MI or angina hospital discharge
Holahan 2008	USA	Cross-sectional	Mixed cardiac diagnosesc	130	49.0	60.2 ± 12.4	Outpatients recruited

[133]							through medical settingsk
Hou 2025 [179]	China	Cross-sectional	Coronary heart disease	239	61.9	72.0 ± 7.5	0.5-10 years since diagnosis for 59%,<0.5 or >10 years for 41%
Huang 2022 [157]	Taiwan	Cross-sectional	Coronary heart diseaseb	215	62.8	68.8 ± 10.8	Mean 9.4 (SD 6.9) years disease duration
Hussain Jafri 2023 [178]	USA	Cross-sectional	Cardiac rehabilitation	15,613	56.0	66.6[e]	Prior to CR
Kałka 2021 [164]	Poland	Cross-sectional	Coronary heart diseaseb	751	100	59.5 ± 9.4	After CR completion
Kanning 2010 [134]	Germany	Longitudinal	Coronary heart diseaseb	108	91.0	55.0 ± 10.0	6 months after CR completion
Kaushal 2023 [177]	USA, Canada and France	Cross-sectional	Heart failure	671	77.9i	72.3 ± 5.4	Baselinek
Kim 2022 [165]	USA	Longitudinal	Cardiac rehabilitation	25	64.0	64.6 ± 10.5	9 months after CR completion
Klompstra 2018 [135]	Sweden	Cross-sectional	Heart Failure	100	62.0	67.0 ± 13.0	Median 37 (range 2-192) months after diagnosis
Knapik 2019 [136]	Poland	Cross-sectional	Coronary heart diseaseb	135	56.3	71.9 ± 4.8	Stable patients recruited from cardiology clinick
Kronish 2006 [137]	USA	Longitudinal	Acute coronary syndrome	492	58.9	60.6 ± 12.2	3 months after hospital discharge
Le Grande 2006 [138]	Australia	Longitudinal	Post-PCI	200	74.0	59.0 ± 10.1	6 months after PCI
Le Grande 2015 [139]	Australia	Longitudinal	Post-MI, bypass surgery or PCI	133	84.0	60.0 ± 9.3	6 weeks after hospital discharge
Lee 2024 [176]	South Korea	Cross-sectional	Heart failure or MI	189	75.7	62.1 ± 12.0	Patients with a history of heart failure or MIk
Li 2024 [175]	China	Cross-sectional	Bypass surgery	376	71.01	n.r.	3-18 months after surgery
Liu 2022 [166]	China	Cross-sectional	Post-PCI	260	65.8	57.2 ± 9.6	>1 year after PCI
Lund 2016	Denmark	Longitudinal	Heart valve	524	64.7	70.0[f]	6-12 months

[140]			surgery				after surgery
Luszczynska 2006 [141]	Poland	Longitudinal	Myocardial infarction[a]	114	64.0	54.3 ± 7.0	8 months after MI
Marçal 2024[174]	Canada	Cross-sectional	Atrial fibrillation	619	66.0	66.0[g,e]	Median 8 years for women and 9 years for men since diagnosis[e]
Marques-Sule 2022 [156]	Spain	Cross-sectional	Heart transplantation	117	56.4	56.0 ± 12.1	Mean 79.5 (SD 65.6) months since transplantation
Millen 2008 [142]	Canada	Longitudinal	Cardiac rehabilitation	50	62.0	62.0 ± 13.0	12 weeks after CR completion
Moreno 2024 [173]	Spain	Longitudinal	Acute myocardial infarction	503	79.9	58.8 ± 10.4	12 months after AMI
Murray 2012 [143]	Canada	Longitudinal	Cardiac rehabilitation	129	85.3	59.5 ± 10.3	1 month after CR completion
Peersen 2020 [144]	Norway	Cross-sectional	Post-MI and/or a revascularization procedure	1101	79.2	62.0 ± 10.0	Median 16 (range 2-36) months after cardiac event
Peláez 2010 [145]	Canada	Cross-sectional	Coronary heart disease[b]	756	69.0	60.0 ± 10.0	Patients at a tertiary care cardiac center[k]
Prapavessis 2005 [146]	New Zealand	Cross-sectional	Congenital heart disease	64	47.0	28.8 ± 9.9	Surgical repair of cardiac defect in childhood
Racodon 2020 [147]	France	Cross-sectional	Cardiac rehabilitation	100	76.0	59.9 ± 10.5	1 year after CR completion
Rodgers 2013 [148]	Canada	Longitudinal	Cardiac rehabilitation	114	78.1	57.6 ± 9.8	1 month after CR completion
Russell 2009 [55]	Canada	Longitudinal	Cardiac rehabilitation	68	86.8	64.9 ± 8.9	6 weeks after CR completion
Russell 2010 [149]	Canada	Longitudinal	Cardiac rehabilitation	53	100	62.8 ± 10.8	2 weeks after CR completion
Salman 2019 [150]	Scotland	Cross-sectional	Mixed cardiac diagnoses[c]	3128	49.4	63.3[e]	Patients recruited by survey[k]
Schmitz 2022 [167]	Germany	Longitudinal	Psycho-Cardiological rehabilitation	164	54.6	54.6 ± 7.5	6 months after CR completion
Setny 2022	Poland	Longitudinal	Acute coronary	1003[h]	71.0[i]	64.5[f] ±	6-24 months

[168]			syndrome			8.0[d]	after cardiac event
Shen 2025 [172]	China	Cross-sectional	Transcatheter aortic valve replacement	195	58.5	74.4 ± 6.1	Mean 24.2 (17.4) months after intervention
Slovinec D'Angelo 2014 [54]	Canada	Longitudinal	Coronary heart disease	801	75.4	61.4 ± 10.0	12 months after hopitalisation
Sweet 2014 [151]	Canada	Longitudinal	Cardiac rehabilitation	109	68.0	62.3 ± 9.6	4 months after CR start
Teleki 2022 [169]	Hungary	Longitudinal	Post-PCI or CABG	117	66.0	62.5 ± 6.2	6 months after hospital discharge
Tokunaga-Nakawatase 2012 [152]	Japan	Longitudinal	Coronary heart disease[b]	76	100	67.0 ± 7.8	Patients recruited from an outpatient clinic[k]
Van Der Wal 2006 [153]	Netherlands	Cross-sectional	Heart failure	501	60.0	72.0 ± 11.0	Median 40 (IQR 11-79) months of HF symptoms
Wang 2023 [170]	China	Longitudinal	Coronary heart disease[b]	279	63.0	64.7 ± 13.2	1 week after hospital discharge
Werren 2022 [158]	Italy	Cross-sectional	Acute coronary syndrome	372	86.3[i]	65.4[f,e]	Median 31 (IQR 24-38) months after CR start
Yakut Ozdemir 2023 [171]	Turkey	Cross-sectional	Myocardial infarction	42	69.0	58.4 ± 5.6	Mean 6.4 (2.5) months since MI
Zullo 2010 [154]	USA	Cross-sectional	Myocardial infarction[a]	1374	53.0	64.4 ± 12.1[d]	≤10 years after MI

[a] includes STEMI and NSTEMI
[b] includes descriptors coronary artery disease, ischemic heart disease, and stable coronary heart disease
[c] includes patients with a variety of cardiac diagnoses but not recruited from a cardiac rehabilitation programme
[d] SD calculated by authors
[e] SD or range not reported
[f] weighted mean calculated by authors
[g] median reported
[h] sample size calculated by authors
[i] percentage calculated by authors
[j] if a longitudinal study, furthest time point of physical activity measurement chosen
[k] time since cardiac event not reported
n.r., not reported
AMI, acute myocardial infarction
MI, myocardial infarction
CR, cardiac rehabilitation
HF, heart failure
PCI, percutaneous coronary intervention
CABG, coronary artery bypass grafting
SD, standard deviation
IQR, interquartile range

Methodological quality assessment

Forty-one studies were rated good quality and 29 studies fair quality. There were no study exclusions because of poor methodological quality. Individual quality ratings for all included studies are given in Additional file 4.

Physical activity behaviour

The majority of studies measured PA behaviour based on various self-reported questionnaires (n=63), one study [152] employed both a self-reported questionnaire and a wearable sensor device (pedometer), one study [178] used staff-reported PA and five studies [130,132,163,165,185,186] used wearable sensor devices (accelerometers) only.

Collectively, these different methods of measuring the outcome PA behaviour capture activities such as walking, cycling, housework, gardening, exercise and training, leisure and work-related physical activities. The units of measurements include amount of light, moderate, and/or vigorous PA (minutes and hours per week), metabolic equivalents of tasks (METs), weekly frequency of exercise, step counts, or instrument-specific scores. In several studies, participants were dichotomised into those meeting the PA recommendations versus those not meeting the PA recommendations. The specific units of measurement for each included study are given in Additional File 5.

Determinants of physical activity behaviour

The 70 studies included in this review yielded 699 bivariate association statistics between various determinants and PA behaviour. Most determinants were self-reported, except for clinical measurements and demographic determinants which were mainly extracted from medical records. Determinants represent 17 overarching categories (factors) and 56 subcategories mapped to the OPTImAL ontology (table 3). Table 3 shows the distribution of determinants across the OPTImAL categories.

Table 3. Categories of the OPTImAL ontology for which bivariate association statistics (N=699) were extracted.

Overarching category (factor)	Number of extracted association statistics n (%)	Sub-category (determinant)	Number of extracted association statistics n (%)
Anthropometric factors	15 (2.15)	Body mass index	15 (2.15)
Cardiovascular disease factors	31 (4.43)	Cardiovascular risk score	4 (0.57)
		NYHA class	8 (1.14)
		History of heart disease	15 (2.15)
		Family history of CVD	4 (0.57)
Cognitive factors	166 (23.75)	Self-efficacy	73 (10.44)
		Self-regulation / monitoring	6 (0.86)
		Motivation / exercise motivation	30 (4.29)
		Life attitude	7 (1.00)

		Subjective norm	5 (0.72)
		Intention	18 (2.58)
		Illness / health perception	10 (1.43)
		Exercise belief	17 (2.43)
Morbidity factors	39 (5.58)	Comorbidity	39 (5.58)
Demographic factors	129 (18.43)	Age	36 (5.15)
		Education	26 (3.72)
		Ethnicity	8 (1.14)
		Gender	37 (5.29)
		Marital status	15 (2.15)
		Socioeconomic status	7 (1.00)
Environment factors	33 (4.72)	Physical environment	4 (0.57)
		Adaptation to weather	8 (1.14)
		Residence	6 (0.86)
		Transport	4 (0.57)
		Living arrangements	9 (1.29)
		Home exercise equipment	2 (0.29)
Health behaviour factors	42 (6.01)	Exercise behaviour	35 (5.01)
		Habit formation	6 (0.86)
		Patient activation	1 (0.14)
Healthcare service factors	24 (3.43)	Exercise recommendation	3 (0.43)
		Cardiac rehabilitation attendance	18 (2.58)
		Access to care	1 (0.14)
		Treatment	2 (0.29)
Health literacy factors	10 (1.43)	Knowledge / information	10 (1.43)
Insurance factors	1 (0.14)	Insurance	1 (0.14)
Lab test	6 (0.86)	Lipid profile	6 (0.86)
Lifestyle factors	18 (2.58)	Smoking	10 (1.43)
		Alcohol	1 (0.14)
		Stress	1 (0.14)
		Lack of time	4 (0.57)
		Lifestyle choice	1 (0.14)
		Diet	1 (0.14)
	13 (1.86)	Arterial hypertension	3 (0.43)

Patient physiology factors		Left ventriular ejection fraction	9 (1.29)
		Physical fitness	1 (0.14)
Symptom factors	18 (2.58)	Fatigue / sleepiness	12 (1.72)
		Pain	5 (0.72)
		Frailty	1 (0.14)
Social support factors	39 (5.58)	Social support	39 (5.58)
Psychological factors	96 (13.73)	Loneliness	1 (0.14)
		Emotion	44 (6.29)
		Depression	20 (2.86)
		Psychological well-being	31 (4.43)
Social environment factors	19 (2.71)	Family circumstances	2 (0.29)
		Dog ownership / dog walking	2 (0.29)
		Employment	15 (2.15)

Details of all extracted association statistics are given in Additional File 5. Figure 3 presents a descriptive graphical summary of all bivariate association statistics. For each determinant sub-category, this allows a visual comparison of the relative amount of data (number of bivariate association statistics and number of studies from which these were extracted), the directions and strengths of associations, and the number of associations which were categorised as 'none'.

Out of the 56 determinant sub-categories, 27 (48.2%) showed predominantly positive associations with PA behaviour, 13 (23.2%) showed predominantly negative associations, 11 (19.6%) showed mixed positive and negative associations, and for 5 (8.9%) determinant sub-categories all associations were categorised as 'none'.

Out of those determinants which were associated predominantly positively with PA behaviour, self-efficacy, life attitude, intention for PA, exercise belief, education level, adaptation to weather, (prior) exercise behaviour, habit formation, knowledge/information, social support, psychological wellbeing and employment provide the strongest indicators, based on the number of respective association statistics and the distribution of strengths of associations. Self-efficacy represents by far the strongest indicator (31 weak, 31 moderate, 3 strong and 1 very strong positive associations as compared to only 7 associations which were categorised as 'none'), followed by exercise behaviour (10 weak, 14 moderate, 5 strong, and 3 very strong positive associations as compared to only 3 associations which were categorised as 'none') and social support (18 weak, 6 moderate, and 3 strong positive associations as compared to 2 weak negative associations and 10 associations which were categorised as 'none'). The remaining determinants which were also associated positively with PA behaviour were family history of CVD, self-regulation, subjective norm, illness/health perception, socioeconomic status, physical environment, residence, transport (i.e., availability of transportation), home exercise equipment, patient activation, exercise recommendation, treatment, insurance, physical fitness, and dog ownership (figure 3).

The determinants which were associated predominantly negatively with PA behaviour are New York Heart Association (NYHA) class, history of heart disease, comorbidity, age, alcohol consumption, arterial hypertension, fatigue, pain, frailty, loneliness, emotion, depression, and family circumstances. Out of these, the strongest indicators were age (13 weak, 6 moderate, 1 strong, and 2 very strong negative associations as compared to 1 weak positive association and 13 associations which were categorised as 'none'), emotion (11 weak, 9 moderate, 6 strong, and 2 very strong negative associations as compared to 16 associations which were categorised as 'none'), and comorbidity (19 weak, 2 moderate, and 1 strong negative associations as compared to 2 weak positive associations and 15 associations which were categorised as 'none'); followed by depression (6 weak, 3 moderate and 1 strong negative associations as compared to 1 moderate positive association and 9 associations which were categorised as 'none'), fatigue (3 weak, 2 moderate and 4 strong negative associations as compared to 3 associations which were categorised as 'none'), NYHA class (5 weak, 1 moderate, and 2 strong negative associations), and history of heart disease (6 weak and 1 moderate negative associations as compared to 1 weak positive association and 7 associations which were categorised as 'none') (figure 3).

The determinants which showed mixed associations were body mass index, motivation, ethnicity, gender, marital status, living arrangements, cardiac rehabilitation attendance, lipid profile, smoking, lack of time, and left ventricular ejection fraction. The determinants for which all associations were categorised as 'none' include cardiovascular risk score, access to care, stress, lifestyle choice, and diet (figure 3).

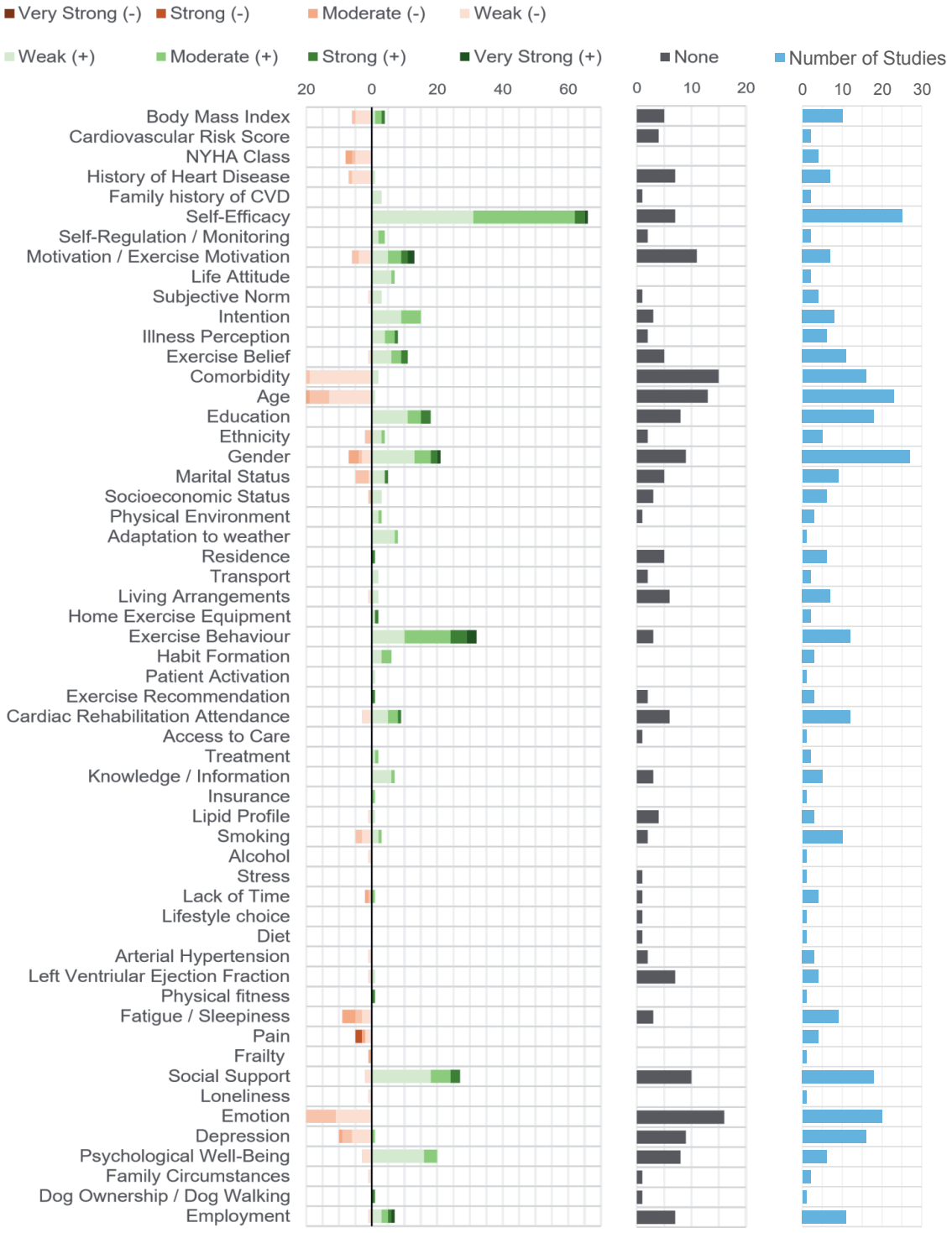

Very Strong (-)
Strong (-)
Moderate (-)
Weak (-)
Weak (+)
Moderate (+)
Strong (+)
Very Strong (+)
None
Number of Studies
20
0
20
40
60
0
10
20
0
10
20
30
Body Mass Index
Cardiovascular Risk Score
NYHA Class
History of Heart Disease
Family history of CVD
Self-Efficacy
Self-Regulation / Monitoring
Motivation / Exercise Motivation
Life Attitude
Subjective Norm
Intention
Illness Perception
Exercise Belief
Comorbidity
Age
Education
Ethnicity
Gender
Marital Status
Socioeconomic Status
Physical Environment
Adaptation to weather
Residence
Transport
Living Arrangements
Home Exercise Equipment
Exercise Behaviour
Habit Formation
Patient Activation
Exercise Recommendation
Cardiac Rehabilitation Attendance
Access to Care
Treatment
Knowledge / Information
Insurance
Lipid Profile
Smoking
Alcohol
Stress
Lack of Time
Lifestyle choice
Diet
Arterial Hypertension
Left Ventriular Ejection Fraction
Physical fitness
Fatigue / Sleepiness
Pain
Frailty
Social Support
Loneliness
Emotion
Depression
Psychological Well-Being
Family Circumstances
Dog Ownership / Dog Walking
Employment

Figure 3. Associations for 56 determinants of physical activity behaviour. Shown are the number, direction and strength of associations, and the number of studies from which association statistics were extracted for each determinant. For numerical determinants, a greater value of the determinants relates to the shown association, such that a positive association (+) indicates that a higher value of the determinant is associated with more PA (e.g., higher self-efficacy related to more PA) and a negative association (-) indicates that higher value of that determinant is associated with less PA (e.g., more depressive symptoms related to less PA). For gender, the association relates to the male gender.

Discussion

This systematic review extracted 699 bivariate association statistics from 70 primary studies with altogether 39,101 study participants. These observational data provide collated empirical evidence for 56 determinants and their patterns of association with PA behaviour among individuals with cardiovascular disease. Those determinants showing distinct positive associations with PA behaviour are self-efficacy, life attitude, intention, exercise belief, education level, adaptation to weather, exercise behaviour, habit formation, knowledge, social support, psychological wellbeing and employment; whereas those determinants showing distinct negative associations with PA behaviour are age, emotion (including anxiety and kinesiophobia), comorbidity, depression, fatigue, and history of heart disease.

Determinants with particular relevance to individuals with cardiovascular disease

This study provides a valuable overview of determinants of PA behaviour based on empirical data and specifically for individuals with CVD. While many of the included determinants are also relevant to PA behaviour in the general population (e.g., self-efficacy, intention, social support) [1,188], several determinants bear particular importance in the context of CVD: kinesiophobia, psychological wellbeing and depression, cardiac rehabilitation attendance and prior exercise behaviour.

Kinesiophobia in the context of our systematic review describes the fear of PA and exercise in the presence of CVD. Its reported prevalence in patients with coronary artery disease ranges from 19% to 25%, with a tendency to reduce over time [189,190]. Kinesiophobia can lead to maladaptive avoidance behaviour such as lower levels of PA and reduced attendance at exercise-based cardiac rehabilitation programmes, resulting in negative health consequences, disability and depression [191]. It is therefore important that CVD secondary prevention interventions include processes to detect and address kinesiophobia.

Similarly, psychological wellbeing and depression can have considerable influence over patients' adherence to PA recommendations and other CVD secondary prevention measures [192]. Depressive symptoms are prevalent in up to 45% of patients with coronary heart disease and are associated with increased morbidity and mortality as well as decreased quality of life [193,194]. For example, in a global study of 14,577 patients with stable coronary heart disease, psychosocial stress – including depressive symptoms – was associated with increased cardiovascular mortality despite optimal medical secondary prevention treatment [194]. Accordingly, the importance of addressing psychological wellbeing and depression in CVD secondary prevention is gaining increased attention [192,193].

Exercise-based cardiac rehabilitation should constitute a gateway for CVD patients to (re-)establishing lifelong heart-healthy PA habits, but cardiac rehabilitation attendance is only moderately predictive of longer-term PA behaviour. This was shown in a systematic review that summarised evidence from 26 randomised controlled trials and investigated the impact of cardiac rehabilitation on mid-term (up

to 6 months) and long-term (more than 6 months) PA behaviour. Completion of a cardiac rehabilitation programme as compared to non-attendance showed that despite initial success in the short run, there was no clear positive effect on longer-term PA habit formation among individuals with cardiovascular disease [195]. Another systematic review of 40 randomised controlled trials corroborates these findings, with only 9 included studies showing that cardiac rehabilitation increased the proportion of physically active participants at median 6 months follow-up. Only 3 studies showed that cardiac rehabilitation increased the proportion of physically active participants at median 5 years follow-up, and only 26% of PA outcomes across all included studies showed statistically significant improvement compared to control [196]. This is also reflected in the mixed pattern of associations found for the determinant cardiac rehabilitation attendance in this review.

After self-efficacy, exercise behaviour (referring to exercise behaviour prior to the cardiac index event, as well as shortly thereafter) was the determinant with the second-most consistent pattern of positive associations in this review, demonstrating that those who exercise more are also more likely to be physically active several months later. This emphasises the role of physical activity promotion in the general population, in clinical practice in general [197,198], and specifically early on in the CVD secondary prevention pathway, including through cardiac rehabilitation programmes [199,200].

In sum, this review identifies kinesiophobia, psychological wellbeing and depression, cardiac rehabilitation attendance and prior exercise behaviour as determinants which warrant particular attention in the context of supporting PA among individuals with cardiovascular disease. Further relevant determinants emerging from this review are age and comorbidity which both show distinct and consistent negative associations with PA behaviour. As these are non-modifiable factors, this confirms the need for adapting PA opportunities to the capabilities and preferences of older patients and those with greater comorbidity, and for raising awareness of the benefits of PA and minimising the perceived risks of PA in older age, as has been highlighted by others [201].

Underrepresented determinants in this review

Most empirical evidence in this review was found for cognitive, demographic and psychological determinant categories, but limited data were available for other determinant categories and sub-categories which are also of interest in this context.

Surprisingly few studies included data on determinants concerning the environment, despite a relatively large literature describing associations between, e.g., the built environment and PA in the general population [202,203] and across the life span [204]. In the environment category, several singular statistics in this review indicate interesting associations, such as the availability of PA resources (e.g., exercise facilities at work, community infrastructure, such as jogging trails, bike paths) showing moderate positive association in comparison with lack of resources [162] and possession of a bike or home exercise equipment showing weak positive associations[123,162], as well as several weak and moderate positive associations for adapting to adverse weather conditions [152]. Overall, however, this evidence primarily indicates a lack of extractable data and research gaps specific to individuals with cardiovascular disease. For example, the availability and vicinity of supervised exercise sessions for CVD patients, the distribution and density of public access defibrillators, the usability and appropriateness of public infrastructure for PA (fitness trails, hiking routes, etc.) for individuals with CVD, or the availability of emergency alert systems for people exercising in remote rural locations could be more focused aspects of interest for individuals with cardiovascular disease.

The same applies to other underrepresented determinants in this review. The sub-category health literacy, for example, only includes data on knowledge [125,129,153] and lacks the more

differentiated elements that are represented in current conceptualisations of health literacy, such as the ability to actively engage with healthcare providers and the ability to find good health information [205]. Patient activation describes a more recent concept of the extent to which an individual actively engages in self-management behaviours [206], which is a relevant aspect in the secondary prevention of CVD but was only represented in one study [118]. Exercise recommendation by healthcare professionals was addressed in only two studies [159,163], although this has been identified as an issue requiring attention, with 46% of coronary patients reporting that they did not recall having received personal advice on PA [35]. The impact of (different models of) health insurance on PA behaviour presents another point of interest [207]. One study in this review included data showing a moderate positive association between private health coverage and PA behaviour [139], but more differentiated aspects could be investigated, such as comparisons between private and universal health coverage, impact of proportion and size of co-payments (e.g., for participation in cardiac rehabilitation programmes), and impact of PA promotion schemes offered by health insurances [207].

These are some examples of underrepresented determinants in this review. Readers are referred to Additional File 5 for further singular or underrepresented determinants which may bear particular relevance to individuals with cardiovascular disease.

Related research

A discussion of the methodological choices made for this review in comparison with related research [208–211], and a discussion of the respective advantages and disadvantages of self-reported (subjective) versus tracked (objective) measurement methods for PA behaviour are provided in the protocol for this review [102]. Further to this, it is noticeable that all studies included in this review measured individuals' PA levels at certain time points or during short time periods, or with respect to an assumed general average PA level. But the dynamic aspects of PA behaviour over time, including adoption, maintenance, drop-out and resumption of PA [188], and determinants relating to these aspects, were not represented. One previous systematic review and meta-analysis of 34 studies examined determinants of specifically PA maintenance in previously sedentary individuals (samples recruited from the general population and from different diagnostic groups, including CVD in two studies), by comparison of 'maintainers' with 'relapsers' [210]. This study showed that self-efficacy and intention were higher among maintainers compared with relapsers, and that maintainers also held more positive attitudes and perceived more positive and less negative consequences of PA compared with individuals who relapsed. While these findings are in general alignment with data from the present review, further investigation into the dynamics of PA behaviour specifically among individuals with cardiovascular disease is warranted.

Strengths and limitations

A strength of this review was the completion of screening and eligibility assessment, data extraction, quality assessment by independent parallel reviewers, supporting the quality of the review. A limitation of this review was that – despite the use of the OPTImAL ontology as helpful framework - some choices had to be made when one determinant could match two or more OPTImAL categories. Another limitation concerns the lack of meta-analysis, which was not warranted due to the heterogeneity of included studies. Vote counting provided an acceptable alternative method, although it does not convey information on the magnitude of effects, and it does not account for differences in the relative sizes of the included studies [115]. Moreover, the heterogeneity of the included studies (e.g., type of cardiovascular disease and stage of recovery process) presented both strengths and limitations for this review. On the one hand, it allowed for a comprehensive synthesis of the determinants that are relevant broadly across the secondary prevention stage of cardiovascular

disease. However, it led to less nuanced findings specific to particular cardiovascular disease conditions or stages of secondary prevention (e.g., early or long-term). Here, we suggest that future research explore these more nuanced findings. Additionally, another limitation of this review was the exclusion of studies prior to 2005 and thereby excluding findings of these earlier studies. However, the large number of search results yielded, consisting of 17,377 records, suggests an extensive overview of the determinants of physical activity among individuals with cardiovascular disease. Lastly, this review was limited by the (lack of) reporting of bivariate association statistics in the literature, as 101 articles had to be excluded because they contained only multivariate models or adjusted analyses. A trial to contact corresponding authors and request raw data for this review was discontinued due to high administrative burden and low response.

Future directions

This review provides intervention developers with an overview of determinants and their relative strengths, which may be taken into account when designing behaviour change interventions. This is particularly useful for those intervention development approaches that take behavioural determinants as their conceptual starting point [212]. Intervention developers may directly target those determinants which emerge as strong indicators from this review, including determinants that are important for the general population as well as determinants with specific relevance to individuals with cardiovascular disease. Alternatively, or additionally, intervention delvelopers may consider investigating and generating new evidence for determinants which are underrepresented in this review but which have potential impact on the PA behaviour of individuals with CVD.

Future research should address the imbalance in the geographical distribution of evidence, as most studies included in this review contributed data from the Global North. Moreover, future research should strive to capture more continuous and long-term (over 24 months) patterns of PA behaviour, to provide insight into the dynamic changes of PA behaviour and inform about long-term habit formation. Methodological challenges around logistics, costs and participant burden are acknowledged, but rapid advances in digital technology and wearable and implantable sensor devices promise future solutions for realising a vision of ubiquitous sensing and big data analysis [213]. Lastly, given the heterogeneity of primary studies included in this review, in terms of cardiovascular disease condition type and time since diagnosis or acute event, we suggest future research to explore how these factors may relate to determinants of PA, potentially through sub-analyses or other methodological approaches.

Conclusions

This systematic review highlights several determinants that emerge as strong indicators for PA behaviour among individuals with cardiovascular disease: self-efficacy, (prior) exercise behaviour, social support, emotion (including anxiety and kinesiophobia), psychological wellbeing, depression, age and comorbidity. These findings align with determinants of PA identified in the general population and in other clinical populations, but also identify determinants that bear particular relevance among individuals with cardiovascular disease. Developers of behaviour change interventions may draw on these findings to inform intervention concepts, methods and designs. Further research in underrepresented geographic regions, and studies into underrepresented determinants of PA and dynamic changes of PA behaviours over time specifically among individuals with cardiovascular disease are warranted.

CHAPTER 3

Exploring physical activity preferences and motivation in long-term cardiac prevention: An Austrian cross-sectional study

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Abstract

Cardiac rehabilitation (CR) patients often do not sustain physical activity (PA) behaviour in the long run, once they progress into a self-management stage of secondary prevention. This study aimed to explore former CR patients' PA preferences, determinants (i.e., influencing factors) and motivation for sustained PA engagement. We conducted a cross-sectional multi-centre survey using an original questionnaire based on prior qualitative interviews with cardiac patients. Five CR centres in Austria posted 500 questionnaires to former CR patients who had completed CR approximately three years prior, and 117 patients (23%) responded. Descriptive analysis was used to analyse closed-ended questions, and self-determination theory (SDT) was applied as a qualitative framework to analyse open-ended questions concerning motivation for PA engagement. Patients were generally physically active, but the majority (75.3%) did not fulfil the World Health Organisation's recommendations for aerobic PA and muscle strengthening. Most patients preferred being physically active outdoors (70%), engaging in aerobic-related (95%), individual and non-competitive exercises, with cycling (52%), walking (32%) and hiking (25%) among the most popular activities. Main determinants of PA were health, pain and motivation for 80%, 68%, 67% of patients, respectively. A subset of patients (77%) expanded on their motivations behind PA. According to SDT, most reasons (90%) were regulated by autonomous motivation (either extrinsically autonomously-regulated or intrinsic motivation) and stemmed mostly from health-related goals (e.g., fitness, general health, weight control), future quality-of-life aspirations (e.g., self-sufficiency in old age, presence for loved ones, preserving mobility) and enjoyment of PA. Patients' responses underscore the importance of promoting not only general PA, but also muscle strengthening training in CR interventions to maximise optimal health benefits. Our data further suggest that interventions which are aligned to patients' health goals and foster autonomous motivation may be particularly beneficial in increasing adherence to PA in the long-term.

Introduction

The incidence of cardiovascular disease (CVD) has nearly doubled worldwide in the past thirty years (1990 – 2019), and CVD remains the leading cause of death globally, including Austria [12,214,215]. Life-style modifications, in particular physical activity (PA) engagement, has been reported as an effective secondary prevention measure for cardiac conditions [216]. Increased PA is associated with reduced mortality risk and improved health-related quality of life [217][218]. Despite this, a survey across 27 European countries reported that two-thirds of coronary artery patients do not reach the recommended guidelines for PA [35].

Intervention strategies focused on increasing sustained PA adherence are, thus, increasingly important in the domain of secondary prevention. Although cardiac rehabilitation (CR) programs are beneficial in initiating immediate PA behaviour change, they often do not result in long-term adherence, as patients have difficulty maintaining behaviour change [75,195,196,219]. The premise that adapting PA interventions to the patient's preferences and needs may increase adherence has been explored in the context of CR programs [220–222]. Less attention, however, has been focused on PA preferences after CR (e.g., activity types, location) when patients move from a structured and supervised CR programme to a self-management phase of care. Insight into PA preferences in this stage of prevention may be useful for transitioning PA behaviours into daily habits at the end of CR *or* for developing PA initiatives in later stages of secondary prevention.

Additionally, understanding determinants of long-term PA adherence may allow health care professionals (HCPs) to optimise PA integration into patients' daily lives. A variety of factors are associated with PA adherence among cardiac patients, including demographics (e.g., age, gender, education), psychological factors (e.g., distress, lack of energy, well-being, self-efficacy, motivation), environment (e.g., weather, nature), physical (e.g., health), social support (e.g., family, friends, peers) and health beliefs (e.g., knowledge, awareness of threat) [45,46,162,223,224]. Among those factors, motivation is expressed to play a key role in PA behaviour, specifically in the context of PA maintenance [54].

In understanding motivation for PA, self-determination theory (SDT) - a well-developed psychological theory stipulating motivation exists in various forms - has extensively been applied to the domain of PA motivation [51]. Specifically, SDT focuses primarily on the type of motivation versus the degree of motivation present, and is largely driven by a distinction between self-determined or autonomous motivation and controlled motivation [53,225] The former refers to motivation that is self-endorsed, i.e., self-regulated and aligned with an individual's personal values or interests, which can be driven by both extrinsic factors (e.g., positive health outcomes) or by intrinsic factors, an innate joy of engaging in an activity. The latter refers to motivation that is solely extrinsically regulated and lacks volition or alignment with self, where behaviour is engaged in either to fulfil others' demands or out of avoidance of negatively experienced consequences from others (e.g., feelings of shame, guilt) [53,225]. A third type of motivation defined by SDT is amotivation, which relates to someone unwilling or undesiring to engage in a behaviour [53,225].

Consistent with SDT, it has been repeatedly shown that autonomous motivation is more greatly associated with improved PA adherence than control-regulated motivation [50,51,54,226]. For instance, a study by Courtney et al. (2021) found that during the transition from adolescence to early adulthood, autonomous motivation was longitudinally associated with PA, suggesting its role in sustained, habitual PA [50]. In terms of CVD secondary prevention, this is additionally supported, showing more autonomously-motivated patients adhered better to PA recommendations during follow-up periods of CR [55,149]. However, motivation type may also be influenced by the setting and

content of CR provided to patients, with prior findings reporting higher levels of controlled motivation in a conventional (HCP- monitored) CR setting, as compared to remotely-supported rehabilitation setting, where monitoring was shared between HCPs and patients [227]. As such, we are interested in assessing how motivation plays out in later stages of secondary prevention, i.e., when patients are primarily in a self-management stage. Specifically, we are interested in understanding the extent to which motivation is controlled versus autonomously-regulated in long-term PA engagement in secondary prevention.

Overall, we aim to assess patient preferences and determinants of PA engagement among a typical demographic (e.g., predominantly older age, male) Austrian sample of individuals in long-term secondary prevention of cardiovascular disease. Additionally, we aim to gain insight into motivating factors for sustained PA by applying SDT to patients' reasons for being physically active. Goal of these findings is to highlight determinants associated with sustained PA adherence, which may be particularly relevant for HCPs who aim to increase or maintain PA engagement in later stages of CVD secondary prevention. Overall, our findings provide useful insights into PA behaviour in secondary prevention.

Methods

Procedure

We conducted a cross-sectional survey using a postal questionnaire of closed- and open-ended questions. In our reporting of the study, we follow the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines [228]. Study recruitment took place from 01 May 2022 to 31 January 2023 at five cardiac rehabilitation (CR) centres located in four Austrian federal states (Carinthia, Lower and Upper Austria, Vorarlberg). One hundred questionnaires were administered to each of the five centres summing to a total of 500 distributed questionnaires. At the centres, internal staff identified patients who had completed an in- or outpatient phase II CR completion three years prior (starting from January 2019) from their internal patient documentation systems. Once these individuals were selected, staff sent out the questionnaires via the post to the patients' home addresses retrieved from their patient documentation systems. In Austria, the phases of cardiac rehabilitation are defined as follows: phase I describes acute care; phase II consists of an intensive CR programme of 3-4 weeks duration in an inpatient setting or 4-6 weeks duration in an outpatient setting; phase III describes a 6-12 months outpatient CR programme with less frequent supervised sessions; and phase IV describes patients' lifelong self-management of a recommended secondary prevention lifestyle [76]. After completion, respondents posted the questionnaires to our research institute using pre-paid envelopes. Participation in the study was voluntary, and as an incentive, patients could enter a random drawing to win one of four fitness trackers. In addition to the paper-and-pen survey, patients could opt to complete an online version (LimeSurvey © version 3.25.6) following a quick response (QR) code displayed on the front page of survey packet.

Materials

An original pencil-and-paper questionnaire was designed and developed to address the specific aims of our study. Content of the questionnaire was based on qualitative interviews with 25 cardiac patients in 2020 (unpublished data) and underwent a rigorous, iterative testing process with members of the research team and seven cardiac patients. It additionally incorporated two standardised instruments: the EQ-5D-5L [229] and Rapid Assessment of Physical Activity [230].The EQ-5D-5L measures self-assessed health status using both a descriptive system (mobility, self-care, usual activities,

pain/discomfort and anxiety/depression) and a visual analogue scale (EQ-VAS). Dimension scorings consist of 1 (no problems) to 5 (extreme problems), and the EQ-VAS measures perceived health on a 0 – 100 scale (higher score representing better health). The RAPA consists of two parts, the RAPA-I, using a seven-question ordinal scale to assess active vs. suboptimal levels of aerobic PA and RAPA II which measures adherence to recommendations for muscle strengthening and flexibility exercises on a nominal scale.

The questionnaire was written in German and included four sections (demographic information, general health information, cardiac rehabilitation history and physical activity behaviour). In total it contained 32 items consisting of 17 multiple-choice, seven Likert scales, one visual analogue scale, six fill-in-the-blank questions and one open-ended response option. The content of the questionnaire can be accessed on the Open Science Framework platform (https://osf.io/hypmg).

Inclusion Criteria

Patients were included if they were ≥18 years old, had a diagnosed cardiovascular disease, had successfully completed a phase II (in- or outpatient) CR from one of the participating clinics in 2019 (approximately three years prior to the start of the study), were a resident in Austria and fluent in the German language. An upper age limit was not set as CVD primarily affects older-aged individuals [231] and we aimed to recruit as representative a sample of CVD patients as possible.

Data storage

Patients were included if they were ≥18 years old, had a diagnosed cardiovascular disease, had successfully completed a phase II (in- or outpatient) CR from one of the participating clinics in 2019 (approximately three years prior to the start of the study), were a resident in Austria and fluent in the German language. An upper age limit was not set as CVD primarily affects older-aged individuals [231] and we aimed to recruit as representative a sample of CVD patients as possible.

Statistical analysis

Closed-ended (multiple choice, Likert, VAS scale and fill-in-the-blank) questions were analysed descriptively in terms of frequencies and percentages (n, %), central tendency (mean and median depending on item) and measure of spread (standard deviation [SD] or interquartile range [IQR]). Differences between men and women were assessed by Mann Whitney U test (two-tailed, $p<0.05$).

Thematical analysis using self-determination theory

One open-ended question regarding patients' motivations for exercising was analysed thematically using self-determination theory (SDT) as the guiding framework. SDT was chosen because it's a well-supported theory in human motivation and extensive application in PA psychology, specifically, understanding individuals' motivation for exercising [232]. In summary, SDT proposes that motivation lies on a spectrum ranging from *amotivation* (no motivation) to *intrinsic motivation* (out of enjoyment) with varying degrees of extrinsic motivation lying in between [53]. The analysis of our question follows the sub-theory of SDT called the organismic integration theory (OIT), which categorises and defines each component of motivation based on individuals' locus of control vs. autonomy. Specifically, control-regulated motivation (i.e., regulated by others versus self) encompasses two extrinsic motivation categories, including the most controlled form of external motivation, *external regulation* (do something because others say so) to a less, but still controlled form, *introjected regulation* (acting

out of guilt, pressure or contingencies). Autonomous motivation (i.e., self-regulated), on the other hand, encompasses two extrinsic motivation categories and intrinsic motivation. Here, the two autonomously-regulated extrinsic motivation categories are defined as *identified regulation* (behaving out of valued benefits of outcomes) and integrated *regulation*, the most autonomous form of extrinsic motivation (behaving because behaviour aligns with individuals' sense of self or goals) [53]. According to SDT, autonomously regulated motivation is expected to relate to more long-term behaviour than controlled forms [53,225]. In categorising patients' motivations according to the OIT, we followed a similar approach to Burn et al. (2019) –an inductive-deductive analysis of PA motivations through SDT using Braun and Clarke (2006) six steps to thematic analysis [233,234]. Specifically, the following steps were performed by the first author (HM); (step 1) an initial reading and transcribing of hand-written quotes from German to English onto an electronic platform (Microsoft Word, 2016). Translations of quotes were discussed with author SK to ensure meaning and significance of quotes were held. Transcripts were then read and re-read to allow for a familiarisation of data; (step 2) reading of transcripts line-by-line to generate initial codes deductively organised into SDT constructs. For consensus and clarity of coding, codes were iteratively discussed with author RC i.e., rationale for coding categorisation were discussed, any discrepancies addressed and a consensus drawn, and a re-coding of codes performed based on newly formulated definitions. If any discrepancies remained, this process was revisited; next (step 3), codes within the SDT constructs were inductively clustered together with those of similar codes to provide candidate themes; (step 4) an iterative process of reviewing and refining the themes to ensure themes worked in relation to the coded extracts and entire data set; (step 5) a final iterative re-defining and naming of each theme; (step 6) presentation of the themes in a coherent and logical, illustrative flowchart including number of occurrences of themes and overall number of occurrences of SDT constructs.

Ethical considerations

The study was granted ethical approval from the following regional research ethics committees: Ethikkommission des Landes Kärnten (reference M2022-27), Ethikkommission der Medizinischen Fakultät der Johannes Kepler Universität (reference 1078/2022), and Ethikkommission für das Bundesland Niederösterreich (reference GS1-EK-4/795-2022). One regional research ethics committee (Ethikkommission des Landes Vorarlberg, reference EK-0.04-397) waived the need for formal ethical review. In conjunction with the postal questionnaire, patients received written information about the study. For this anonymous self-completed postal survey written consent was not required, but self-completion and return of the questionnaire were taken as implied consent and so approved by the research ethics committees.

Results

Demographics

In total, 117 patients responded to the survey (response rate: 23%). The sample consisted of mostly older (mean age 70±11 years), retired (76%), non- or ex-smoker (93%), male (76%) cardiac patients. For the majority of patients (82%), their cardiac history was attributed to coronary heart disease and/or heart failure (including angina pectoris, myocardial infarction, percutaneous coronary intervention, and coronary bypass surgery), and 13% had heart valve surgery.

Nearly half of patients (47%) had participated in an inpatient phase II CR, 43% in outpatient phase II CR and 3% in both an in- and outpatient phase II CR. Only 14% had additionally completed a phase III

outpatient CR. Patients reported a median [IQR] perceived health score (EQ-VAS) of 80 [65,85] out of 100 *(higher scores indicating better health)*. In the EQ-5D categories mobility, self-care, usual activities, pain/discomfort and anxiety/depression the proportions of patients reporting problems (slight, moderate, severe or extreme problems combined) were 33%, 9%, 27%, 70% and 34%, respectively. Moreover, 47% of patients expressed confidence in their ability to manage their own health, 46% were rather confident, and 7% rather not confident. An overview of respondents' demographic and clinical characteristics is displayed in Table 1.

Table 1. Respondents' demographic and clinical characteristics.

Demographics	Subcategories	Output
Female, n (%) *(N = 116)*		28 (24)
Age (years), mean (SD) *(N = 113)*		70 (11)
Body mass index (kg/m^2), mean (SD) (*N =115)*		26.4 (3)
Employment status, n (%) *(N =115)*	Employed	24 (21)
	Unemployed	1 (1)
	Retired	87 (76)
	Permanently unable to work	1 (1)
	Other	2 (2)
Family status, n (%) *(N =114)*	Single	10 (9)
	Partnership	7 (6)
	Married/registered partnership	80 (70)
	Widowed	13 (11)
	Divorced/separated	4 (4)
People per household, median (IQR) *(N =117)*		2 (2-2)
Smoking status, n (%) *(N = 115)*	Lifelong non-smoker	47 (41)
	Ex-smoker	60 (52)
	Since (years), mean (SD)	25 (16)
	Smoker	6 (5)
Country of birth, n (%) *(N =117)*	Austria	113 (97)

	Other	4 (4)
Belonging to religious group, n (%) *(N = 117)*		68 (58)
Education, n (%) *(N = 117)*	Mandatory school (completion of nine years of school)	14 (12)
	High school degree (completion of 12 years of school)	14 (12)
	Apprenticeship with vocational school	38 (33)
	Technical or commercial school	21 (18)
	University or technical college degree	20 (17)
	Other	10 (9)
Household income (euros/month) after tax, n (%) *(N = 115)*	≤ 1200	5 (4)
	1,201 – 2,600	39 (34)
	2,601 – 4,000	25 (22)
	4,001 – 6,000	24 (21)
	6,001 – 8,000	4 (3)
	> 8,001	1 (1)
	No response	17 (15)
Medical cardiovascular history, n (%) *(N = 115)* *	Angina pectoris	10 (9)
	Coronary bypass surgery	14 (12)
	Cardiac arrhythmias	13 (11)
	Heart failure	20 (17)
	Heart valve surgery	15 (13)
	Myocardial infarction	36 (31)
	Percutaneous coronary intervention	61 (53)
	Pacemaker	4 (3)
	Other	15 (13)

Type of CR, n (%) *(N = 114)* *	Inpatient phase 2	53 (47)
	Outpatient phase 2	49 (43)
	Inpatient and outpatient phase 2	3 (3)
	Outpatient phase 3	16 (14)
	Long-term ambulatory rehabilitation	3 (3)
	Other rehabilitation provision	1 (1)
Perceived health status, EQ-VAS median (IQR) *(N=116)*		80 (65-85)
Mobility, EQ-5D-5L, n (%) *(N=117)*	No problems	78 (67)
	Slight problems	16 (14)
	Moderate problems	17 (15)
	Severe problems	5 (4)
	Unable/extreme	1 (1)
Self-care, EQ-5D-5L, n (%) *(N=115)*	No problems	106 (92)
	Slight problems	6 (5)
	Moderate problems	1 (1)
	Severe problems	2 (2)
	Unable/extreme	-
Usual activities, EQ-5D-5L, n (%) *(N=117)*	No problems	85 (73)
	Slight problems	22 (19)
	Moderate problems	7 (6)
	Severe problems	3 (3)
	Unable/extreme	-
Pain/discomfort, EQ-5D-5L, n (%) *(N=117)*	No problems	35 (30)
	Slight problems	53 (45)
	Moderate problems	23 (20)

	Severe problems	5 (4)
	Unable/extreme	1 (1)
Anxiety/depression, EQ-5D-5L, n (%) (*N=116)*	No problems	76 (66)
	Slight problems	28 (24)
	Moderate problems	7 (6)
	Severe problems	5 (4)
	Unable to function/extreme	-
RAPA I, n (%) *(N=114)*	Sedentary	2 (2)
	Under-active	1 (1)
	Under-active regular – light activities	11 (10)
	Under-active regular	23 (20)
	Active[§]	77 (68)
RAPA II, n (%) *(N =104) **	Muscle strengthening guidelines	38 (37)
	Flexibility guidelines	72 (69)

** multiple responses permissible*

[§] 30 minutes or more per day of moderate physical activities on 5 or more days per week; or 20 minutes or more per day of vigorous physical activities on 3 or more days per week.

CR, cardiac rehabilitation

RAPA, Rapid Assessment of Physical Activity questionnaire

Physical activity behaviour

The sample was predominantly physically active in terms of aerobic training (68% as determined by the RAPA I). Flexibility goals as assessed by the RAPA II were achieved by 69% of patients and muscle strengthening goals by 37%. Nearly a quarter (24.7%) of patients achieved physical activity goals for *both* aerobic training and muscle strengthening. Overall, the median frequency and hours of PA per week were 4 [2,6] times a week and 4 [2,8] hours a week.

Preferred type and place for physical activity

We assessed patients' preferred locations to engage in PA. The most popular PA location was outdoors in nature (70%), followed by at home (62%) and in the garden (48%). In comparison, less than a quarter (21%) reported being physically active in fitness studios *and/or* sports clubs (Fig 1A). Additionally, through an open-ended question, 81 (69%) patients expanded on the types of sport and physical activities they engaged in regularly. The most frequently reported sport was cycling, engaged in by over half (52%) of respondents. This was followed by walking (32%) and hiking (25%). On the other

hand, traditional *team* sports were less frequently mentioned. Occurrences of tennis, football, martial arts, dancing and rowing were reported, but combined represented only ~15% of respondents. Furthermore, nearly all sports were cardio-based, whereas only 5% of patients reported engaging in muscle strengthening training (Fig 1B).

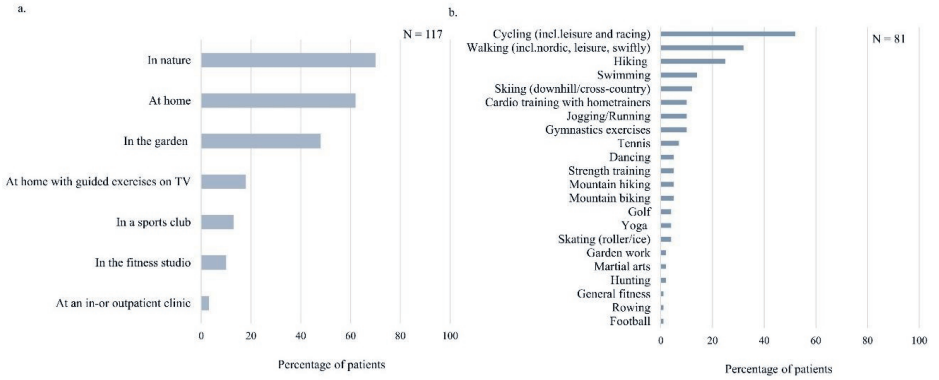


Figure 1. Physical activity location and type preferences. (A) Response rate to the questions 'Where are you physically active?'. (B) Response rate to open-ended question 'If you do play sports, what type(s) of sports do you engage in regularly? (Explanation: by sports we mean: 'physical activity carried out according to certain rules, out of enjoyment of physical activity or games, for the purpose of physical activity'). *For A and B, multiple responses were permissible.*

Reasons and perceptions of physical activity

Responses to patients' perceptions and personal reasons for engaging in PA are displayed in Fig 2. Overall, the majority of patients (~74%) *strongly* expressed that their PA engagement stemmed from an importance to do something good for their health and a desire to strengthen the heart (Fig 2A and 2B). On the other hand, weight control was generally viewed positively, but less strongly as a reason for exercising, and competitiveness (skill-measuring against others) negatively i.e., was not generally perceived as a reason for PA (Fig 2E and 2D). In comparison, social factors (i.e., exercising to meet others) showed more varied results among patients, but for most patients did not serve as a reason for PA (Fig 2F).

Viewing PA as pleasant, satisfying and joyful was *strongly* expressed by ~58% of our respondents suggesting the majority of respondents exhibited intrinsic motivation for PA (Fig 2C and 2J). On the other hand, externally regulated factors - specifically because others say so - appears to play a marginal role in patients' reasons for exercising (Fig 2I). Only 5% of patients *strongly* agreed that their reasons for exercising were impacted from other people saying so. In contrast, feeling bad for not exercising, which may reflect externally-regulated feelings of guilt or shame (e.g., introjected regulation) was reported to a larger extent (Fig 2H). Nearly 40% of patients *strongly* agreed that they felt bad when not being physically active. Thus, although most patients expressed intrinsic motivation for exercising, feeling bad for not exercising could reflect some extrinsically motivated drives.

Overall, patients expressed an understanding of the benefits and need for PA, as 90% of patients reported knowing why they should carry out PA and felt that it was not a waste of time (Fig 2L and

2M). However, when asked specifically if PA was important for the individuals themselves, only ~65% strongly agreed or felt that PA was something they should engage in (Fig 2G and Fig 2K).

Lastly, most patients (~70%) did not report having a fear of exercising. This was expressed in terms of worry in hurting themselves and based on their medical condition (Fig 2N and 2O).

For all questions 2A to 2O, there were no statistically significant differences between men and women, except for question 2F (social factors), with a median of 2 versus 1, respectively (p=0.03).

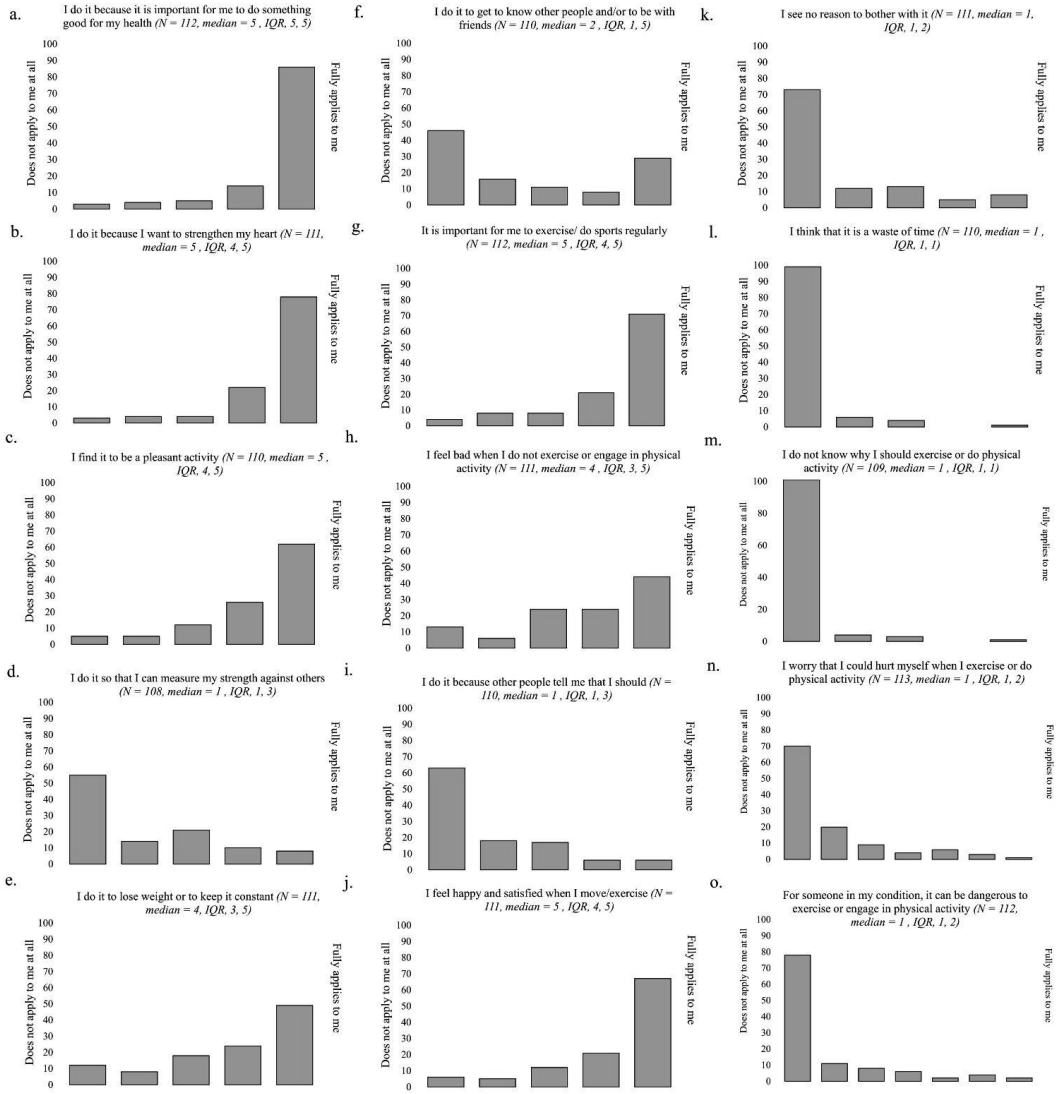


Figure 2. Response distribution of physical activity opinion statements. (A-M) Responses are provided on a 5-point Likert scale from 1 (does not apply to me at all) to 5 (applies fully to me) in response to the question 'Please indicate to what extent the following statements apply to you'. (N-O) Responses are provided on a 7-

point Likert scale from 1 (does not apply to me at all) to 7 (applies fully to me) in response to the question 'To what extent do you agree with the following statements: Please think about physical activity and sports in relation to your heart conditions when you answer this question'. Frequency count (number of participants) is reported for all graphs.

Determinants of PA

Respondents rated the directionality and strength in which certain factors (e.g., sociodemographic, environmental, psychological) facilitated or hindered their engagement in PA (Fig 3). The top-3 influencing factors on PA were 'one's own health', 'pain' and 'motivation', which served as determinants for 80%, 68% and 67% of patients, respectively. Furthermore, 'weather', 'time', and 'age' also served as determinants for PA, but to a lesser extent, by ~50% of patients.

In contrast, all other factors did not serve as determinants by most patients, with each factor only serving as a determinant for <40% of patients. Of these, 'care of dependents', 'cost', 'responsibility of minors', 'lack of quality options', and 'availability and opening times of sport facilities' were the least influencing factors on PA, as expressed by only roughly a quarter of patients.



Figure 3. Directionality of the 22 queried determinants (potential facilitators and barriers) of physical activity behaviour. Responses are provided on a 7-point Likert scale ranging from 'very hindering' to 'very facilitating' in response to the question "To what extent do you find the following factors to personally be a hinderance or a facilitator for you in engaging in physically activity or doing sports?". Shown are the direction and strength of each determinant ('green' = facilitating, 'red'= hindering, 'grey'= neutral) *(n = total sample size for question, y-axis = number of respondents)*.

Motivation factors for engaging in PA

Ninety patients (77%) provided free-text responses expanding on the factors that personally motivate them to engage in heart-healthy PA. Overall, the top-3 most frequently mentioned reasons for PA engagement were 'to stay physically fit/healthy'(n=20), 'for one's own health' (n=18) and 'because it's

fun/enjoyable' (n=17). The representation of these factors as organised according to the motivation continuum of the SDT are displayed in Fig 4. Results showed that majority of patients' reasons for exercising (90%) fell under autonomous motivation, i.e., acting because of individual choice, values or own will. Only ~10% of motivating reasons were categorised under controlled regulation - motivation stemming for someone else's control (e.g., exercising out of avoidance of adverse outcomes, guilt or perception/impact of others).

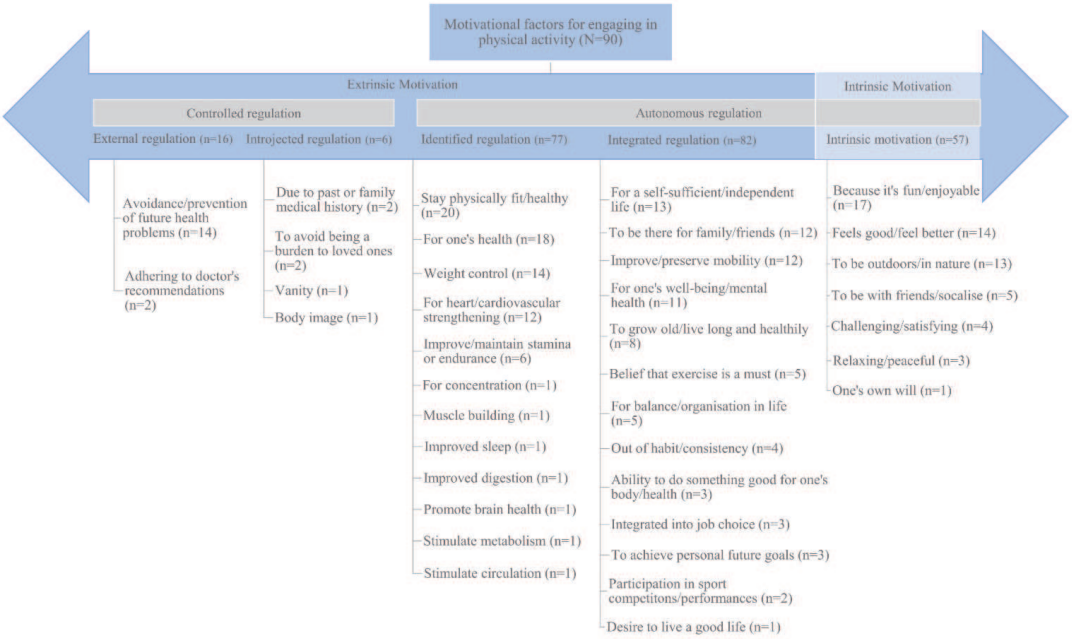


Figure 4. Patient-provided motivating factors for physical activity engagement categorised according to a framework of the self-determination theory of motivational continuum. Open-ended responses were provided to the question 'State three things, circumstances or thoughts that personally most motivate you to engage in heart-healthy PA and keep you going'. *Multiple responses permissible per respondent (N = total sample size, n = number of response occurrences).*

Under autonomous regulation, the majority of reasons that patients reported were associated with integrated regulation, i.e., motivating factors which related to individuals' sense of self, values and goals. The most frequently occurring reasons for PA mentioned by patients were for sustaining a self-sufficient/independent life in old age, to be present for loved ones, for preserving mobility in age and for their well-being. Additional reasons relating to patients' desires to increase length and quality of life, beliefs of PA, habits and personal goals were mentioned and categorised as integrated regulation.

Next, reasons for engaging in PA relating to the perceived benefits of PA were frequently expressed by patients and categorised under identified regulation. In terms of identified regulation, the most frequently perceived benefits of PA were related to fitness and health outcomes. Specifically, perceived benefits of physical health, general health, weight control and heart/cardiovascular strengthening were most frequently mentioned. Additional benefits of PA viewed by patients were relating to improved endurance, everyday functioning aspects (e.g., concentration, sleep, digestion, brain health) and muscle building.

Finally, intrinsic motivations for PA were present, but to a lesser occurrence than identified or integrated regulation reasons. The most frequently mentioned intrinsic motivations were those associated with viewing PA as a sense of enjoyment (e.g., fun and feeling good) and it relating to a desire and opportunity to be outdoors. Other factors that were mentioned were associated with ability to socialise, relax, as well as providing a sense of a satisfaction/challenge and one's own will.

Discussion

We conducted a cross-sectional multi-centre survey to assess cardiac patients' behaviours, preferences and opinions of PA in long-term secondary prevention. Overall, we observed that our sample was generally physically active in terms of aerobic activities and displayed preferences for cardio, individual and outdoor sport activities (e.g., cycling, walking, hiking). Moreover, determinants for PA behaviour were mostly stipulated by physical factors (e.g., health and pain) and motivation - with autonomously regulated motivation playing a key role in PA engagement.

Physical activity behaviour, preferences and beliefs

Overall, patients displayed a relatively high engagement in aerobic PAs in terms of minutes and frequency per week. However, only approximately a quarter (24.7%) of patients achieved the World Health Organisation (WHO)'s recommendations of combined aerobic and muscle strengthening training consistent with trends in the Austrian general population [235]. The need for increased muscle training is evident due to the positive combined outcomes of aerobic and muscle training observed. Specifically, the addition of resistance training on top of aerobic training leads to greater increments in physical fitness and muscle strength in CVD patients [236]. Moreover, muscle weakness is a strong predictor of premature death in CVD patients [237]. As such, our findings suggest that there may be a need for greater attention of muscle strengthening training in CVD secondary prevention. One potential practical implication is to initiate muscle strengthening interventions at the end of CR with the focus of supporting patients in transitioning to a home-based resistance routine. For example, a prior study, which utilised a social cognitive theory-based resistance training manual and Thera-Bands found increased self-efficacy, outcome expectations for and adherence to resistance training after CR, compared to standard exercise recommendation use [238]. Other possibilities could involve mobile health strategies, such as supportive push-messages and educational messages related to CVD management, which was found to be effective in increasing PA in a pilot randomised control trial [239]. Given that heart strengthening served as major motivational factor for PA engagement in our sample, interventions which educate patients on the beneficial effects of resistance training on heart strengthening, provide tailored training based on CVD condition [240], and exercise recommendations or materials that can be performed in a home setting may aide in increasing resistance training after a structured CR. For some patients, community-based strength training classes incorporating behavioural change strategies and peer support may be more fitting [241].

The majority of patients displayed PA location preferences for being outdoors, in their garden or at home, as well as activity preferences for individual, non-competitive sports. This reflects previous findings which report that retired adults spent more time in outdoor, natural environments, and older adults showed lower preferences for scheduled, competitive or team-based physical activities [242,243]. As our patient sample consisted primarily of older adults, our results could reflect age-related preferences for exercising. Practical implications might, thus, involve having clinicians or

healthcare professionals recommend community programmes, such as walking groups or participation in non-competitive community-led events, such as fun-runs or group walks [244]. This could assist with goal-setting strategies and elicit positive effects associated with a sense of community feel. Additionally, given the high marital rates and older aged sample, couple-focused PA interventions could be a focus of secondary prevention, as the spouse often plays a significant social support role in later life [245,246]. This could allow for interventions that are adapted to the physical and social environment of the patients' home. Furthermore, previous findings show that physically better and healthier patients prefer home- over centre-based cardiac rehabilitation [220], which could reflect the preferences we see for home-situated over sport facility-based PA among our sample which reported relatively high health-related quality of life. Thus, for this sample, promoting home-based exercises may encourage patients to exercise regularly, as it aligns with their preferred social-environmental setting and simultaneously limits barriers associated with gym-based exercising, such as travel time and membership costs [247]. However, for patients who are frail or less well, considerations may be required to ensure that at-home exercising is engaged in safely. Implications for this may include home-based PA coaches or novel digital approaches. For example, a computerized decision support system that could guide patients in their physical exercises may serve as a beneficial tool [248].

Overall, we found that patients displayed a strong understanding of why they should be physically active, indicating high awareness and knowledge of the positive outcomes associated with PA. However, fewer patients expressed strong agreement that they perceived being physically active was important for *themselves.* Thus, we highlight a potential dissociation for some between knowledge and internalised beliefs, and support prior studies that PA knowledge itself may not be sufficient for PA behaviour, and other approaches to increase a positive view of PA are needed [249]. Here, our suggestions include following guidelines for increasing PA, which is multi-faceted orientated. For example, Fletcher et al. (2018) addressed that promoting PA should be targeted at the individual, educational/community and societal level. This included actions such as personalised exercise recommendation, self-monitoring and reducing barriers to PA (at the individual level), PA promotion during outpatient visits by physicians and community-led initiatives (at the educational/community level) and better PA-promoting infrastructure and green spaces (at the societal level) [199].

Determinants of physical activity engagement

We found that patients perceived their own health, pain and motivation as main determinants for PA engagement. For the majority of patients, their health – whether good or bad (self-reported)– was perceived to facilitate their engagement in PA. Thus, patients in our sample may have generally viewed their health positively in terms of supporting an active lifestyle (i.e., providing them with the capacity and ability to engage in physical activities). This would align with the general high perception of health-related quality of life status we report in our results, and highlight prior findings that greater perception of health is correlated with more PA engagement [133]. Similarly, health may function as facilitator for PA primarily out of motivation for improved or better health, as health benefits of PA are indicated to play a significant role in cardiac patients' engagement in PA [45,162]. On the other hand, poor health may hinder PA engagement if health constraints limit ability and/or participation in PA [250,251]. In this case, PA prescription may be particularly useful in bridging communication between health care providers and patients, and ensuring PA is appropriate, safe and fitting to patient

needs [252]. Here, we suggest the use of shared decision making between an HCP and patient to ensure that PA exercises align to patients' identified health goals and values [253,254] . In our study, we found that along with physical and general health outcomes, patients expressed specific goals of weight control, heart strengthening, and quality of life among others. Thus, practical implications may involve educating patients and recommending physical activity regimes that target these goals.

Pain similarly served as an important determinant of PA engagement, but functioned primarily as a barrier to PA engagement, as is mirrored in recent literature [250,255]. Specifically, an association between musculoskeletal pain and greater mobility disability highlights the role that pain plays in reduced bodily movement and performance of daily activities [256]. Despite this, a few patients rated pain as facilitating for PA engagement, which may indicate motivation to engage in PA for reasons of pain reduction or improved physical function goals [257]. Interestingly- and somewhat surprisingly, in our study, fear-related factors (e.g., worry of injury, perceived danger, anxiety) were not greatly present, despite documentation in similar research reporting a close link between pain and fear [258]. In particular, prior studies highlight fear of PA poses a major challenge in PA engagement among cardiac patients [189,259]. Potential reasons for the low-reported mental distress in our sample may be a result of having attended CR, where they learned about the needs, benefits and safe manners to be physically active. This would support prior findings indicating an association between CR attendance and reduced odds of kinesiophobia (i.e., fear of movement) [189]. Thus, our data call for further intensifying the current practice of implementing PA interventions which simultaneously target physical and mental factors to enhance PA adherence in secondary prevention.

Finally, motivation additionally served as an important determinant for PA, and was mostly viewed as facilitating for PA engagement. Given the general high engagement in aerobic training in our sample, our findings echo those of earlier ones that motivation is important for engagement in PA [46,260]. On the other hand, some patients marked motivation as hindering for PA engagement, which likely suggests a lack or inability to motivate themselves to be active. This may be attributed to a variety of factors including loss of interest, inability to see benefits or health constraints [261]. In this case, goal-setting strategies may be particularly effective for increasing PA behaviour, as has been supported in a prior systematic review [262]. Practical implications could thus involve self-tracking methods to monitor progress or supported guidance from a healthcare provider or sports coach. Given that goal-setting interventions were observed to be effective regardless of the delivery mode [262], this sheds light on the possibility of digital tools to serve as a practical medium for goal tracking.

Although age, time and weather were reported to a lesser extent as determinants for PA, they still played a role in PA engagement for roughly half of patients. Thus, these factors still warrant observation and may contribute to PA adherence for certain demographic groups. For instance, time and age factors suggest that PA interventions should be adapted for a variety of age- or scheduling needs (e.g., older age, retired vs. working adults, etc) [242,263]. Moreover, as weather factors may influence PA engagement, efforts to encourage PA in a variety of weather and climate conditions may help to increase adherence among patients, and may be especially needed during colder or rainy seasons [264]. Promoting indoor physical activities or adapting PA intensity to seasonal changes may encourage PA in seasons with low PA, such as winter [265].

Overall, the least influencing factors on PA were caring responsibilities (e.g., dependents or minors) and resource-related factors (e.g., cost, quality or availability of sport facilities). Given our general older age, retired sample, this may reflect generational-specific influences. Specifically, in that

responsibility-related barriers (e.g., family, job) may play less of role in PA engagement for older adults, allowing for more flexibility in terms of time commitment and scheduling [263]. Moreover, the largely neutral stance of resource-related factors suggests that patients mostly do not perceive sport facilities (e.g., options, quality, availability, etc) as influencing for PA and echo the aforementioned preferences we see for outdoor or home-based PA locations over sport centres. This may lend itself well for PA interventions, such as digital health interventions, which can be engaged in remotely, self-sufficiently, and in the comfort of patients' home or outdoor environment [60]. Interestingly, we did not find that social support factors (e.g., family and friends) contributed greatly to PA engagement, which again may indicate higher preferences for individualistic rather than team-based activities in this demographic group [242]. Overall, our findings highlight the importance of considering generational and lifestyle needs and preferences in the design of PA interventions.

Motivation for PA using self-determination theory

In terms of patients' motivating factors for PA, our results display an overwhelming amount originating from autonomously regulated motivation. As our respondents had been in CR approximately three years prior to our survey and were therefore in a phase of lifelong lifestyle change, i.e., long-term secondary prevention, our results support other findings suggesting that intrinsic motivation and more autonomously regulated extrinsic motivation contribute to long-term behaviour maintenance [54,266].

The most frequently mentioned motivating factors, namely, enjoyment, positive health outcomes, and alignment with goals and sense of self (e.g., remaining self-sufficient, present for family, for one's well-being, aging healthily) are consistent with previous findings of PA adherence among cardiac patients. Specifically, Fraser et al. (2022) reported that cardiac patients were motivated to be physically active out of reasons for regained independence, improved mental and physical well-being, as well as prolonged life [45]. Additionally, Warehime et al. (2020) reported that improvements in individual health and changes to well-being motivated heart failure patients to engage in long-term PA adherence [260]. Interestingly, we also reported a frequent mention of being in nature and outdoors as a motivating reason for PA in our sample. This is aligned with our aforementioned closed-ended question results pertaining to patient preferences for exercising outdoors and further strengthens the role of nature as a motivating factor in PA engagement in our sample.

In contrast, we do not report many controlled extrinsic motivations (e.g., others saying so, out of reasons to escape guilt) in our findings. However, out of the controlled motivations we see, the most frequently mentioned factor was exercising out of an avoidance or prevention of adverse health problems. Although avoidance or prevention may be facilitating for PA, reasons stemming from a fear of disease progression may be linked to distress and negative emotional responses in chronic disease patients [267]. Thus, it is important that individuals who are mainly motivated to engage in PA primarily out of avoidance reasons are also provided with necessary emotional support to cope with illness distress if needed.

Overall, the general few frequencies of controlled motivation we see may be related to the stage of secondary prevention in which patients found themselves. It is likely that patients were initially more extrinsically motivated to be physically activate due to physician or CR recommendations, but over time these motivations became more internalised. This would be supportive of prior findings, which show increased autonomy satisfaction during CR predicted increased intrinsic motivation and in turn long-term PA [268]. On the other hand, this may suggest that patients who struggle to internalise behaviour regulations during initial stages of secondary prevention, may have difficulty adhering to PA in the long-term. As such, specific attention may be needed to support those who struggle to internalise behaviour regulations. Practical implications may include assessing patients' sense of

autonomy, competence and relatedness, as well as self-determined motivation during CR, as it can provide potential indication of long-term PA adherence [268,269] .

Despite the observations we see in our study, cardiac patients do not generally maintain adherence to PA recommendations following CR [35,195,196,270]. Possible reasons for this are that patients are not provided with the resources, knowledge or time to integrate these behaviours into their daily lives. To combat this, habit-formation techniques (e.g., guidance, cues, reminders, discussed shared experiences and action planning) may be of particularly use in increasing adherence [271]. Thus, improvements in long-term PA interventions could be focused on increasing patient autonomy and capacity to establish PA habits in conjunction with service models that cater for patients long-term, such as provision of ongoing supervised exercise therapy and digital/telerehabilitation offers.

Limitations and future directions

Our study was mainly limited by the self-selected nature of the sample, leading to possible response bias towards more physically active and healthy cardiac patients. Additionally, as the study was self-administered and anonymous, we were unable to follow-up on patient responses, which would have been particularly beneficial for understanding influences on response reasoning behind determinant selection and motivating factors. Moreover, this meant that we could not verify that the posted individuals filled out the questionnaire themselves or if anybody influenced their response decision (e.g., caregivers, family members). Use of the CR clinics to send the questionnaires did help ensure that the questionnaires were correctly addressed to patients' addresses, however, the absence of a present researcher meant that a direct observation of questionnaire completion or the ability to intervene if participants had questions/difficulties was not possible. We attempted to counter this by using two main strategies. Firstly, the questionnaire underwent a prior rigorous, iterative testing process with seven cardiac patients to pilot test understanding of the questionnaire content in a small sample. Secondly, we provided contact information (email and phone number) of the research team, in case any patients wished to contact us for assistance or information. We acknowledge a limitation in that, despite having an older age sample, we did not assess participants' cognitive level nor could accurately assess cognitive level given the study design. Given the results of the EQ-VAS, it suggests our sample mainly consisted of patients with relatively good health-related quality of life, but future work would benefit from assessing cognitive level in such an older-aged patient sample.

Despite our limitations, we gained important insights into a rather unexplored area of PA motivation in long-term CVD secondary prevention, and through the use of a postal questionnaire, were able to also reach those less technologically affined, typically older adults. Future directions could focus on conducting in-depth qualitative interviews and focusing on recruiting harder-to-reach patients (e.g., physically inactive and/or less healthy). Furthermore, our findings highlight the importance of increasing autonomous motivation for long-term PA engagement in secondary prevention. Future work could be focused on implementing specific SDT-theory techniques in long-term secondary prevention. For instance, Teixeria et al. (2020) employed an iterative expert consensus procedure to develop a classification list of 21 SDT-driven motivation and behaviour change techniques for use in health contexts [269]. The classification is based on the three underlying psychological constructs of SDT, namely increasing autonomy, competence, and relatedness, which in turn, are intended to promote autonomous motivation [269]. These include techniques, such as promoting self-monitoring, electing meaningful (e.g., personal, tailored) rationale for behaviour change, creating a concrete plan of action and eliciting perspectives on the condition or behaviour [269]. As such, the integration of health behaviour change techniques that are in alignment with existing patient-desired health

outcomes (e.g., longevity, independence, mobility) may encourage greater autonomous motivation and in turn adherence to PA.

Conclusions

The success of PA-promoting interventions in the secondary prevention of CVD is based on the needs and preferences of cardiac patients. Our results indicate that individual, cardio and outdoor activities are especially well received by cardiac patients and could be of particular use in designing PA interventions. Additionally, although increasing general PA levels should be of primary importance, our findings call on a need for promoting muscle strength training in secondary prevention. Moreover, our findings highlight that physical factors (e.g., health, pain) and motivation – especially autonomous motivation – play important roles in engagement of PA in long-term secondary prevention. Thus, PA interventions which foster autonomous motivation – specifically through alignment with patient preferences and/or health or pain-related goals – may lead to increased adherence to PA, even in later stages of the CR pathway.

CHAPTER 4

Use and perceptions of digital technology for daily life, physical activity and health information among former cardiac rehabilitation patients in Austria: A cross-sectional study

Chapter 4: Use and perceptions of digital technology for daily life, physical activity, and health information among former cardiac rehabilitation patients in Austria: a cross-sectional study

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Abstract

Objective

Digital health technologies offer great potential to improve access and adherence to cardiovascular disease secondary prevention measures such as regular physical activity (PA). However, the use and perceptions of digital technology (DT) among cardiac rehabilitation (CR) patients are not well understood. The aim of this study was therefore to explore the use of DT in former CR patients' daily lives, for PA, and for health information; and to gain insight into patient perceptions of DT for PA, including barriers, facilitators, and requested features.

Methods

A cross-sectional postal survey was conducted between May 2022 and January 2023. Five Austrian CR centres contacted 500 former patients who had completed a phase 2 CR programme from January 2019 onwards. One-hundred seventeen patients (mean (SD) age, 69±10 years, 22% female) responded. Descriptive and thematic analyses were conducted for closed and open-ended questions, respectively.

Results

Results indicated high DT usage for communication and informational aspects, and to a large extent also for PA and health information seeking. Main facilitators of DT use for PA were attributed to health and behavioural monitoring. Main barriers were lack of perceived need, lack of interest, and poor usability. Most frequently requested features included pulse and blood pressure measurement, step count, and compatibility to other devices.

Conclusions

Patients generally used and perceived DT as beneficial in daily life and for secondary prevention purposes such as PA. The survey identified facilitators, barriers and feature requests, which may inform the design and implementation of digital health interventions for CR patients.

Introduction

Globally, cardiovascular diseases (CVDs) remain the leading cause of death [12]. Cardiac rehabilitation (CR), a secondary prevention model classified as a class 1 level A indication for treatment of CVDs, has been shown to reduce morbidity and mortality, and increase health related quality of life [272–274]. The major goal of CR are changes in lifestyle behaviours, e.g., increased physical activity (PA), to reduce the likelihood of progression of the disease, recurrent cardiac events and hospitalisations [275]. However, CR is often underutilised, and recommended behavioural changes, such as PA engagement, are often not sustained over time [75,219,270,276,277].

Digital health technologies offer great potential to support patients with behavioural changes. For instance, digital health interventions – including web-based, telemonitoring and mobile health (mHealth) applications – can provide physiological and behavioural tracking capabilities, motivational feedback, and access to educational materials; and have been shown to achieve desired changes in behavioural, health and patient satisfaction outcomes [59,278–280]. Despite these benefits, the acceptability and use of digital health technologies among CVD patients remain suboptimal. For one, many digital health developments are often driven by technology and fail to adequately incorporate perceptions and needs of patients during the development process [67]. Moreover, previous studies investigating outcomes of digital health technologies often excluded individuals without access to internet or mobile devices (e.g., not owning a smartphone), or recruited comparatively young study samples (mean ages 50 to 65 years) [280]. Therefore, insights obtained from these studies may be biased towards more digitally skilled or younger individuals and not generalisable to all CVD patients, especially older adults who face the greatest burden of CVD [231] but typically use digital technology (DT) less [281,282].

As such, if digital health interventions are intended to be used for CVD secondary prevention, the use and perception of DT in a typical, older aged sample is a necessary step to investigate. The aim of this study was therefore to explore the use of DT in former CR patients' daily lives, for PA, and for health information; and to gain insight into patient perceptions of DT for PA, including barriers, facilitators, and requested features.

Methods

Procedure

We conducted a cross-sectional survey using a postal questionnaire. In the reporting of the study, we adhere to the STROBE guidelines [228]. Between May 2022 and January 2023, a total of 500 postal questionnaires were distributed from five CR centres (100 questionnaires per centre) located in four Austrian federal states (Carinthia, Vorarlberg, Upper and Lower Austria). Questionnaires were posted to patients' home addresses corresponding to the chronological order (beginning from January 2019 onwards) of completing a phase 2 in- or outpatient CR programme. Participants returned completed questionnaires to the research institute by post using a prepaid envelope. Participation in the survey was voluntary. As an incentive, participants could choose to enter a random draw for four fitness trackers. For individuals who preferred to complete the survey online, the link and quick response (QR) code for an online version (LimeSurvey©) were provided.

Materials

We developed a customised pen-and-paper questionnaire for self-completion in German language, as no existing published questionnaire was available to address the study aim. Questionnaire content was informed by qualitative interviews with 25 former CR patients conducted in 2020 (unpublished data).

The questionnaire included seven sections (demographic information, general health information, cardiac rehabilitation history, internet use for health information, DT use in daily life, DT use for PA, and data privacy) composed of 46 items with multiple-choice, Likert scale or free-text response options. Most items were newly developed or adapted from items in the Austrian health [235] and information and communication technology (ICT) use surveys [283,284]. The questionnaire also incorporated two short standardised instruments (EQ-5D-5L [229] and Rapid Assessment of Physical Activity [RAPA][285,286]).

The questionnaire underwent iterative development and rigorous pilot testing by members of the research team and seven cardiac patients. The questionnaire can be accessed via the Open Science Framework platform (https://osf.io/8ec2j).

Inclusion criteria

Participants were included if they were ≥18 years old, resided in Austria, and had completed in- or outpatient CR phase 2 starting from January 2019 at one of the participating CR centres. During that time, the use of digital tools such as mobile health applications had not been established at the participating CR centres, except for the use of wearable heart rate sensors to monitor exercise training intensity. Participants without proficient German language skills were excluded.

Data analysis

All returned questionnaires were anonymised and manually transferred to an online format (LimeSurvey©). From there, data were exported to Microsoft Excel files and analysed in R (version 4.2.1).

Statistical analysis was conducted primarily using descriptive analysis of central tendency (mean or median depending on the presented variables), measure of spread (standard deviation [SD] and interquartile range [IQR]) and frequencies and percentages (n, %). Two exploratory inferential analyses were conducted (McNemar test with Bonferroni correction for multiple comparison), assessing paired differences in DT use between daily life and PA, and use of internet sources versus judgement of their trustworthiness.

To assess the free-text responses, a content analysis was utilised to measure the frequency of themes (e.g., barriers/facilitators), which were determined through the use of an inductive approach [287,288]. Specifically, the following steps were performed by the first author (HM): an initial reading of the responses to identify emerging themes; categorisation into overarching themes and subthemes; points of diversion regarding overarching themes and sub-themes discussed with the last author (STK); and frequency count of the confirmed themes and sub-themes.

Ethical considerations

The study received ethical approval from three regional research ethics committees, and one regional committee waived the need for formal ethical review. In conjunction with the postal questionnaire, patients received written information about the study. For this anonymous self-completed postal

survey written consent was not required, but self-completion and return of the questionnaire were taken as implied consent and so approved by the research ethics committees.

Results

Demographics

One-hundred and seventeen former CR patients (mean age, 69±10 years, 22% female, 74% retired) participated in our survey (response rate 23.4%). Fifty-six percent had participated in inpatient CR phase 2, 50% in outpatient CR phase 2, and 25% also participated in outpatient CR phase 3 prior to the study *(with more than one type of former CR possible*). Patients' cardiovascular history consisted of mainly coronary heart disease (*including angina pectoris, myocardial infarction, percutaneous coronary intervention, and bypass operation*) (73%), heart failure (16%), and heart valve surgery (10%). Table 1 presents participants' sociodemographic and clinical characteristics.

Physical activity

The sample was predominantly physically active (66% as determined by the RAPA questionnaire) and healthy (median [IQR] perceived health score, 80 [60,85] out of 100). The median frequency and hours of PA per week were 4 [3,5] times a week and 4 [2,8] hours a week.

Table 1. Participants' sociodemographic and clinical characteristics

Female, n (%) *(N = 116)*		25 (22)
Age (years), mean (SD) *(N = 112)*		69 (10)
Body mass index (kg/m^2), mean (SD) (*N = 115*)		28 (5)
Employment status, n (%) *(N = 115)*	Employed	26 (23)
	Unemployed	2 (2)
	Retired	85 (74)
	Permanently unable to work	1 (1)
	Other	1 (1)
Family status, n (%) *(N = 115)*	Single	6 (5)
	Partnership	7 (6)
	Married/registered partnership	89 (77)
	Widowed	7 (6)
	Divorced/separated	6 (5)
People per household, median (IQR) *(N = 115)*		2 (2-2)
Smoking status, n (%) *(N = 114)*	Lifelong non-smoker	42 (37)

	Ex-smoker	63 (55)
	Since (years), mean (SD)	21 (17)
	Smoker	7 (6)
Country of birth, n (%) *(N = 115)*	Austria	111 (97)
	Other	4 (3)
Belonging to religious group, n (%) *(N = 115)*		57 (50)
Education, n (%) *(N = 115)*	Mandatory school (completion of nine years of school)	9 (8)
	High school degree (completion of 12 years of school)	17 (15)
	Apprenticeship with vocational school	49 (43)
	Technical or commercial school	15 (13)
	University or technical college degree	20 (17)
	Other	6 (5)
Household income (euros/month) after tax, n (%) *(N = 112)*	≤ 1200	8 (7)
	1,201 – 2,600	31 (28)
	2,601 – 4,000	40 (36)
	4,001 – 6,000	19 (17)
	6,001 – 8,000	1 (1)
	> 8,001	4 (4)
	No response	9 (8)
Cardiovascular medical history, n (%) *(N = 116)* *	Angina pectoris	12 (10)
	Coronary bypass surgery	20 (17)
	Cardiac arrhythmias	13 (11)
	Heart failure	19 (16)
	Heart valve surgery	11 (10)
	Myocardial infarction	34 (29)
	Percutaneous Coronary Intervention	58 (50)
	Other	14 (12)

Type of CR, n (%) *(N = 116)* *	Inpatient Phase 2	64 (55)
	Outpatient Phase 2	58 (50)
	Outpatient Phase 3	29 (25)
	Long-term ambulatory rehabilitation after CR phase 2 or 3	7 (6)
	Other rehabilitation provision	1 (1)
RAPA I, n (%) *(N=116)*	Sedentary	0 (0)
	Under-active	1 (1)
	Under-active regular – light activities	15 (13)
	Under-active regular	24 (21)
	Active	76 (66)
RAPA II, n (%), *(N = 103)*	Muscle strengthening	43 (41)
	Flexibility	63 (61)

CR, cardiac rehabilitation; RAPA, Rapid Assessment of Physical Activity questionnaire.
* Multiple responses permissible

Use of digital technology in daily life and for physical activity

We compared respondents' use of DT in daily life (i.e., for all purposes) and specifically for physical activity. For exercise-specific DT such as pedometers and fitness trackers, this distinction would indicate whether the device is worn throughout the day (in daily life) or whether it is applied only for the purpose of tracking a planned physical activity or exercise session. Internet and DT usage were highly prevalent in respondents' daily lives. Eighty-three percent used the internet for personal use, and 96% used DT for daily life. Depictions of internet and DT use are presented in figures 1a and 1b, respectively, and show relatively low number of hours spent using the internet per week. Most frequent use of DT related to email (77%), calling (74%), and use of the internet (69%).

Seventy-seven percent of respondents used some kind of DT for PA. Ownership of a smartphone or smartwatch in this sample was 77% and 27%, respectively. The smartphone was the most popular device for both PA (35%) and daily life (66%) (figure 1c). Although the smartphone was used significantly more in daily life than for PA purposes (unlike step counters, fitness trackers, and smartwatches), it was still the most popular device for PA suggesting its preference over more exercise-specific DT. In fact, nearly half of all smartphone users (49%) also used the smartphone for PA. Additionally, 25% of patients used either step counters or fitness trackers in daily life, and a combined 40% of patients reported using either or both types of devices frequently in daily life. In contrast, significantly more respondents did not use DT for PA (23%) as compared to not using DT in daily life (4%) (figure 1c). Therefore, we see a near ubiquitous integration of DT in patients' daily lives, but to a lesser extent in PA.

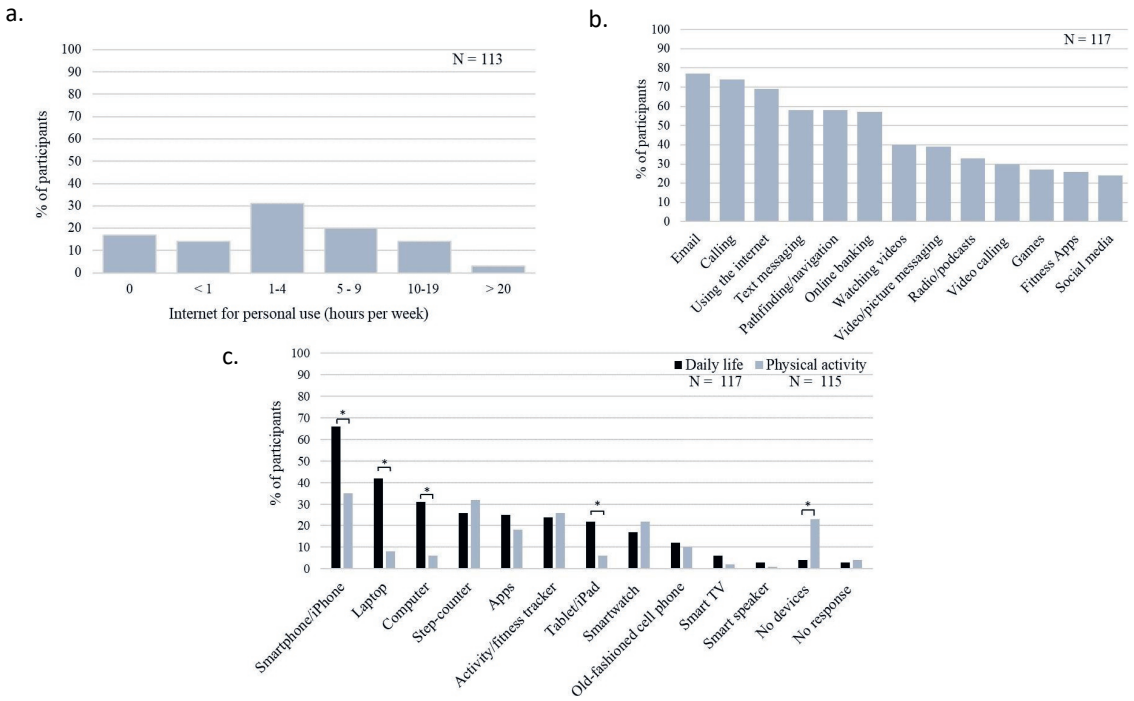


Figure 1. Use of digital technology in daily life and for physical activity: (a) Response rate to question 'If you think about your internet use (including Apps on your smartphone or tablet), how many hours do you use the internet for personal use in a typical week?' (b) Most frequently (≥20% of participants) recorded uses of technology in response to 'I use digital technology for…' (less frequent responses were 'Other Apps' and 'Status update posting') (c) Comparing response rates of question 'What digital technology do you use most frequently in daily life?' to question 'What digital technology do you use for physical activity and exercise?' For (b and c), multiple responses were permissible *p < .001.

Use of internet for health information

The majority of respondents (73%) had searched online for health information in the past three months. The most frequently searched topics are displayed in figure 2a. Searching for health information online was primarily motivated by personal health concerns or general interest (75% to 100% of times), but to a lesser extent on someone else's behalf (up to 25% of times). Besides the health topics listed for multiple choice, 33 additional topics were mentioned in optional free-text responses, including (long) COVID, polyneuropathy, blood pressure, dizziness, and cholesterol.

Types of online sources and their respective trustworthiness ratings are depicted in figure 2b. YouTube, social networks, forums, and blogs were rated least trustworthy, while the greatest discrepancy between frequency of use and trustworthiness rating was observed for Wikipedia and YouTube. Other sources of health information listed in optional free-text responses included health magazines and other print media, television, information from doctors, testimonials from other patients, Google, and webinars.

Lastly, in terms of using online information for contact with health professionals in the past three months, one third of respondents (32%) reported using the internet to search for a health

professional, and 26% reported having contacted a health professional because of health information found online.

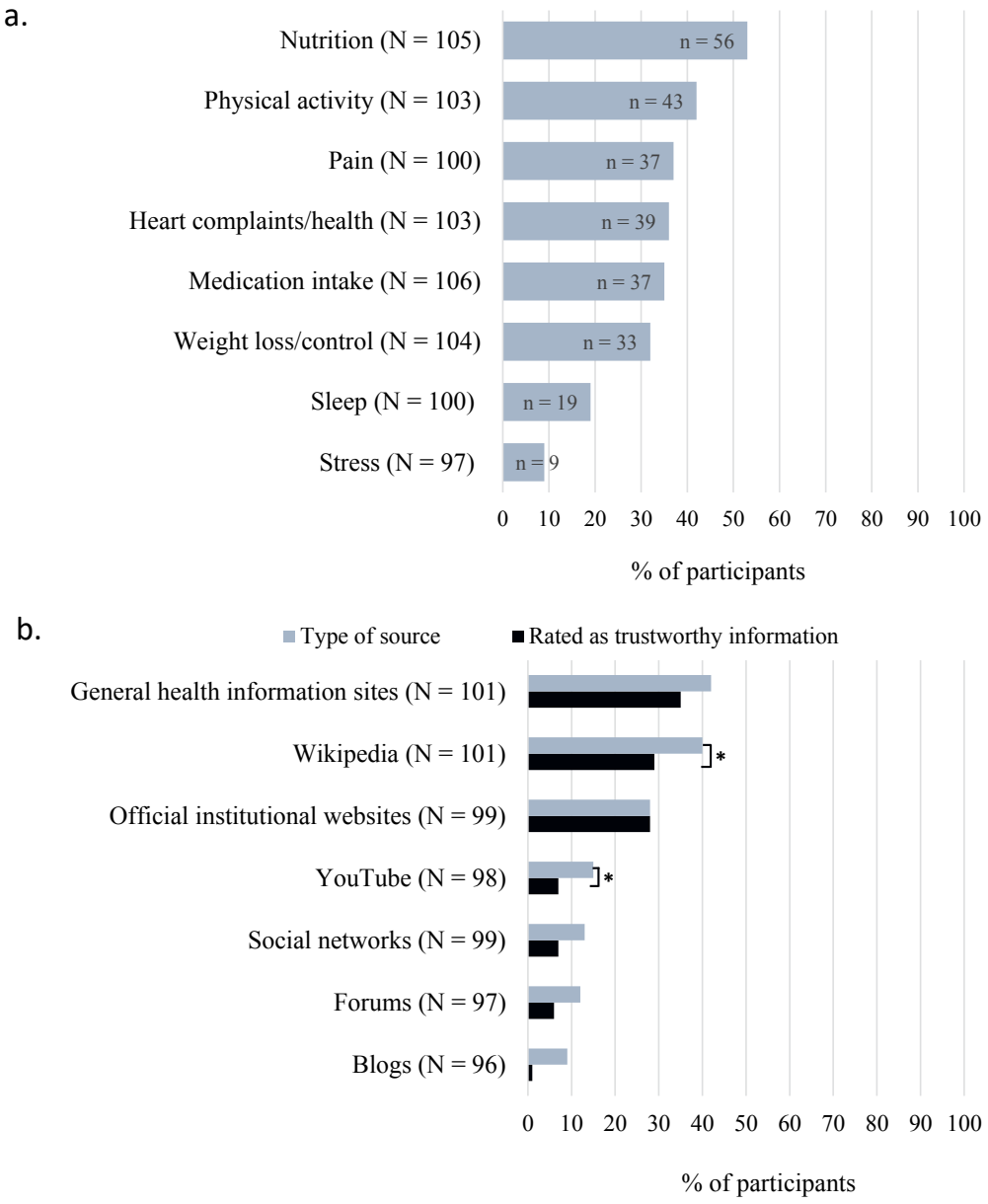


Figure 2. Use of internet for health information, N=total sample size (multiple responses permissible): (a) Eight most frequently searched health topics in response to question 'During the past 3 months, which of the following health information did you obtain from the internet and for what purpose?' (b) Comparing response rates of question 'In the past 3 months, what sources of information on the internet have you used to obtain

health information, and how would you rate the information you found?' to response 'Yes, trustworthy information'.

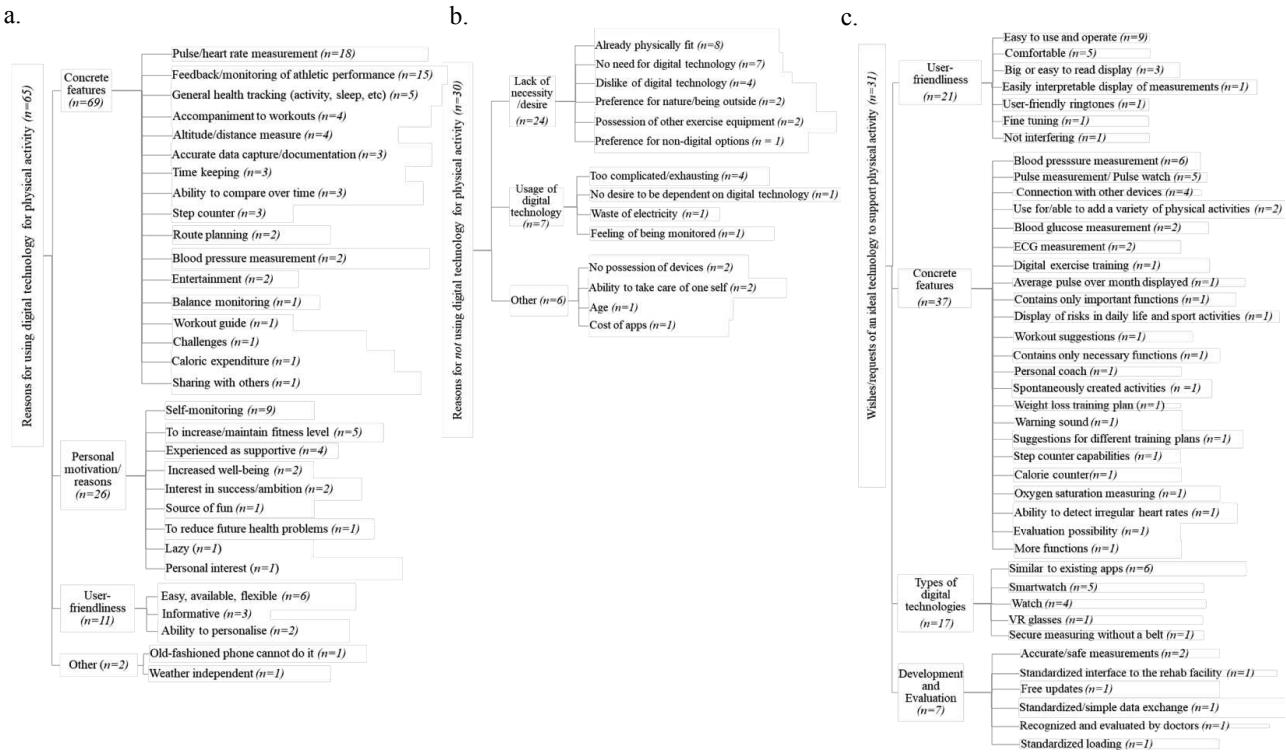


Figure 3. Perceptions of digital technology for physical activity purposes (schematic diagram according to thematic analysis of free-text responses); multiple responses permissible per participant (N=total sample size, n=number of response occurrences): (a) Response to question 'State your personal reasons for using digital technologies for physical activity'; (b) 'Give your personal reasons why you do NOT use digital technologies for physical activity'; (c) 'If you could wish for an ideal digital technology to help you engage in regular heart-healthy exercise and sports, what would it look like?'.

Perceptions of digital technology for physical activity purposes

Ninety-three respondents (79%) provided free-text answers expanding on their reasons for or against DT use for PA (figures 3a and 3b, respectively). Here, measurement of pulse or heart rate, monitoring of PA and general health status, and self-monitoring for motivational reasons were the top-reported facilitators for DT use. Trust in the accuracy of measurements (e.g., pulse, step count) was generally high, with a median [IQR] of 6 [5,6] on a 7-point Likert scale (higher ratings indicating greater trust). The top barriers to DT use were already being physically fit, having no need for DT, disliking DT, or finding DT too complicated.

Thirty-one respondents (26%) provided free-text answers regarding their ideal imagined DT for PA (figure 3c). The most popular requests were an easy to use/operate technology, sharing similarities to existing fitness apps, containing blood pressure and pulse measuring capabilities, as well as it being comfortable. These themes align with multiple-choice responses indicating a high desire for blood pressure and pulse measuring capabilities (figure 4). Additionally, although compatibility/connectivity

features were only requested by about half of participants (48%), among those that did, the smartphone was the most requested item for compatibility/connectivity purposes (81%).

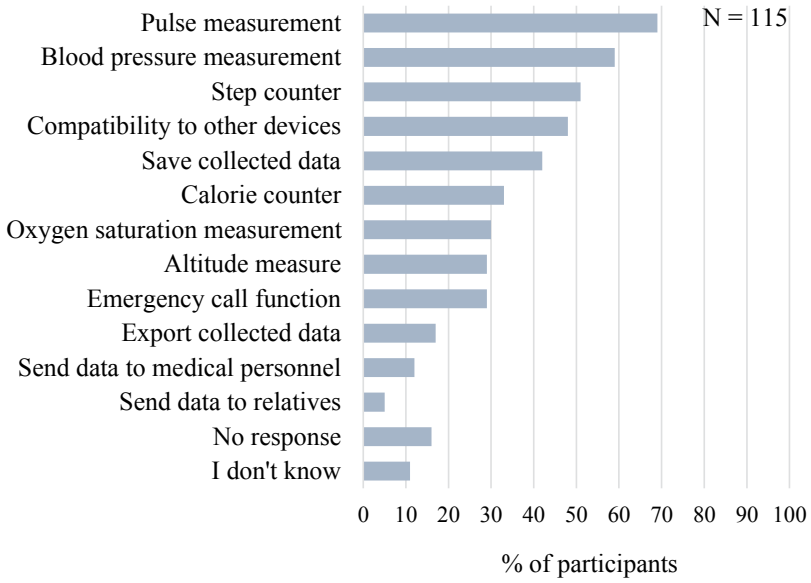


Figure 4. Responses to multiple-choice question 'What features should a digital technology ideally have so that you would use it to support your physical activity?'.

Data privacy

Responses to data privacy questions are reported in figure 5. Overall, participants indicated variable familiarity with current data protection regulations and terminology (figures 5a to 5c), but found current data protection regulations generally understandable (figure 5d). Participants indicated a tendency to not read through data protection statements before agreeing to them (figure 5e), and also indicated that information on data protection was worded in an incomprehensible way (figure 5f).

Respondents reported high willingness to share medical data for personal health benefits (figure 5g) or non-commercial research (figure 5h), but not for commercialised reasons (figure 5i). However, in an optional open question, 37 respondents (32%) expanded on circumstances under which they would share medical data for commercialised use: if it benefits others (patients or the general public) (n=12); if it confers a personal medical advantage (n=7); if anonymity is ensured / personal information is excluded (n=4); and if it is helpful for research (n=3).

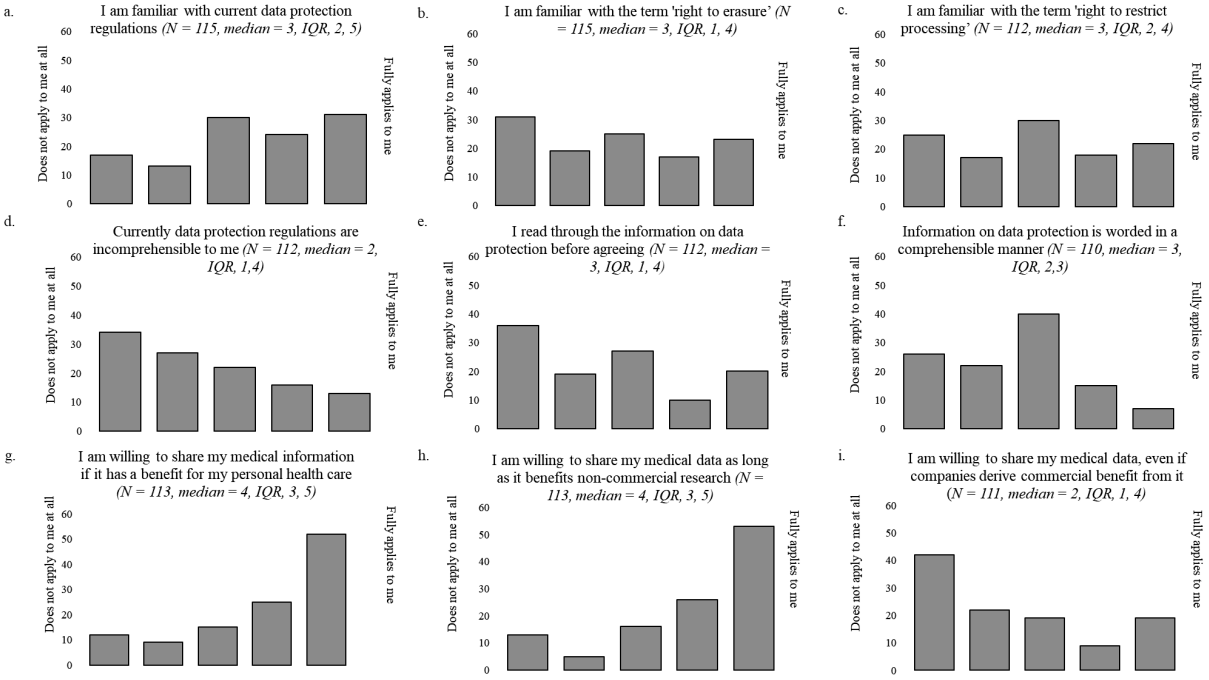


Figure 5. Response distribution of data privacy questions. Responses provided on a 5-point Likert scale from 1 (does not apply to me at all) to 5 (fully applies to me) in response to the question 'Please indicate to what extent the following statements apply to you'. Frequency count (number of participants) is reported on the y-axis.

Discussion

This study found that DT use – specifically smartphone use – was highly prevalent in CR patients' daily lives, and to a large extent also for PA purposes. DT use in daily life was primarily focused on communication and informational aspects (i.e., email, calling, internet use), whereas use of DT for PA was focused on measurement of pulse or heart rate, monitoring of PA and general health status, and self-monitoring for motivational purposes. Main barriers to DT use for PA were perceived lack of need, lack of interest, and poor usability. The majority of patients searched online for health information and displayed a willingness to share medical data dependent on a motivation to contribute to health care, research, and patient outcomes.

Representativeness of the sample

We compared our study findings to approximate age-matched population data (age groups 45-74 years old) from the 2019 Austrian health survey [235] and the 2020 and 2021 Austrian ICT survey [283,284]. While only 19.6% of 45-59-year-olds and 21.3% of 60-74-year-olds in the Austrian general population meet the World Health Organisation PA recommendations for endurance-type and muscle strengthening exercise, the percentage in our survey sample was somewhat higher (27.6%).

Nevertheless, this finding indicates a gross lack of long-term adherence to physical activity recommendations among CR patients, corroborating results from the EUROASPIRE V survey from 27 European countries which reported that only 34% of patients performed regular physical activity (≥30 minutes on average five times a week) around one year following an acute coronary event [35].

With regard to ICT use, the percentage of internet and smartphone users in our survey sample was similar to the Austrian population (approximately 85% and 70%, respectively), but there was a higher percentage of smartwatch users in our sample by approximately 10%, possibly due to a greater perceived need for CVD patients to self-monitor their health. We also compared DT use specifically among internet users (83% in our survey) against Austrian ICT survey data. Instant messaging (text and video/image) was used by approximately 72% in both groups. More respondents in our survey engaged in calling (phone and/or video calling), email use, and online banking (by 40%, 15% and 10%, respectively), while more respondents in the general population reported using social networks (by 10%). Because our sample included older age groups (≥75 years old) than the Austrian population surveys, these differences may be related to age-related preference. For instance, prior literature reported calling to be a preferred form of communication over text messaging among older adults in contrast to younger segments of the population [289]. Therefore, our findings highlight certain discrepancies in preferred communication forms, which could be related to age but also to changes in patients' preferences over time. In summary, we see that survey respondents were somewhat more physically active and used ICT and DT more than the Austrian general population.

Digital health literacy

Digital health literacy, or electronic health literacy, describes the ability to seek, find, understand and appraise health information from electronic resources, and to apply this information to address a health problem [290]. Searching for health information online was common in our sample and approximately 30% more prevalent than in the Austrian general population [21], despite our sample including older adults, who are typically reported to use the internet less for health information than younger adults [282]. This is likely related to our sample consisting of individuals with significant chronic health conditions, who have been reported to show greater health information seeking behaviour [291]. Thus, DT for health information purposes may be particularly valuable and useful for CR patients. Additionally, as our findings indicate that less than half of patients used trustworthy online sources such as general health information sites or official institutional websites, there is scope to increase access to vetted information materials and offer training in digital health literacy skills [292].

Development and implementation of digital health interventions

In terms of DT use in daily life, the smartphone was the most commonly used device and may be targeted opportunistically by intervention developers as the most prevalent conduit for digital health interventions. We saw a preferred use of more traditional communication forms (e.g., email and calling) as compared to newer communication forms (e.g., video calling, social media use). As our sample was comprised of mostly older adults, this could reflect age-related preferences or barriers to social technology use (e.g., communication preferences, low self-efficacy, fear and/or physical constraints of DT use) as reported in prior literature [293]. As such, technology preferences and barriers are necessary aspects to consider when developing digital health technologies for – typically older-aged – CVD patients.

The main reported reasons for DT use for PA in our findings suggest that DTs are largely perceived as beneficial for health and behavioural monitoring by end users. Specifically, comments such as *'to verify my performance'* and *'control for myself personally'* suggest a sense of perceived knowledge gain and self-efficacy as primary facilitators of DT use. Our findings, therefore, echo those of a previous review by Whitelaw et al. which found 'perceived usefulness' and 'empowerment' to be important facilitators for DT uptake among cardiac patients [68]. Additionally, we also report common themes between our findings and those of Whitelaw et. al. relating to ease of use and personalisation, which emphasises how ensuring user-friendliness and incorporating options for personalisation may facilitate use of digital health interventions.

Our findings regarding patient requests for PA-supporting DT again highlight the importance of user-friendly design of monitoring features for mainly pulse/heart rate and blood pressure. This is in alignment with prior literature which shows that meeting the desired functionality and enhancing ease of use contribute to digital health intervention uptake in both older adults and CVD patient samples [68,294]. DT for pulse/heart rate and blood pressure measurement are currently not integrated into smartphones but require the use of separate wearable sensor devices, often in conjunction with a smartphone app. This may explain why in our survey compatibility of digital devices was the fourth most frequent feature request for a PA-supporting DT.

The main reasons for not using DT for PA in our survey – lack of perceived need, lack of interest and difficulty of use – correspond with previously reported barriers by Whitelaw et. al. [68] and present challenges for digital intervention developers. Increased communication and education on the benefits and features of digital health interventions can explain the need and create interest in DT, particularly in patient groups who struggle with managing behavioural changes and who feel indifferent or undecided about DT. However, it is also necessary to cater to those who deliberately reject the use of DT for PA, which includes involving these groups in intervention development processes to identify how the possibilities and benefits afforded by DT may still be utilised in such user scenarios.

Overall, our survey findings support the key message that user-centred co-design – involving patients in the development of digital health interventions – is of importance to ensure optimal feature fit and user-friendly design [295], and to maximise the likelihood of DT adoption and spread from the perspective of the individual technology user [296]. Such user-centred co-design may be implemented under different academic traditions. For example, in the field of human-computer interaction, user-centred co-design methods have long been part of DT developers' toolbox [297,298] and are now increasingly applied in more nuanced and differentiated ways to address the requirements of different segments of DT development such as mobile health [299]. These established co-design methods include specific techniques for the entire development cycle from needs analysis to prioritisation of requirements, ideation, rapid prototyping, user feedback, and formative and summative evaluation. In health services research, co-production and co-creation have become familiar methodological terms describing approaches for shaping health services jointly and in collaboration with users (i.e., patients and their informal carers) [300,301]. This links with the patient and public involvement (PPI) approach, which aims to open up research and health service design to the intended user groups in order to take direction from those who should eventually benefit from the design [302] and is increasingly reflected also in the digital health domain [303]. In sum, these academic traditions offer a spectrum of perspectives on the practice of user-centred co-design, ranging from specific co-design

techniques and methods to overarching methodologies that value the close collaboration between developers (including designers, researchers, and healthcare providers) and users (including patients, informal carers and members of the public).

Data privacy

The collection and use of individuals' health data presents a pressing issue in the digital transformation of healthcare systems. While the possibility of ubiquitous data collection via smartphones, apps, and wearables promises untapped potential for patient management and research, this needs to be balanced against justified data privacy concerns [304]. With the General Data Protection Regulation (GDPR), the European Union has created a strict regulatory framework that also applies to digital health [305]. Our findings demonstrate that respondents had varied knowledge and understanding of this, and a low response to reading through data protection statements. In fact, reading through data protection statements prior to agreeing was approximately 20% less prevalent in our sample than in the Austrian general population [284], coupled with over half of respondents indicating that information on data protection was worded in an incomprehensible way.

A lack of understanding may lead to data privacy concerns and subsequent resistance to digital health technologies [294]. Transparency of data usage and storage are critical. This is particularly supported by our findings regarding patients' willingness to share medical data, provided that it is known who benefits from the data and that data are anonymised. Beyond individual patient care, these findings also have implications for the big data agenda in health as it is currently being advanced through the European Health Data Space initiative [306]. Concerted efforts to design highly accessible and user-friendly data protection statements for digital health technologies, e.g., incorporating pictorial and audio-visual designs[305], will support patients' digital health literacy and foster trust in data processing organisations.

Limitations

This study was limited due to the self-selected nature of our sample, leading to possible response bias with higher responses from more health-literate (e.g., physically active) or digitally skilled individuals. We attempted to counter this by using a postal paper-and-pencil questionnaire, recruiting patients from a geographically diverse area and including in- and outpatients CR centres (whereby the latter tend to serve somewhat younger and physically fitter patients). The response rate of 23.4% may be regarded as fair, considering that patients were approached three to four years after their episode of care at the respective centres. Of note, it was considered important to collect data from patients several years after their CR, to inform the use of DT for supporting long-term PA behaviour in the secondary prevention of CVD. A further limitation relates to the lack of psychometric validation of those questionnaire items which were developed anew for this study (as opposed to those questionnaire items which were incorporated from national surveys and standardised instruments). Lastly, the study was limited by the lack of a prospective sample size calculation. While aiming to recruit as large a sample as feasible, the sample size for this exploratory and descriptive survey was guided by considerations of cost and resources.

Conclusions

Digital health technologies have the potential to greatly improve CVD secondary prevention, but their usefulness depends on their perception and likelihood to be utilised by patients. Our results

demonstrate that DTs – especially the smartphone – play an integral part in former CR patients' daily lives and are frequently used to support PA. Thus, our findings suggest the potential use and benefit of DT for CVD secondary prevention, but also highlight current barriers of DT use and suggestions for developers of digital health interventions.

CHAPTER 5

Factors influencing the uptake of digital health interventions for cardiovascular disease prevention among healthcare providers: a systematic review

Chapter 5: Factors influencing the uptake of digital health interventions for cardiovascular disease prevention among healthcare providers: a systematic review

This chapter is currently under review at Global Heart:

Kraselnik, A., McGowan, H., Amiali, I.A., Gibson, I., Joshi, S., Magero, N., Miller, C., Oulousian, S., Sharma, A., Mbiydzenyuy, F.S., Kulnik, S.T., Shah, N.S (2025). Factors influencing the uptake of digital health interventions for cardiovascular disease prevention among healthcare providers: a systematic review. ***Under review*** at Global Heart.

ABSTRACT

Digital health interventions (DHIs) offer major potential for improving cardiovascular disease (CVD) prevention, but their adoption by healthcare professionals (HCPs) remains inconsistent. This systematic review aimed to identify barriers and facilitators to DHI uptake in CVD prevention from HCPs' perspectives. We included 125 primary studies published between 2020 and 2024 (101 qualitative, 15 quantitative, 9 mixed methods), analysing perceptions of DHI implementation. Factors were categorised using the World Heart Federation Roadmap domains: HCPs, patients, technology, and health systems. Quality was appraised using validated tools.

The most frequently cited barrier was excessive workload, both from existing responsibilities and additional tasks introduced by DHIs. The leading facilitator was the perceived positive clinical impact of DHIs—such as improved adherence, reduced hospital readmissions, and better outcomes. HCP motivation, adequate training, and system integration also facilitated adoption. Many factors—like effects on HCP-patient relationships and workflow—functioned as either barriers or facilitators, depending on the setting.

Patient-related barriers included limited digital access and literacy; facilitators included perceived gains in patient-centred care. Health system factors such as organizational structure, financing, and policy support were commonly mentioned, with mixed views. Technology-related facilitators included usability, adaptability, and integration with electronic records; instability was a key barrier.

This is the first systematic review to synthesize post-COVID-19 literature on HCP perceptions of DHIs in CVD prevention. While offering a rich, global overview, limitations include a predominance of qualitative studies and lack of data from low-income countries. Effective implementation must address workload, align with workflows, and build trust through training and leadership.

Introduction

Cardiovascular diseases (CVDs) remain the leading cause of death globally, taking an estimated 17.9 million lives each year [307]. A significant discrepancy persists between best practice (based on high-quality evidence) and the care provided in routine practice [308]. There is increased recognition of the potential of digital health interventions (DHIs) and digital health tools (DHTs) to address this discrepancy and transform and improve CVD care.

DHIs include an array of tools that facilitate enhanced patient care. Examples include DHIs that enable remote monitoring for efficiency (e.g., "smart" versions of blood pressure cuffs), remote monitoring and management for improved care (e.g., apps and devices for daily measurement of weight), clinical decision support (e.g., apps that integrate within electronic health records), patient engagement (e.g., solutions that promote patients' active participation in their care), telehealth and virtual visits, point-of-care and workflow enhancement (e.g., communication and sharing of clinical data electronically), and patient access to clinical data (e.g., online portals showing results of lab or imaging tests) (3). Evidence of effectiveness is available for numerous DHIs that support CVD prevention, from physical activity promotion [309–312], healthy eating [313–316], weight management [312,317,318], smoking cessation [319–322], to the management of hypertension [316,323–327], prediabetes [328,329] and type 2 diabetes [330,331].

Despite the availability of many evidence-based DHIs for the management and prevention of CVDs, low acceptability from healthcare providers (HCP), patients, and other key stakeholders remains a significant roadblock to the global uptake of these DHIs [332]. Acceptability of clinical interventions has been defined as 'the perception among implementation stakeholders that a given treatment, service, practice, or innovation is agreeable, palatable, or satisfactory' or satisfaction with various aspects of the innovation (e.g., content, complexity, comfort, delivery, and credibility) [333]. Specific to technology acceptance, the Unified Theory of Acceptance and Use of Technology describes 11 factors influencing use intention and use behaviour, such as the expectation of performance, expectation of effort, social influence, and facilitating conditions. There is an urgent need to facilitate global adaptation and uptake of existing evidence-based DHIs to bridge the gap between best practice and usual care, as emphasized in the World Health Organization (WHO) Global Strategy on Digital Health 2020-2025 strategic objective 4 (advocate people-centred health systems that are enabled by digital health) which states:

"The strategic objective places people at the centre of digital health through the adoption and use of digital health technologies in scaling up and strengthening health service delivery. The individual is an essential component in the delivery of trust-based, people-centred care. This focus covers not only patients, families and communities but also the health workers who need to be prepared to deploy or use digital health technologies in their work" [334].

Several investigations focus on patient-level facilitators and barriers to DHI uptake. However, HCP represents another important stakeholder group for the implementation of DHIs in clinical practice, because HCPs are often the group that introduces, initiates or recommends DHIs to patients. We therefore performed a systematic review to identify factors influencing the uptake of DHIs for CVD prevention, with a focus on acceptability among HCPs.

Two recent systematic reviews (Whitelaw et al. [68] and Borges do Nascimento et al. [72]) summarize prior evidence regarding facilitators and barriers to uptake of DHIs among HCP.

Whitelaw et al. (2021) conducted a systematic scoping review identifying key barriers such as increased workload, lack of integration with clinical workflows, insufficient institutional support, and limited reliability or usability of technologies, while facilitators included organizational endorsement, perceived usefulness, and enhanced communication and efficiency. More recently, Borges do Nascimento et al. (2023) performed an umbrella review encompassing over one hundred systematic reviews, reporting that infrastructural limitations, psychological barriers (e.g., lack of confidence or digital competence), and concerns about time burden were the most common obstacles, whereas education, training, and demonstration of clinical effectiveness were consistent facilitators of adoption. Together, these reviews highlight that both individual- and system-level factors must be addressed to optimize DHI implementation in healthcare settings. However, the review by Whitelaw et al did not include evidence generated during the COVID-19 pandemic, a period in which the relevance and perceptions of DHI were deeply modified. The review by Borges do Nascimento et al, while more recent, included only systematic reviews, did not analyse primary studies, and did not focus specifically on CVD.

The objective of this systematic review is to address the existing knowledge gap by synthesizing evidence on the use of digital health interventions for cardiovascular disease (CVD) prevention, focusing on studies published during and after the COVID-19 pandemic (2020–2024), and thereby extending prior evidence syntheses conducted in CVD populations.

Methods

This systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) 2020 checklist [101] and was registered in the International Prospective Register of Systematic Reviews database (PROSPERO Number: CRD42024535062).

Eligibility criteria

Eligible were primary studies which address factors (i.e., facilitators and barriers) that influence the uptake of DHIs by HCPs, published between 2020 to 2024. For this review we only considered studies that involve HCPs as participants, including physicians, nurses, social workers, pharmacists, caregivers, psychologists, nutritionists/dietitians, physiotherapists, paramedics, rehabilitation professionals, podiatrists, and exercise physiologists. DHIs were considered broadly to include tools that facilitate communication with and engagement of patients (such as telehealth); collect and summarize patient-level clinical data (such as wearable devices); and measure quality of care (such as clinical decision support tools), guided by the American Medical Association's classification of digital health tools [332] and the WHO 2.0 classification of digital interventions [335]. CVD prevention was defined broadly, including both primary and secondary prevention, and with no restrictions based on type of CVD (e.g., atherosclerotic CVD, heart failure, arrhythmia, etc).

Qualitative, quantitative and mixed-methods study designs were included, as long as the study obtained HCPs' perspectives (e.g., interviews, focus groups, questionnaires) in order to maximize responses. Excluded were studies without generalizable findings, providing only quantitative usability

scores of a single DHI, and studies used to inform the design, instead of the perceptions of an existing DHI. Additionally, excluded were case studies, conferences, posters and non-peer-reviewed manuscripts. Studies which did not focus on CVD prevention, did not include perspectives from HCPs, or did not involve patient-facing DHIs (i.e., direct or indirect interaction and engagement of the tools with patients) were excluded.

Information sources

We searched Ovid MEDLINE, CINAHL, Embase, Scopus, Web of Science, ACM Digital Library, IEEE Xplore, and Google Scholar in May 2024. We also performed a collateral search of reference lists from relevant systematic reviews.

Search strategy and study selection

Records were retrieved using the search strategy developed and executed by a clinical librarian at the Galter Health Sciences Library at Northwestern University (Chicago, IL, USA). Full search strategies are provided in Additional file 1. Following the creation and execution of the search strategy, a pilot screening of 100 titles and abstracts was conducted by all members of the research team. Any disagreements were resolved through discussion to ensure alignment in the screening process.

After the pilot screening, records were distributed among nine members of the research team for independent double-screening of titles and abstracts to identify studies that met the inclusion criteria or those in which the available information was insufficient for a decision. After compiling the list of studies deemed potentially appropriate based on the study aims, design and overall findings, full-text versions of all selected articles were reviewed. This stage involved a detailed review of the studies to determine if the inclusion criteria were indeed met and if extractable (relevant) findings related to factors influencing uptake of DHIs could be obtained. Disagreements regarding inclusion were resolved through discussion and consensus among the study team members. These disagreement points often revolved around decisions relating to the determination if the tool is patient-facing, if the factors are generalizable to the uptake of DHIs overall and if the clinical population aligned to our inclusion criteria. Those full-text articles that after determination were not included in our review were recorded in the PRISMA diagram with their reason for exclusion provided, corresponding to the *inclusion and exclusion criteria we set.*

Data collection

Data was extracted from all finally included full-text articles using a Microsoft Excel file. Four members of the research team divided up the full-text articles and extracted data to the following categories: title, DOI number, first author name, year published, country or countries where the study was conducted, classification of country income level, WHO classification of country region, study aims, study design, classification of HCPs, classification of DHIs (according to American Medical Association and WHO 2.0 classification), description of DHI, type of CVD prevention (primary versus secondary), sample characteristics (total sample size, sub-samples of different HCPs if applicable, age, sex), quantitative results (type of variable, measurement method, descriptive statistics), qualitative results (type of analysis, facilitators, barriers). For an alignment of the data extraction approach, each team member first completed roughly five to ten full-text data extractions separately. Then, they met and

discussed questions pertaining to the classification of data (e.g., DHIs and type of CVD prevention) and best approaches for consistent data recording. Afterwards, each of the four team members independently completed the remaining full-text extractions with regular meetings planned to discuss questions and align discrepancies. For a select number of studies, two members independently extracted the same data and met for discussion to reach a consensus.

Quality of evidence appraisal

Six reviewers independently assessed the risk of each included study using the "Standard Quality Assessment Criteria for Evaluating Primary Research Papers from a Variety of Fields" tool from the University of Alberta [336]. This tool considers research design, study population, lack of end point data, potential for bias (including selection, measurement, and confounding), and internal and external validity and accommodates assessment of quantitative and qualitative studies.

Data synthesis

We performed a qualitative synthesis of reported factors that influence HCPs' uptake and acceptance of DHIs. Extracted data were coded and organized into overarching factors (e.g., attitudes, accessibility, usability, etc.), and subsequently categorized to one of four domains according to the World Heart Federation Roadmap for Digital Health in Cardiology: HCPs, patients, technology, and the health system [63]. Coding was conducted by one researcher with constant comparison and peer review by other members of the research team. This continued progression of coding data and organization to factors led to an ongoing revisiting of factor terminology and collaborative decisions on whether to merge, separate or develop new factors. Quantitative data (e.g., Likert scale responses, odds ratios) were also coded using this qualitative approach, based on their reported findings, such as statistically significant factors influencing DHI uptake or identified factors from descriptive analyses. The decision to analyse both qualitative and quantitative data together was: 1) to allow for an overall synthesis of factors influencing uptake across study designs, 2) out of the overwhelming majority of included qualitative studies, and 3) the overall qualitative focus of this review's aim on perspectives of HCPs. The frequency of reported factors was visualized in bar charts, indicating the number of occurrences of any one factor across all included studies, how often a factor was reported or framed as a facilitator or barrier, and differentiating between country income levels.

We performed a qualitative synthesis of reported factors that influence HCPs' uptake and acceptance of DHIs. Extracted data were coded and partially merged to arrive at a coherent list of factors. Coding was conducted by one researcher with constant comparison and peer review by other members of the research team. The frequency of reported factors was visualised in bar charts, indicating the number of occurrences of any one factor across all included studies, how often a factor was reported or framed as a facilitator or barrier, and differentiating between country income levels. All extracted factors were categorized as relating to one of four domains according to the World Heart Federation Roadmap for Digital Health in Cardiology: HCPs, patients, technology, and the health system [63].

Results

After removal of duplicates, 7,638 abstracts were eligible for screening, of which 117 studies were included in the analysis. Eight articles from the collateral search were added, resulting in the final number of 125 studies included in the analysis (Figure 1).

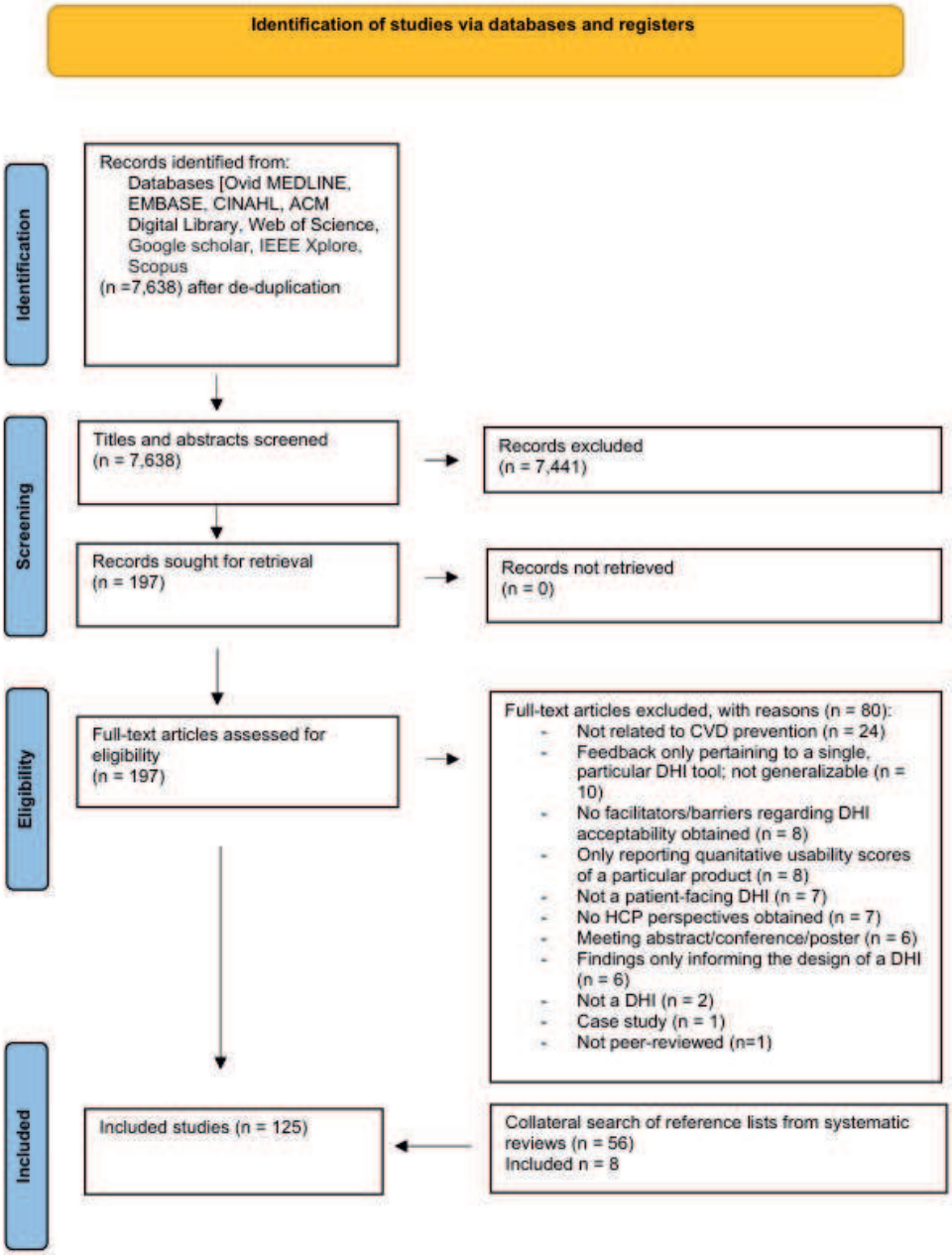


Figure 1. PRISMA flow diagram.

Study characteristics

One hundred and one studies were qualitative (predominantly interview and focus group studies) [337–437], 15 quantitative (all surveys) [438–452], and 9 both qualitative and quantitative [453–461]. In terms of regional income level, the distribution was high income (107) and middle income (18) countries, with no studies from low-income countries. The included studies' main characteristics are summarized in Additional file 2. The global distribution of included studies and number of respondents is shown in Figure 2. The raw data for Figure 2 is presented in a table in Additional file 2. Overall, 33 countries were represented in this review presenting perspectives from 8,821 HCPs (mean 72 participants [range 1-1753] per study). The average percentage of males was 35 (range 0 – 87).

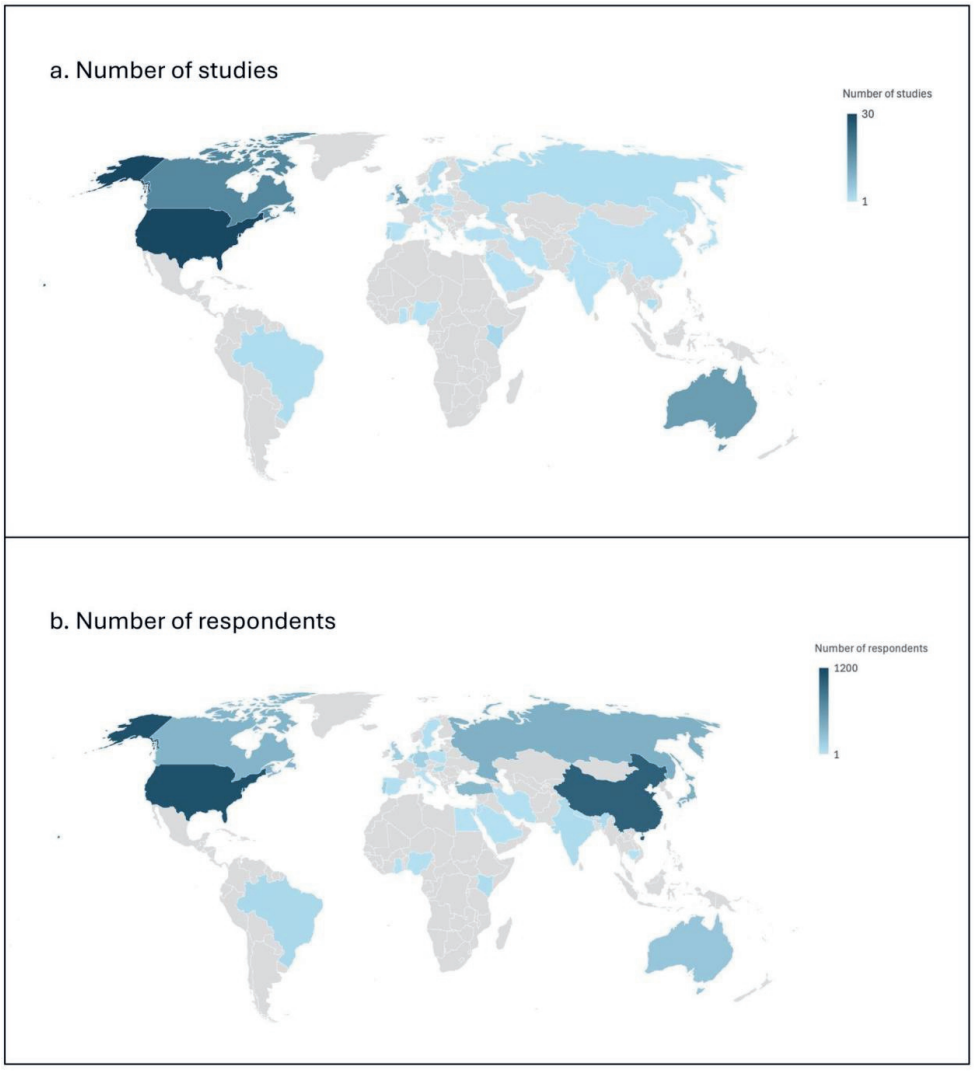


Figure 2. Global distribution of included studies (a) and number of respondents (b).

Clinical characteristics of study samples were described as follows: CVD and/or CVD risk factors in 41 studies (33%), hypertension in 23 studies (18%), heart failure in 19 studies (15%), general population samples in 12 studies (10%), coronary artery disease in 8 studies (6%), pregnancy-related hypertension and/or diabetes in 7 studies (6%), atrial fibrillation or risk of atrial fibrillation in 6 studies (5%), implantable cardiac device in 2 studies (2%), and 1 study (1%) each for cancer, cardiac surgery, children with CVD, hospitalized patients, heart transplantation, stroke and transcatheter aortic valve implantation,

The respondent groups represented across all included studies were physicians (78%), nurses (11%), allied health professionals including physiotherapists and clinical physiologists (2%), pharmacists (2%), administrators/managers (2%), policy makers (<1%), healthcare assistant staff (<1%), psychologists (<1%), social workers (<1%), researchers <1%) and other roles and professions (4%). The average age of participants was not calculated because of an overwhelming majority of missing data values for mean age from the included primary studies (90 out of the 125 studies).

Quality of primary studies

Overall, on a scale from zero (indicating lowest quality) to one (indicating highest quality), half of the qualitative studies had a quality score of 0.80 or higher, and three quarters of studies had a quality score of 0.65 or higher. For the quantitative studies, half had a quality score of 0.81 or higher, and three quarters a quality score of 0.69 or higher. Mixed methods studies were assessed using both qualitative and quantitative criteria, such that qualitative components were assessed qualitatively and quantitative components quantitatively. Quality appraisals for all included studies are given in Additional file 3.

Main Findings

Our data identify key factors reported by HCPs (i.e., factors representing HCPs' perceptions) that influence the adoption of DHIs in routine practice. We categorized these factors as related to one of four domains: HCPs, patients, technology, and the health system. In the primary studies, factors could be reported or framed as either facilitators or barriers. For example, regarding the factor "HCP attitudes toward technology" positive attitudes act as a facilitator and negative attitudes act as a barrier. Here, we report on the most prominent factors and their respective framings as either facilitators or barriers.

Factors influencing DHI uptake related to HCPs

The most frequently reported facilitator was perceived positive clinical impact, reported 83 times as a facilitator. Moreover, HCPs' motivation for using DHIs was cited as a facilitator 38 times, and HCP training/education on DHIs 36 times. The type of HCP-patient relationship (e.g., rapport, familiarity, trust), the expected impact of DHIs on the HCP-patient relationship dynamics, a perceived lower workload due to the DHI, and HCP technology attitudes towards DHIs were also reported as facilitators, 30, 25, 22 and 21 times, respectively. Following closely behind, HCP autonomy and trust of DHIs were reported as facilitators 19 times.

The most frequently reported barrier was perceived added workload due to DHIs, identified as a negative factor 56 times. Additionally, HCPs' current workload was cited as a barrier 38 times. Taking

both added and current workload together, the "workload" factor emerges as the main barrier perceived by HCPs in adopting DHIs. Other factors mostly seen as barriers were HCP trust of DHIs (33 times), HCP negative attitudes towards technology (30 times), perceived negative clinical impact of the DHI (26 times), HCP improper use or misunderstanding of DHIs (23 times), concerns about privacy/security (23 times), and concerns of increased responsibilities and liability (17 times).

Due to the mixed groups of HCPs in many of the study samples it was not possible to determine how factors of uptake differentiated between HCP type (e.g., physicians, nurses, physiotherapists).

Lastly, in terms of the top-five factors influencing uptake of DHIs in high- and middle-income countries, similar overlapping factors were identified in both groups. They were perceived clinical impact, perceived added workload due to DHIs, and motivation to use DHIs. However, among high income countries, trust in DHIs, HCPs' attitudes, and HCP training emerged as additional key factors, while among middle-income countries, HCP views of DHI on (personal and patient) privacy and security, and current workload were more prominent.

Figure 3 presents the frequency of the most commonly cited (≥10 times) factors related to HCPs, their framing as either facilitators or barriers in the primary studies, and their distribution across middle and high-income country level. The full figure with all the factors identified is in Additional file 4.



Figure 3. Most commonly cited (≥10 times) factors influencing digital health intervention (DHI) uptake by health care providers (HCPs). Numbers represent the number of times that the factor was cited, either as

a facilitator (green) or as a barrier (red). Studies from high-income countries are represented in dark green and red, and studies from middle-income countries in light green and red.

Factors influencing DHI uptake related to patients, technology and health systems

Patient-related factors influencing HCPs' adoption of DHIs were the perceived impact of DHIs on patient-centred care (42 studies) and patients' access to technology (i.e., mobile phones, internet) and care (38 studies), with the former mostly reported as a facilitator and the latter as a barrier for HCP adoption. Moreover, patient training/education on the DHI and perceived impact of the DHI on patient access to care were reported as factors in 33 studies, with training/education reported as a facilitator 25 times and perceived impact of the DHI on improved patient access to care reported 30 times.

Patient digital literacy and patient motivation for using DHI were additionally frequently reported as factors for HCP adoption (31 studies). Patient digital literacy was primarily reported as a barrier for HCP adoption (29 times), whereas patient motivation for DHIs was reported as both a facilitator (18 times) or a barrier (17 times) for HCP adoption. Other factors mostly seen as barriers were patients' improper use or misunderstanding of DHIs and patients' older age, and patients' attitudes towards technology, whereas a perceived impact of DHIs on improved patient empowerment was seen predominantly as a facilitator for HCP adoption.

HCPs' perspectives of health system factors influencing DHIs adoption centred on work structure (e.g., staffing, scheduling, workflow, work environment), cited in 77 studies, serving both as a facilitator (58 times) and as a barrier (43 times). Financing and funding aspects (e.g., sustainability, staff compensation) appeared in 34 studies, reporting both as a barrier (23 times) and as a facilitator (17 times). Similarly, policies, laws, and regulations (e.g., insurance, reimbursement) were reported in 32 studies, 17 times as a facilitator and 21 times as a barrier. Other notable factors included ICT equipment/software, HS leadership influence, and physical space. ICT equipment/software was predominantly reported as a barrier due to mostly a lack of equipment (19 compared to 6), whereas HS leadership influence was mostly reported in terms of a facilitator and physical space for DHIs showing more mixed results as both barriers and facilitators. Overall, across middle and high-income countries, no substantial differences were observed among the top-five HS factors influencing uptake of DHIs. The only variation was in their relative ranking of their reported frequencies with factors of financing and funding of DHIs slightly more prominent than polices, laws and regulation factors in high-income countries, whereas reversed in middle-income countries.

Lastly, HCPs' perceptions of technology-related factors influencing DHI adoption emphasized DHI usability and user-friendliness (59 studies), more often reported as a facilitator (44 times) as compared to a barrier (28 times). Adaptability of the DHI (e.g., to patient needs, HCP and patient preferences, language) was also another key factor as reported in 54 studies, mostly seen as a facilitator (40 times) as compared to a barrier (24 times). Integration of the DHI with other systems (including electronic health records and clinical software) was discussed in 37 studies, with this factor reported as a facilitator 29 times and a barrier 11 times. Other relevant aspects included data visualization and presentation, technical stability of the DHI (often a barrier), integration of the DHI into the clinical workflow, accuracy/reliability of the DHI content, automation and scientific evidence-based of the DHI.

Figure 4 summarizes key recommendations to improve DHI uptake among HCPs in CVD prevention, based on the findings of this review. Figures displaying all factors related to HCPs, patients, technology and health system are given in Additional file 4.



Figure 4. Key recommendations to improve uptake of CVD prevention digital health interventions among health care providers.

Discussion

The successful adoption of DHIs among HCPs hinges on addressing critical barriers while leveraging facilitators. The most frequently reported barrier to DHI uptake among HCPs was excessive workload, including increased responsibilities such as data management and technical support, and current workload, leading to time constraints and burnout. Nevertheless, perceived influence on workload was cited as a facilitating factor 22 times, reflecting HCPs' perception that DHIs can also help alleviate some tasks and reduce their overall workload.

As seen across multiple other fields, skepticism about DHIs among HCPs, highlighted by concerns about technology attitudes and trustworthiness, underscores the need for transparency, robust evidence, adequate training, and integration into existing clinical processes. Structural factors and infrastructure limitations (e.g., availability of wireless Internet access) were also relevant, particularly in middle-income settings.

It is encouraging that the perceived clinical impact was the most prominent facilitator, with HCPs recognizing the potential of DHIs to improve adherence, reduce readmissions, and enhance clinical outcomes. In the context of CVD prevention, these barriers and facilitators are especially relevant. For example, DHIs that support medication adherence or early detection of decompensation can help reduce readmissions for heart failure, aligning with HCPs' perceptions of clinical benefit.

This highlights an opportunity to leverage HCPs' positive perception to promote the wider adoption of DHIs among them, ultimately improving CVD prevention efforts. Motivation, driven by perceived value, interest and financial incentives, also played a significant role as facilitating factor. Adequate training and education and building trust through pilot testing and evidence-based practices are critical in fostering confidence and positive attitudes.

In the primary studies included in this review, most factors were framed as both facilitators and barriers. For example, the expected impact of DHIs on HCP-patient relationships was frequently reported as both a facilitator and a barrier, suggesting that while a DHI can enhance communication, it may also be perceived as disrupting established and valued HCP-patient interactions.

These findings highlight the importance of targeted efforts to optimize DHI adoption among HCPs, including enhanced training, education, workload management strategies, and organizational support.

HCPs also identified several patient-, health systems-, and technology-related factors influencing the adoption of DHIs. Regarding patient-related aspects, the perceived impact on patient-centered care and the perceived impact on increased access to care were commonly seen as facilitators. However, patients' existing access to technology and care, low digital literacy, improper use or misunderstanding of DHI features, and patients' older age emerged as significant barriers, both in high- and middle-income countries. Such findings are aligned with prior studies evaluating DHI in older adults.

Perceptions about health system factors influencing DHI adoption were mostly mixed, seen frequently as both facilitators and barriers. The main factor cited was work structure, which includes staffing, scheduling, workflow, guidelines, job roles, task delegation/sharing, and work environment. Financing and funding, as well as policies and regulations, were also perceived with this duality. This variability

in perception reflects an opportunity to optimize these structural elements in ways that enhance DHI adoption, whether by improving workflow integration, ensuring sustainable financing models, or adapting policies to better support implementation.

In the technology domain, good user experience and adaptability of the DHI to different scenarios (such as language preferences or diverse health conditions) were widely recognized as important, with mostly positive perceptions. Integration with electronic health records and existing clinical software was often seen as a relevant facilitator for DHI uptake, while technical stability was more frequently cited as a challenge. Other key aspects, such as integration of the DHI into the clinical workflow, accuracy of the DHI content, automation and scientific evidence in support of the DHI, were seen as important factors.

Our findings identified similar barriers and facilitators as previous reviews, with several key differences. For example, a recent umbrella review by Borges do Nascimento et al. [72], which included 108 systematic reviews, evaluated barriers and facilitators for DHI uptake among HCPs, although only 2 of the reviews focused exclusively on CVD. In the Borges do Nascimento et al paper, infrastructure and technical barriers (such as lack of existing technologies/devices, issues with connectivity speed or access to electricity) and personal/psychological barriers (such as HCP resistance to change, difficulty understanding the technology, or perception of less human interaction) were the two most frequent barriers described, while excessive workload was the third most reported barrier. This contrasts with the findings of our review, in which excessive workload was identified as the most frequent barrier, and only a few studies cited HCP accessibility as a barrier for DHI uptake.

This difference could be explained by several factors: For instance, more than half of the reviews included in the review by Borges do Nascimento et al. were from Africa, Latin America and Caribbean regions, where infrastructure and technical barriers may be more prominent, while our review included mostly high-income countries. Also, Borges do Nascimento et al. included older studies [72], in which overcoming basic infrastructural and technical challenges could be a significant barrier. Since we focused on studies published from 2020 onwards, this barrier may become less apparent, as technology evolves, the prevalence of digital technology among the general population increases, and digital technology becomes more pervasive to the clinical domain. In this respect, the COVID-19 pandemic acted as a catalyst for the development and uptake of DHIs for both HCPs and patients, but also amplified workload pressures on HCPs, increasing its salience as a barrier in more recent studies included in the current review. The heightened demands on HCPs during and after the pandemic may have shifted focus toward time constraints and stressors related to workload. Lastly, our review focused exclusively on CVD prevention, and HCPs in this clinical field may perceive different barriers and facilitators for DHI uptake compared to other clinical domains.

Developers should take note of our findings, addressing the main barriers to improving the uptake of DHIs by HCPs and integration into existing clinical processes. This could be achieved by optimizing workflows (i.e., by reducing duplicate or unnecessary tasks), integrating seamlessly into current systems without adding complexity, utilizing automation to handle repetitive activities (such as sending reminders or generating routine reports), and ensuring that tasks related to DHIs (e.g., data entry, follow-ups) fit naturally into HCPs' daily routines rather than interrupting them. HCPs need to be involved in DHI development to ensure optimal workflow integration and user-friendly design.

Also, policymakers should establish clear guidelines, support educational programs, provide financial incentives, and prioritize trust-building measures to ensure the sustainable adoption of DHIs among healthcare professionals in CVD prevention, as these were the most commonly identified facilitators of DHI uptake.

Strengths and limitations

A key strength of this study is its comprehensive analysis of HCPs' perceptions of factors influencing DHI adoption, synthesizing findings from 125 studies published after 2020. Overall, the review incorporates data from 8,821 healthcare professionals across 33 countries, providing a broad and diverse international perspective. By focusing exclusively on recent literature, this review captures the post-COVID-19 pandemic healthcare landscape, making this the first review to examine HCP perspectives on DHI adoption in a world where digital health plays an increasingly central role. The study also covers a broad range of factors—spanning patient-related, technological, and health system domains—offering a nuanced understanding of both facilitators and barriers. The identification of factors that may constitute barriers but may also serve as facilitators highlights opportunities for optimization rather than fixed obstacles, providing valuable insights for future DHI implementation.

However, some limitations should be acknowledged. The variability in study methodologies and healthcare settings presents challenges, limiting generalizability across different contexts. Most studies were qualitative, which limits the ability to generalize the findings to broader populations or settings. While qualitative studies provide in-depth insights into the experiences and perceptions of HCPs, they are often context-specific and may not represent the views of all healthcare professionals across different regions or healthcare systems. Additionally, the lack of quantitative data makes it challenging to measure and compare the magnitude of the identified facilitators and barriers, as well as their relative impact on DHI adoption.

Another limitation of the evidence is that we did not find relevant studies from low-income countries, highlighting a persistent geographical imbalance in digital health literature. This gap likely reflects disparities in technological infrastructure, research funding, and access to digital health tools, which may limit the generalizability of current evidence and underscore the need for greater investment and capacity-building efforts in these settings. The absence of data from these settings means that the perceptions of HCPs in resource-limited environments, where DHI adoption may face unique challenges, are not represented. Future research incorporating quantitative assessments of DHI adoption and including low-income settings could offer a more comprehensive understanding of the factors influencing their success.

While digital health technologies offer clear benefits, their widespread adoption also raises important sustainability considerations that are rarely addressed in current discussions. The growing reliance on cloud-based data storage and processing demands substantial energy use from data centers, contributing significantly to the sector’s carbon footprint [462]. Future implementation strategies should therefore integrate environmental sustainability into digital health planning, promoting energy-efficient infrastructures and responsible data management practices.

Conclusions

The most frequently reported barrier for uptake of DHIs for CVD prevention among HCPs was the perception of an excessive workload, both in terms of current responsibilities and those anticipated with the implementation of DHIs. It is promising that the perceived clinical benefits emerged as the main facilitator identified, with HCPs acknowledging the potential of DHIs to enhance adherence, decrease readmissions, and improve clinical outcomes. This presents an opportunity to capitalize on HCPs' favourable views to encourage broader adoption of DHIs, ultimately strengthening CVD prevention initiatives.

To balance barriers and facilitators, DHIs must align with clinical workflows and address HCP concerns through clear role delineation, effective training, and leadership support. Particular emphasis should be put on not adding additional workload, highlighting the clinical benefits of DHIs and offering incentives, since these were the most influential factors identified among HCPs.

CHAPTER 6

General Discussion

6. Discussion

The first aim of this dissertation was to identify the main determinants (i.e., factors) and motivating reasons related to physical activity engagement among individuals with cardiovascular disease. These findings are crucial to inform the design of physical activity interventions tailored for a cardiac population. This aim was approached through both a global perspective, consisting of synthesised quantifiable associations between determinants and physical activity from primary studies, as well as patient-reported perspectives and insights from a cross-sectional study in a sample of individuals with cardiovascular disease in the Austrian healthcare context.

The second aim of this dissertation was to understand the potential of digital health technologies in cardiovascular disease secondary prevention, specifically physical activity. Here, this was approached by exploring patient-reported use and perspectives of digital technologies in a sample of individuals with cardiovascular disease in the Austrian healthcare context. Moreover, this was also approached through a global perspective, from synthesised healthcare provider-reported factors (i.e., facilitators and barriers) of their uptake in the clinical context from primary studies. The approach of incorporating both patient and healthcare provider perspectives was to provide suggestions for the design of digital health technologies and their implementation.

The following sections will be organised in the order of these two main aims. The first focusing on determinants of physical activity among individuals with cardiovascular disease and the second on digital health technologies for cardiovascular disease prevention. Each of these sections will concentrate on the main findings extracted from the chapters of this dissertation and the implications that arise from these findings. Together they aim to provide recommendations for the design and implementation of (digital) health technologies targeted at increasing physical activity among people with cardiovascular disease.

6.1 Aim 1: Determinants of physical activity in the cardiac population

Concerning the first aim of this dissertation, chapters two and three were focused on understanding the determinants and motivation of physical activity among individuals with cardiovascular disease. The second chapter began with a broad scope from a systematic review to gain general global focus of relevant determinants, whereas the third chapter allowed for a more focused, in-depth extraction of patient insights of determinants, preferences and interests of physical activity through a primary study of a cross-sectional study design.

The systematic review (chapter two) was focused on collecting observational data on the determinants for heart-healthy physical activity levels in individuals with cardiovascular disease. In a timespan from 2005-2025, 70 primary studies reporting on bivariate associations between determinants and physical activity behaviour were included in the review. These represented findings from 29 countries and a total number of 56 determinants extracted. From these 56 determinants, 699 bivariate association statistics were extracted and some determinants accounted for a disproportionately higher representation compared to others. The most frequently measured determinants, those presented in the greatest number of studies, were related to cognitive, demographic and psychological constructs. On the other hand, only a few studies assessed determinants in socioenvironmental, environmental, healthcare categories (e.g., insurance,

treatment, access to care), cardiovascular risk score, and genetic components (e.g., family history of cardiovascular disease). In the following subsections, the most prevalent determinants – those appearing frequently across studies and showing a consistent direction of association with physical activity - are discussed in greater detail.

Chapter three was focused on a cross-sectional survey among former cardiac rehabilitation patients with the Austrian healthcare context. A total of 117 patients who had completed cardiac rehabilitation approximately three years prior were recruited from five cardiac rehabilitation centres. Close- and open-ended questions were used to understand individual physical activity habits, preferences and motivation. Self-determination theory was applied as a qualitative framework to analyse the open-ended responses of motivation for physical activity engagement. Overall, participants in this sample preferred exercising outdoors, engaging in aerobic-related and individual, non-competitive sports. Health, pain and motivation were the main determinants of physical activity. In terms of motivation, autonomous motivation played the largest role in physical activity engagement. In the below subsections, following the determinants, the role of motivation in physical activity engagement will be expanded on.

6.1.1 Self-efficacy and 'prior exercise behaviour' as main facilitators of physical activity

Self-efficacy and 'prior exercise behaviour' were the determinants with the highest consistent positive associations with physical activity behaviour in chapter two *(in terms of directionality and representation across studies)*. For self-efficacy, 25 primary studies were included resulting in 73 extracted effect size measures with 66 of them showing a positive association to physical activity (varying in weak, moderate, strong and very strong). For 'prior exercise behaviour', 12 primary studies were included resulting in 35 extracted effect size measures with 32 showing a positive association. Overall, roughly 90% of the extracted effect size measures showed a positive association to physical activity for both self-efficacy and 'prior exercise behaviour'.

These findings from chapter two are consistent with prior literature reporting the importance of self-efficacy and prior physical activity on physical activity engagement [37]. Interestingly, from the findings of chapter two, self-efficacy was repeatedly positively associated with physical activity even after months and years after an acute cardiac event, diagnosis or completion of a cardiac rehabilitation programme. Given the findings of Slovinec D'Angelo et al. (2014), where self-efficacy was only reported as a significant predictor for short-term behaviour (six months since discharge) [54], it may have thus been expected that self-efficacy would no longer show consistent positive associations to physical activity behaviour in the long-term. These findings, therefore, recognize the importance of supporting self-efficacy for physical activity behaviour among persons with cardiovascular disease throughout later stages of prevention.

To do so, specific theory-based behaviour change methods could be implemented into physical activity interventions to increase self-efficacy of patients for physical activity. Possible methods could include the following: guided practice, enactive mastery experiences, verbal persuasion, improving physical and emotional states, reattribution training, self-monitoring of behaviour, providing contingent rewards, cue altering, public commitment, goal setting, setting graded tasks and planning coping responses, as presented in Kok et al.'s (2016) Intervention Mapping taxonomy of behavioural change methods [212]. Moreover, among patients with heart failure, successful strategies for improving self-efficacy have been observed through using performance accomplishments approaches

(i.e., setting realistic goals that gradually increase in difficulty), vicarious experience (i.e., role modelling from experts or peers), verbal persuasion (i.e., positive feedback and reinforcement), and emotional arousal (i.e., fostering increased recognition of symptoms and physiological responses to exercise) [463].

Furthermore, as presented in chapter two, 'prior exercise behaviour' is an important component of physical activity engagement among individuals with cardiovascular disease. This may be explained by the role that habit formation plays in physical activity engagement. For instance, in a longitudinal study, it was found that habit significantly mediated the relationship between prior and later physical activity in older adults [464]. Habit formation may, thus, play an important role in physical activity engagement among individuals with cardiovascular disease, as it could mediate the prior and current physical activity behaviour seen. In fact, habit formation was reported in chapter two as a positive determinant for physical activity in all (100%) of its extracted effect size measures. However, the low representation of primary studies (n = 3) that explored habit formation makes it difficult to draw specific conclusions about its role.

Nevertheless, the findings of 'prior exercise behaviour' support physical activity engagement across the lifespan. This relates to the importance of promoting physical activity throughout childhood, adolescence and adulthood [47]. Besides the positive health outcomes associated with a generally active lifestyle [47], such efforts may benefit those who develop cardiovascular disease later in life in maintaining physical activity behaviours and thereby reducing the risk of further adverse outcomes. Thus, initiatives such as health promotion campaigns and community design (e.g., green spaces) [33,465] should be greatly supported in the general public, as well as targeted interventions for individuals with an established cardiovascular disease. Here, interventions to encourage habit-forming behaviours could incorporate the following behaviour change methods for habitual behaviour *(as reported in the aforementioned Intervention Mapping taxonomy of behavioural change methods*): deconditioning, counterconditioning, implementation intentions, cue altering, stimulus control, planning coping responses, early commitment, public commitment, and training executive function [212].

Overall, 'prior exercise behaviour' calls for an increased promotion of physical activity throughout the lifespan. Additionally, it may provide a good indication of physical activity engagement in secondary prevention and highlights that those individuals with low physical activity habits to begin with may require particular attention and support in adopting a physically active lifestyle.

6.1.2 Education, social support, exercise belief, intention, illness perception, and psychological well-being as additional key positive determinants

Education, social support, exercise belief, intention, illness perception and psychological well-being were key modifiable determinants expressed by their frequency of positive associations to physical activity across primary studies in the systematic review (chapter two). The determinants education and social support were explored rather extensively in the systematic review (n = 18 studies) and showed a positive association with physical activity in 69% of the extracted effect size measures. This suggests their relevance to physical activity behaviour and potential application in behavioural change interventions. In comparison, the determinants exercise belief, intention, illness perception and psychological well-being showed less strength and/or were assessed in fewer studies with n = 11 for exercise belief, n = 8 for intention and n = 6 for illness perception and psychological well-being. This indicates that their role on physical activity has been less explored in the context of patients with

cardiovascular disease. Nevertheless, each of these determinants were positively associated to physical activity behaviour in ≥ 65% of the extracted effect size measures with intention showing the highest percentage at 83%.

Higher education in terms of years of schooling completed is generally related to better health outcome [466]. In the context of cardiovascular outcomes, similar trends are reported with lower education associated with a higher risk of coronary artery diseases, cardiovascular events, stroke and cardiovascular death [467]. There are a multitude of factors which contribute to this, but lower education has been associated with greater risk factors of cardiovascular disease, such as unhealthy diets, smoking and a sedentary lifestyle [468]. The findings from this dissertation (chapter two) corroborate those from the literature. For instance, findings from literature have shown that patients with lower education reported lower cardiac rehabilitation attendance rates and adherence to secondary prevention measures [469,470]. As lower education can relate to a number of constraints such as lower income, social disparities, access to health care and childcare, and mistrust of health systems [466,469], it can make the ability to adhere to healthy lifestyles particularly challenging. To address this, strategies can be implemented to promote physical activity engagement and recruitment into health promotion programs among individuals of low socioeconomic status, such as tailored communication methods (e.g., mass media, word of mouth), community-based advertising, targeting limited facilities, and the use of simple mobile features, such as text messaging, for mobile phone interventions [471].

Similarly, social support is positively related to improved health outcomes in the literature [472]. For individuals with cardiovascular disease, social support may be particularly important given the complexities of managing a cardiac condition and stark lifestyle modifications (e.g., physical activity, diet, medication adherence) expected of patients. In general, an individual's social network refers to the variety of social relationships surrounding an individual (e.g., family, co-workers, friends), and social support refers to the means in which these networks provide support (i.e., mediating pathways using emotional, appraisal, instrumental, or informational means) [473,474]. Extant literature shows that social support from various social networks can increase physical activity engagement. For instance, received social support from family and friends showed a significant and strong effect on action planning and action control among patients with coronary artery disease, suggesting its role in regulating important components of physical activity (e.g., deciding where, when, and how to be physically activity) [169]. For older adults, this may be particularly relevant as findings show a positive association between social support specific to physical activity, especially from family members, and physical activity levels in this population [475]. Social support from peers with shared health conditions has additionally shown to relate to greater physical activity engagement. For example, a peer mentor support program ('the Buddy Network') following a centre-based cardiac rehabilitation program led to sustained levels of physical activity in comparison to declined physical activity found in non-members [476]. Moreover, social support may affect other factors related to physical activity, such as mental resilience and psychological well-being, as greater social support was found to predict improved emotional status after cardiac rehabilitation [477]. Despite these positive findings, the overall effectiveness of social network and social interventions for increasing physical activity in the secondary prevention of cardiovascular disease was not evident in a recent Cochrane systematic review of randomised controlled trials [473]. However, in this review, only 26% of the included trials (n = 14) reported on physical activity outcomes and the heterogeneity of the trials may have made it difficult to assess consistencies [473]. Overall, the findings of this dissertation suggest that greater social support relates to increased physical activity in secondary prevention, although it remains unclear if it functions in a more indirect effect or its extent in physical activity engagement. Moreover,

building off the Cochrane review, it suggests that further evidence of the effectiveness of social network and support interventions on physical activity is warranted [473].

Exercise belief was frequently positively related to physical activity among individuals with cardiovascular disease in chapter two. This suggests that individual beliefs and expectations (i.e., anticipated consequences) of exercise may shape their participation. In support of this, evidence from a 2022 systemic review and meta-analysis by Bohlen et al. (2022) reported that perceived consequences (e.g., outcome expectancies, perceived benefits) showed a small positive bivariate association to physical activity [478]. This overall suggests that when looking to change physical activity behaviour, attention to these held beliefs may have a reliable but modest utility [478]. This may explain why in chapter two findings showed an overall positive association, but for only 65% of the extracted effect size measures. Reasons why beliefs may or may not relate to physical activity could be due to varied reasons. For instance, the aforementioned review by Bohlen et al. (2022) reported that certain categories of perceived consequences of physical activity showed significant associations, whereas others did not [478]. The ones showing significant associations were perceived consequences related to time (e.g., taking up too much time), health outcomes, self-evaluative (e.g., improving self-esteem), psychological and affective outcomes, whereas those that focused on weight and physical outcomes did not [478]. Therefore, it is possible that certain held beliefs relate to greater physical activity engagement compared to others. Additionally, it may relate to the specific clinical population and/or stage of patient journey that the participants in chapter two found themselves in (i.e., secondary prevention stage). Prior findings identified that recognition and understanding that participation in physical activity results in personal benefits was important for physical activity maintenance [479]. Thus, individuals with cardiac conditions may recognise this and internalised the benefits of exercise as important to their future health outcomes, which may explain this observed finding in chapter two. Therefore, exercise beliefs coupled with other factors, such as internalised motivation and knowledge may contribute to greater engagement. On the other side, individuals that that do not recognize or observe the positive outcomes of physical activity may struggle to maintain physical activity behaviour in the long-term. Overall, exercise beliefs appear to play an important role in the physical activity behaviour of individuals with cardiovascular disease with further research calling to explore the type of held beliefs most related to behaviour and other possible interacting factors.

Intention is an important predictive factor of physical activity in the literature [480]. Behavioural intention refers to a person's readiness to perform a behaviour [481]. Interestingly, in comparison to the determinant self-efficacy, surprisingly few included articles (n = 8) in chapter two assessed intention as a determinant among people with cardiovascular disease. Additionally, in terms of the strength of the associations, none were labelled as 'strong' or 'very strong', as compared to four for self-efficacy. Reasons for this observation may relate to the intention-behaviour group reported in literature stating that intention does not necessary translate to behaviour alone, but depends on other factors (e.g., perceived behavioural control) [482–485]. Specifically, a 2023 meta-analysis quantified that roughly half of all intenders (47.6%) were not able to fulfil their intentions to be physically active in a mostly healthy population [484]. Nevertheless, given the overall consistent positive association of intention and physical activity behaviour found in chapter two (in 83% of the extracted effect size measures), this dissertation underscores that intention likely plays a pertinent role among individuals with cardiovascular disease. In support of this, in the aforementioned meta-analysis, the intention-behaviour gap was reportedly smaller for populations with health risks compared to general populations (e.g., students) possibly due to a stronger motivation as consequences for physical and mental health from individuals with health risks or conditions are more pronounced [484]. Overall, this calls for encouraging intention and efforts to translate intention into behaviour among individuals

with cardiovascular disease. This can be supported by interventions focusing on increasing patient readiness to be physically active and targeting scheduled planning to translate readiness into concrete action.

Moreover, illness perception could serve as an important determinant for physical activity among individuals with cardiovascular disease. Although this factor was measured in only six primary studies (chapter two) meaning that it is still a rather unexplored determinant, its consistent positive associations with physical activity suggests its potential role. Given that illness perception relates to an individual's organized beliefs and understanding of a health condition (e.g., cause, prevention and treatment, duration of illness, sense of control) it is highly relevant to patient understanding of their condition and in turn behaviours they may engage in [486,487]. It has been related to outcomes such as treatment adherence and self-management behaviours [487]. In terms of physical activity, prior evidence supports its role in engagement. A systematic review reported that a direct effect of illness perception on physical activity was found in five out of six studies among patients with coronary heart disease [488]. Among these, the dimensions illness coherence and understanding played a particular role, highlighting the importance of patient understanding of their condition and how health literacy and clear communication between healthcare providers and patients is critical [488]. Moreover, individuals who perceive their condition as more 'controllable', able to change through their actions, may be more likely to engage in self-management behaviours. For example, it was shown that patients who related their illness to more non-modifiable factors were significantly less likely to attend cardiac rehabilitation [488]. Overall, illness perception warrants further exploration, but this dissertation suggests its role in physical activity engagement in individuals with cardiovascular disease.

Psychological well-being was noted as consistently positively associated to physical activity behaviour in chapter two, but also requires further exploration due to its rather low representation across primary studies (n = 6). Overall, this observation is consistent to prior findings [150,489]. For instance, a prospective study using data from the English Longitudinal Study of Ageing found that psychological well-being was independently associated with maintaining higher physical activity levels over eleven years among older adults [489]. As psychological well-being refers to positive feelings and functioning (e.g., life satisfaction, optimism, purpose in life, autonomy) it relates more broadly to positive psychology rather than simply the absence of psychological distress [489,490]. In terms of living with a cardiac condition, individuals may be more vulnerable to lower psychological well-being related to their condition. For example, it was shown that individuals with cardiovascular disease with a long-standing illness or presenting comorbidities (e.g., diabetes, chronic obstructive pulmonary disease) reported significantly lower well-being scores than those without [150]. Given the high prevalence of comorbidities with cardiovascular disease [491,492], this could indicate that low psychological well-being may be a particular barrier to physical activity in the cardiac community. On the other hand, it might also serve as a motivating factor for patients. Given the bi-directional nature of psychological well-being and physical activity with findings reporting that meeting the current recommendations for physical activity served as an independent predictor of greater mental well-being [150] may present opportunities to better educate patients on the psychological benefits of physical activity. In alignment with this, the reverse direction is also supported in chapter two between the determinant 'depression' and lower physical activity behaviour. Half of the extracted associate statistics for depression showed a negative association with physical activity behaviour across n = 16 primary studies.

Lastly, the systematic review (chapter two) also indicated other potentially relevant enablers of physical activity for patients with cardiovascular disease, with greater than 60% of their extracted effect size measures relating to higher physical activity. However, given their limited representation

across primary studies (n ≤ 5), they were not addressed in-depth as key determinants in this general discussion section, but only discussed if complementing a more pronounced determinant.

6.1.3 Negative emotion and older age as concerning barriers to physical activity for individuals with cardiovascular disease

Negative emotion (incl. kinesiophobia and anxiety) and older age were identified as the strongest indictors of lower physical activity based on their representation across studies and frequency of negative extracted effect size measures in chapter two. Roughly 60% of the extracted effect size measures for both determinants showed a negative association to physical activity across ~20 unique primary studies. This observed role of kinesiophobia playing a substantial part in patient physical activity is consistent with prior literature. A 2023 systematic review and meta-analysis reported that across various health conditions, participants with cardiovascular conditions had the highest levels of kinesiophobia with mean ranges of 41.4 to 49.7 *(>37 marking the cut-off of 'high' levels of kinesiophobia),* on average ~10-20 points higher than those found in healthy adults [493]. Furthermore, the role that kinesiophobia plays on physical activity was found to be statistically significant for individuals with a cardiovascular condition using subgroup meta-analysis [493], generally consistent with the findings reported in this dissertation of associated lower physical activity.

Interestingly in the aforementioned meta-analysis by Goubran et al. (2023), no association was found between kinesiophobia and physical activity for individuals with acute and chronic pain [493]. A similar observation was found in chapter three of this dissertation. Here, pain was observed as a relevant barrier to physical activity engagement, as 54% of respondents reported it as hindering their engagement in physical activity. However, ~70% did not report a fear of exercising and only 16% of respondents stated anxiety as a barrier to their engagement in physical activity. Although, this cross-sectional study (chapter three) may represent an anomaly in terms of low levels of kinesiophobia among individuals of cardiovascular disease, it does reveal a potentially important distinction between pain and kinesiophobia discussed prior. Specifically, in that a fear of movement may not necessarily be related to an actual pain preventing physical activity, but a true fear that exercise will exacerbate a health condition, cause injury, and lead to worse outcomes [493]. Unfortunately, in the systematic review of chapter two, pain as a determinant of physical activity was only assessed in four primary studies making it difficult to draw consistent comparisons of the importance it plays in physical activity behaviour. However, in each of those studies, pain was associated with lower physical activity in alignment to the findings of the chapter three presented in this dissertation.

Although older age is generally associated with lower physical activity [494,495], it may be especially relevant among older adults with cardiovascular disease given their health and care needs. A Norwegian cross-sectional study of 1,042 participants of over 70-year-olds found that daily physical activity was significantly lower among those with higher levels of care [496]. Given the health condition of older adults with cardiovascular disease, it is likely that they require greater care needs compared to their counterparts without cardiovascular disease. In fact, a cross-sectional analysis using data drawn from nationally representative studies of older adults and their caregivers in the United States, found higher caring needs for community-dwelling older adults with cardiovascular disease as compared to without cardiovascular disease [497]. Specifically, those with a history of cardiovascular disease were more likely to report needing help with activities of daily living, e.g., needing help with mobility, bathing, getting dressed, picking up and tracking medications, someone accompanying them to medical visits, as compared to older adults without a history of cardiovascular disease [497]. In

addition, they presented overall poorer health, worse physical and cognitive function, greater depression and more comorbidities, suggesting the additional challenges potentially present among older adults with a cardiac condition [497]. In terms of physical activity, these additional challenges may relate to decreased ability to engage in a regular physical activity schedule. This requires greater reflection on how physical activity can be best promoted and tailored to specifically older adults with cardiovascular disease, given their unique challenges associated with living with a chronic condition.

Other determinants identified in this dissertation are *likely* strong indicators of less physical activity due to their negative directionality, but require further research based on lower overall evidence (i.e., either lower strength and/or representation across studies). These are comorbidity, fatigue, higher NYHA (New York Heart Association) class, pain and weather. Comorbidity is the strongest indicator of lower physical activity following negative emotion and age in chapter two. It showed negative associations to physical activity in over half (56%) of the extracted effect size measures across n = 16 studies. This suggests that patients with more health conditions require increased support and aligns to the literature that individuals with greater care needs often present less physical activity [496]. Moreover, in chapter two, fatigue was negatively related to physical activity in 75% of the extracted effect size measures (n = 9 studies), and pain and NYHA class in 100% of the extracted effect size measures, but only reported in four primary studies each. Despite this low representation, this suggests that those with a higher NYHA class, pain and/or fatigue are more vulnerable to physical inactivity. Weather was the second highest barrier to physical activity, following pain, shown in chapter three with 43% of patients reporting it as a barrier. However, in chapter two, only one primary study assessed how 'adaptation to weather' related to physical activity, showing weak to moderate positive associations. This shows there is an overall lack of scientific evidence reporting on the role of weather or environmental conditions on physical activity behaviour. In contrast, depression was a rather frequently explored determinant in n = 16 primary studies in chapter two with half of the extracted effect size measures negatively related to physical activity. Although only half were reported, the determinant depression together with the aforementioned findings of 'psychological well-being', support the role of mental health as an influencing factor on physical activity behaviour among patients with cardiovascular disease. Lastly, chapter two identified other determinants showing negative associations with physical activity, but given their low representation across primary studies were not addressed in-depth as key determinants in this general discussion section.

6.1.4 Role of cardiac rehabilitation as a determinant of physical activity behaviour

The impact of cardiac rehabilitation programmes on sustained healthy lifestyle behaviours for individuals with cardiovascular disease is the underlying aim of such a programme. However, from the findings of chapter two, prior attendance of a cardiac rehabilitation programme did not show consistent positive associations with (later) physical activity behaviour in secondary prevention. Among the extracted effect size measures, only half of them were positively related to physical activity behaviour as compared to non-attenders or those having attended fewer sessions. This represents a concerning image that the reported benefits of cardiac rehabilitation programmes [498] may not necessarily be carried over in the long-term. This is in line with prior literature showing that long-term physical activity adherence after cardiac rehabilitation is not consistently sustained [195,196]. For instance, in a systematic review of forty randomized controlled trials, cardiac rehabilitation increased the proportion of physically active patients in only nine studies during short-term follow-up (under ≤ 12 months). In terms of long-term follow- up (>12 months), this number dropped to only three studies

[196]. To corroborate these findings, in another systematic review of 26 randomized clinical trials, conflicting and limited evidence was found establishing the effectiveness of cardiac rehabilitation on physical activity behaviour, especially in the long-term [195]. There was some evidence suggesting home-based cardiac rehabilitation had better effects when compared to centre-based cardiac rehabilitation [195,196]. This may be because of the ability of home-based cardiac rehabilitation to already adapt to an individual's physical environment making it easier to integrate into one's routine after an established programme.

Recent literature by Redfern et al. (2022) has focused on re-examining how cardiac rehabilitation can be improved to better adhere to current preventive cardiology and delivered to make it more suitable for those groups of people typically underserved by traditional cardiac rehabilitation models, e.g., women and culturally and linguistically diverse groups [499]. These included aspects of implementing lifelong preventive strategies (rather than time-limited programmes) and optimizing personalisation of care, as well as flexibility in programme delivery to improve reach and equity e.g., through home-based programmes, cultural and language tailoring, and ensuring inclusivity [499]. Here, a greater focus on lifelong preventive strategies and personalisation may aide in encouraging physical activity maintenance.

The findings from chapter two highlight the necessity to consider how cardiac rehabilitation programmes can better prepare patients to be physically active in the long-term or what resources can be provided to them in later stages of secondary prevention. For instance, continued education on cardiovascular disease and physical activity may foster greater engagement in physical activity. Although a limited number of studies (n = 5) assessed the determinant 'knowledge/information' on physical activity behaviour in chapter two, the majority (70%) of the extracted effect size measures showed a positive association to physical activity. As this determinant refers to aspects of physical activity knowledge and disease-related knowledge, it could imply that better knowledge of these constructs—including the structural and causal relationships that comprises them—relates to greater engagement of physical activity. As health education is already a core component of cardiac rehabilitation [498], improved efforts can be made to both reinforce such trainings and assess patient knowledge of their condition and physical activity in out-patient settings. However, it remains crucial that knowledge and information be coupled with other behaviour change approaches, as the exchange of knowledge alone is often not sufficient in leading behavioural change [500]. Finally, only three primary studies in chapter two explored the determinant 'exercise recommendation' on physical activity engagement suggesting that if and how exercise is recommended to patients is not a frequently explored factor. Moreover, only one of those included studies showed a positive association to physical activity engagement. It would therefore be interesting to explore this determinant further to understand what aspects of exercise recommendation relate to increased physical activity engagement, so these strategies can be adopted into consultations with patients, especially in out-patient care settings.

6.1.5 Motivation for physical activity: self-determination theory

This dissertation was additionally focused on understanding how and in what forms motivation serves as a determinant for physical activity among individuals with cardiovascular disease. This approach was explored two-fold by (1) collating the extracted quantitative associations between motivation and physical activity behaviour across primary studies (chapter two) (2) exploring its role in a sample of individuals with cardiovascular disease in the Austrian healthcare context, incorporating quantitative and qualitative approaches (chapter three). Together these provide evidence-based insight into the

role of motivation on physical activity behaviour, while also allowing for a more in-depth understanding from patient-reported perspectives.

Overall, as consistent with prior literature [51,52,54], the findings of both chapter two and three support the role of autonomous motivation (i.e., reflecting self-determined forms of motivation) on physical activity engagement. In terms of the collated evidence of chapter two, the determinant 'motivation' itself was not consistently positively associated with physical activity behaviour, as only 43% of the extracted effect size measures showed a positive association. However, when the determinant was separated based on its groupings as 'autonomous' and 'controlled' motivation, some noticeable differences were observed. Namely, for autonomous motivation, 57% of the extracted effect size measures were positively related to physical activity as compared to only 15% for controlled motivation. This implies that autonomous motivation—aligned to one's goals, identity and/or interests—plays a greater role in physical activity engagement among individuals with cardiovascular disease compared to controlled motivation, i.e., motivation stemming more outwardly from others or external pressures. Aligning to this, 38% of the extracted effect size measures between controlled motivation and physical activity behaviour were *negatively* associated compared to only .07% for autonomous motivation. According to self-determination theory, external rewards or pressures can undermine intrinsic motivation—enjoyment and intrinsic value in engaging in a task—if it threatens one's basic needs of competence, autonomy and relatedness, which could explain this observation [53]. Consistent with the principles of self-determination theory, literature has shown that controlled motivation can at times relate to lower engagement of health behaviours [501]. In summary, the collated findings of chapter two support the role of autonomous motivation in physical activity behaviour among individuals with cardiovascular disease, however, the relatively few included primary studies that focused on these groupings of motivation (n = 5) warrant further investigation into the interplay of autonomous and controlled motivation on physical activity behaviour.

The cross-sectional study of chapter three further stipulates the role of autonomous motivation on physical activity adherence. Using thematic analysis to explore open-ended responses of motivation for physical activity, nearly all (90%) of the reported reasons for being physically active were categorized under autonomous motivation. These most frequently related to desires of maintaining or improving physical/general/cardiovascular health, finding it fun/enjoyable, desires of sustaining self-sufficiency (independence and mobility), well-being, being present for loved ones and being connected to the outdoors/nature. Interestingly, when observing under which subcategory of autonomous motivation these reasons were categorised to, there was a greater frequency of reasons classified to 'integrated regulation' (*physical activity engagement is aligned with an individuals' sense of self or goals)* and 'identified regulation' (*engaging out of perceived valued benefits of the outcome)* as compared to intrinsic motivation. Given that these individuals had completed phase II cardiac rehabilitation approximately three years prior and found themselves in a phase of self-sustained, maintenance stage, these results are slightly inconsistent with prior findings in literature of identified regulation being more predictive of initial physical activity adoption, and intrinsic motivation more predictive of long-term exercise [51]. This may reflect the study population sampled, namely, consisting of former cardiac rehabilitation participants. As such, respondents all received education on the importance of physical activity for improved health and quality of life, along with knowledge on the potential adverse consequences of living a sedentary lifestyle. Therefore, this may have led to the observed motivation largely stemming out of internalized factors relating to better health and well-being, rather than necessarily stemming out of pure enjoyment or fun. As such, promoting physical activity interventions that highlight these internalised motivations alongside fun and relatable activities, may be beneficial for encouraging physical activity engagement. For instance, prior findings stemming from different cohorts of patients with cardiovascular conditions report similar motivating

reasons for being physically active related to desires of regained independence, prolonged life, improvements in health, and physical and mental well-being [45,260]. Thus, interventions could incorporate motivating strategies that are aligned to these goals or focus on physical activities that improve aspects of mobility, heart and cardiovascular strengthening, and improved well-being.

Overall, chapter two and three provide indication of the importance of patient autonomy in physical activity engagement. This calls for increased efforts to increase autonomy through intervention techniques. For example, a randomised controlled trial found that applying an 8-week autonomy-supportive intervention with patients with heart failure showed improvements in self-care management and maintenance, as well as autonomous motivation [502]. This intervention consisted of health education and personalised consultation sessions tackling the five core attributes of autonomy-supportive interventions, choice (providing reasons and significance of behaviour change), rationale (options for behaviour change), empathy (understanding and recognition), collaboration (building relationships) and strengths (feedback and positive impact of the behaviour change) [502]. Besides an increase in autonomous motivation, they found a decrease in external regulation (controlled motivation) and amotivation in the intervention group compared to the control group during the one-month follow-up, suggesting that individuals in the intervention group were more driven to change based on internalised reasons [502]. Another randomised controlled trial showed similar findings reporting that a physical activity intervention designed to be supportive of patient psychological needs for autonomy, competence, and relatedness increased autonomous motivation and physical activity [503]. Here, the intervention group participated in a 12-month physical activity programme that centred around participant choice (e.g., choice of activities for self-training, choice of training times), mastery of physical activity adapted to their skill level, providing meaningful rationale of exercise benefits, supportive feedback on progress through a training diary and building meaningful connections with participants [503].

Although findings support beneficial outcomes of autonomy-supportive interventions, it remains difficult to assess which specific behaviour change techniques foster autonomous motivation, partly due to the heterogeneity of components present across interventions [504]. A systematic review and meta-analysis explored this more closely by identifying what features of physical activity interventions were associated with favourable changes in intention, stages of change and autonomous motivation [505]. Overall, the behaviour changes techniques of ‘behavioural goal setting’, ‘self-monitoring behaviour’, ‘behaviour practice/rehearsal’ or those that combined ‘self-monitoring (behaviour)’ with any other behaviour change technique derived from control theory, were related to positive changes in multiple of these three constructs. Additionally, interventions delivered face-to-face or in gym settings were associated with favourable changes [505]. In terms of autonomous motivation itself, only ‘demonstration of behaviour’ was significant, along with intervention modalities of face-to-face, via the telephone, in the gym, delivered by a gym worker or trainer, delivered to overweight individuals, and (inversely) via postal mail [505]. This may highlight that although the other behaviour change techniques are important for behavioural change, demonstrating and showing an individual specifically how to engage in a behaviour may be particularly important for fostering autonomous motivation. The above-mentioned literature provides direction regarding important components to include in physical activity interventions. Overall, this section highlights the importance of assessing and exploring autonomy for physical activity (along with other self-care behaviours) in clinical care, and calls for further exploration into what features of interventions best foster autonomous motivation among individuals with cardiovascular disease.

6.1.6 Preferences for physical activity interventions: insights from an Austrian cross-sectional study

The aforementioned section has drawn attention to the importance of autonomous motivation in sustaining physical activity, involving individuals' need to relate to or identify themselves within the behaviour and exhibiting a sense of volition (i.e., choice) in behavioural engagement. This also relates to individual preferences and interests in behaviour engagement. As little research has focused on patient preferences and needs of physical activity in the phase of long-term secondary prevention (e.g., self-management phase), chapter three allowed for exploratory insights into patient preferences and habits of physical activity in their natural environment, in this stage of the patient journey. These findings provided insight the design of physical activity interventions based on patient-reported perspectives.

Chapter three showed that patients generally preferred aerobic (e.g., cycling, walking, hiking), individual, and non-competitive activities. This is consistent with prior findings reporting preferences for exercising alone, walking, outdoor and home-based settings among patients with heart failure and myocardial infarction [176]. Such preferences may reflect both condition-specific factors (e.g., focused on cardiovascular health), as well as demographic characteristics, such as age-related factors. For instance, a preference for home-based settings was found among older patients' (≥ 65 years) for cardiac rehabilitation [221]. Similarly, findings in the literature report that retired and older adults spend more time outdoors and engage in less competitive, team-based activities [242,243]. Given that the sample in chapter three consisted of an older-aged sample (mean age 70 ± 11 years), age-related factors may explain this observation.

Overall, chapter three highlights the importance of understanding the socio-environmental context of individuals when designing physical activity interventions. Questions that relate to where and when physical activities are engaged in and who is in the social environment are critical to understanding how physical activity interventions can best be built to serve the environment of individuals. As observed in chapter three, there is a large emphasis on the home (and outdoor) environment for the majority of sampled patients, calling for interventions that support physical activity in this context. Understanding the socio-environmental context may be especially important for older patients who may face greater difficulties in adopting a new routine in their daily lives, and thereby could benefit from social support in their already established networks.

These findings align with the growing recognition that interventions should move from a one-size-fits-all approach to tailored ones adapted to user needs and preferences [506,507]. The idea is that tailored interventions can improve adherence rates and increased engagement in a behaviour as they take into consideration individual needs, preferences, their settings, etc [506,507]. Choice in an intervention (e.g., programme structure, treatment) was found to be an important aspect for retention and adherence [507]. Specifically, a meta-analysis found that 14 out of 17 studies favoured interventions offering choice, corresponding to a 46% to 15% reduction in drop-out rate. Similarly, seven out of eight studies favoured choice interventions, relating to a true effect between 1% and 30% for increased adherence [507].

One approach to integrating choice into physical activity interventions for individuals with cardiovascular disease is through the usage of shared decision-making. Shared decision-making refers to the integration of a patient ideas, preferences, goals and values into an informed clinical decision with a healthcare professional [508]. This largely encompasses a structured conversation involving explaining to the patient that a decision has to be made, discussion about the benefits and drawbacks

of the available options, eliciting patient opinions, and establishing a shared partnership that the decision will be reached together [508]. Shared decision-making has been observed to be beneficial in decision-making quality (e.g., satisfaction, reducing conflict), medical outcomes, and improving patient knowledge [509,510]. Approaches such as the use of patient decision aids and posters to encourage questions from patients have been examples employed to encourage shared decision-making [508]. Additionally, the rise of digital technologies has led to the use of innovative approaches to facilitate shared decision-making, such as web-based applications to convey information, calculate personal risk and/or recommend treatment options between patients and healthcare professionals [511].

6.2 Aim 2: Potential of digital health technologies for cardiovascular disease prevention

In regards to the second aim of this dissertation, chapters four and five were focused on understanding the role of digital health technologies for cardiovascular disease prevention. The fourth chapter explored patient reasons for using or not using digital health technologies in secondary prevention in an Austrian sample. The goal was to explore in an observational manner using a cross-sectional study how readily digital tools are already incorporated into the daily lives and for physical activity purposes among individuals with cardiovascular disease, and the barriers and facilitators for their usage. The incorporation of open-ended questions and subsequently a qualitative analysis allowed for a more in-depth understanding of patient-reported perspectives.

The fifth chapter provided a broad scope of the healthcare provider perspectives of digital health technologies and their uptake in clinical care. Given that healthcare providers may encourage and discourage digital tools for clinical practice, the use of a systematic review provided a large overview of the current barriers and facilitators to the implementation of evidence-based digital health technologies in clinical care. Assessing healthcare provider-reported perspectives of digital health interventions in clinical practice is critical for informing implementation strategies.

6.2.1 Perspectives from an Austrian context

6.2.1.1 Patient perspectives

Chapter four explored the integration of digital technologies in the lives of individuals with cardiovascular disease, to better understand the potential acceptability of digital interventions from patient-reported perspectives. This cross-sectional study showed a near ubiquitous integration of digital technology in patients' daily lives and to a large extent for physical activity purposes. As the potential of digital health technologies largely depend on their acceptability and availability for patients, these findings are promising, showing that in this patient sample, individuals readily used digital technologies. Overall, the smartphone was the most popular form of digital technology used in both daily life and for physical activity in this sample, suggesting it might be targeted opportunistically by intervention developers.

Given that the sample of chapter four generally consisted of an older-aged participants (mean of 69 years) and readily used digital technologies, could imply that age itself may not necessary be a barrier

to (certain) digital health interventions among individuals with cardiovascular disease. This aligns to the literature showing high trends of digital technology usage among older-aged adults. For instance, according to the 2024 Austrian National Information and Communication Technology (ICT) survey 79.9% of individuals 65-74 years old were internet users and represented a closing of internet gap between age groups [512]. In addition, according to the Pew Research Centre, 78% of Americans over the age of 65 owned a smartphone in 2025 [513]. Thus, although likely differences in digital literacy competencies exist among age groups, these reports show that smartphone ownership and internet usage is highly prevalent among older individuals i.e., those most affected by cardiovascular disease. Thus, digitally-orientated interventions may be well targeted for such a group, given considerations of patient-, provider-needs, and digital competencies.

Interestingly, according to the 2024 Austrian National Information and Community Technology survey only 11.7% of the general population and 7% of 65-74-year-olds used internet-connected devices that collected health metrics [512], suggesting a rather low use of devices for health-related reasons in the general population. This contrasts to the findings of chapter four showing digital devices were prevalently used for pulse measurement, monitoring of athletic performance and health-related reasons. This may reflect differences in health monitoring needs between generally healthy and clinical populations, with a greater interest in health status monitoring among people with cardiovascular disease. Moreover, it could reflect the specific sample surveyed as all respondents had completed a cardiac rehabilitation programme, which educated patients on the importance of exercising within a targeted heart rate, possibly resulting in a desire for such data capturing.

Chapter four underlined some important technological preferences from patients. These preferences are largely aligned to those found in the literature, among a sample of similarly-aged, older individuals with cardiovascular disease, suggesting age-related preferences [514]. This related to greater preferences of more traditional forms of communication and information referring to email, calling, and internet use over text messaging, video calling or social media. Prior findings in the literature have found similar trends of mobile technologies and text messaging preferred for young adults (19-39 years) and phone calls and direct interactions with healthcare providers found for middle-aged patients (40-64) and senior citizens, respectively [514]. This may also extend to age-related differences in preferred tone of communication suggesting that interventions need to be sensitive to word choice and expression used through digital communication among a specific target group [515].

Additionally, as revealed in chapter four, patients had a variable understanding of data protection regulations and terminology, thus, there is an upmost importance to increase transparency of data usage and storage and clarity through means of communication. This can build trust among developers and users and potentially increase use of digital interventions. Trust of data measurement and data quality is equally important to facilitate use.

6.2.1.2 Healthcare professional perspectives

In a similar, complementary study by Lunz et al. (2025), the perspectives of Austrian healthcare professionals were surveyed on their use of digital health technologies in cardiovascular disease secondary prevention. Complementary to the main reasons found for patient use of digital technology in terms of self-monitoring and tracking (chapter four), healthcare professionals similarly reported using technology for personalised treatment plans, as a key application area for digital technologies [516]. This highlights a shared perception of digital technologies among patients and healthcare professionals for supporting secondary prevention goals. Besides this, healthcare professionals also

reported that digital technologies could be used to support organization, appointment planning, and documentation highlighting a perceived benefit for the administrative aspect of clinical work [516].

Moreover, similar to patients' high usage of digital technologies in their daily lives, healthcare professionals also readily recommended their use to patients with cardiovascular disease. Seventy percent currently recommended digital technologies to their patients with the most common ones being smartwatches and heart rate monitors, apps and step counters [516]. This demonstrates that healthcare professionals largely see their potential for purposes of patient self-monitoring in secondary prevention.

Although healthcare professionals generally recommended and also displayed a high readiness to use digital technologies in their care, their current integration into their clinical work is comparably low with only roughly half of healthcare professionals using them in their practice [516]. Reasons for low usage were related to personal (healthcare provider and patient) factors, e.g., lack of reimbursement or integration into daily tasks, technical skills, negative perceptions, as well as technical aspects, e.g., poor usability and underdeveloped technology [516].

The section below expands on these barriers and delves into the predominant factors that hinder digital technology uptake in clinical practice from the collated perspectives of healthcare providers across primary studies. Here, the potential and challenges of adopting digital health technologies in practice are addressed from an international perspective of healthcare provider insights (chapter five).

6.2.2 Implementation of digital health interventions in the clinical context: healthcare professional perspectives

The main findings from chapter five echo those of prior findings in the literature. In particular, that the adoption and realisation of digital health in clinical care requires a multifaceted approach targeting different levels of influence (e.g., individual users, healthcare system, technology) [63,68,72]. This means that implementing a digital health technology into clinical practice requires taking the whole ecosystem into account, including the involved actors, the health system structure, infrastructure and setting.

One of the striking findings from chapter five was the main concern of added workload through the adoption of digital health technologies, alongside already existing workload constraints. This contrasts the envisioned potential of digital health technologies of enhancing clinical environments by offsetting and alleviating workload pressures [63,517]. Findings from chapter five showed that concerned workload increases were not only related to the initial understanding and onboarding of the technology, but also pertained to its day-to-day implementation. These included added work roles (e.g., providing technology support), increased administrative tasks (e.g., reviewing, documenting data, responding to patients), duplication of data entries or tasks (e.g., due to incompatibilities with existing digital systems), worries about increased responsibilities during non-work hours, and liability concerns. In the clinical context, where high workload, including emotional exhaustion and burnout, is already greatly expressed [518], there is growing urgency not to add to this overworked environment.

This largely draws attention to increased efforts in not only focusing on the initial implementation of digital health technologies, but the long-term, sustained usage of them. In this type of reflection, it is critical to understand the existing work structure as a whole, including understanding the daily responsibilities of personnel, the varied roles taken on by different healthcare professionals, and the

technical systems in place as potential avenues of seamless integration. Efforts to encourage this could include a focused onboarding including training of the technology, clear role and task descriptions and defined procedures for transferring responsibility during work shortages or absences. One aspect highlighted from chapter five that could assist with the sustained implementation of digital health technologies is the integration of so-called 'program or clinical champions'. This refers to a designated healthcare professional who is skilled and motivated to administer the digital health technology, and who can serve as a contact point for colleagues and liaison to the research team or other stakeholders [342,423,436]. In general, this aspect of a supportive leadership underlines the importance of managerial efforts and a team-based approach towards adoption that is supportive and adaptable to healthcare professional needs.

Moreover, consistent with past literature [72], chapter five sheds light on the importance of healthcare professional attitudes and beliefs of digital health technology adoption. Here, barriers were frequently reported relating to negative views and low trust in the technologies. Specifically, these included concerns (e.g., of complete automation, replacement, privacy/security), reluctance to change and low trust in the tool's promised ability or accuracy. On the other hand, a perceived positive clinical impact, such as improved health outcomes and patient-centred care, was frequently noted, implying that healthcare professionals often perceived the potential of these tools in enhancing clinical care. Additionally, motivation driven by a perceived value of the technology, and the availability of training were commonly reported as facilitating factors. This presents an interesting observation of healthcare provider perceived benefits of such technologies, alongside concerns over their ability to fulfil such promises and the potential adverse consequences of relying too heavily on them.

Increased training and education opportunities, including transparency of the potential and limitations of such technologies may aide with concerns and minimize misunderstandings. In regards to this, Borges do Nascimento et al. (2023) recommended adopting training programmes tailored to healthcare professional needs and abilities, alongside providing high-quality, real-time technical support and coaching [72]. Additionally, Ferreira et al. (2025) argued that digital skill development courses must become an integral part of healthcare education curricula and professional trainings to equip healthcare professionals with the necessary skills to navigate a growing digital landscape [519]. Chapter five further highlights that healthcare provider beliefs of patient digital skills and abilities influences their acceptance. Healthcare professionals expressed reluctance to use technologies out of a perceived low patient digital literacy, low patient access to technology and patients of older age. Here, concerns were expressed that certain individuals may be excluded from the opportunities of digital health technologies, such as lower income patients, patients living in rural areas, and the elderly. Thus, for healthcare professionals to use these tools, they likely have to be reassured that these technologies serve the benefit of their patients. This could be fostered by educating healthcare providers on the extent to which technologies like smartphones are already integrated into patients' daily lives, raising healthcare provider awareness of the use of patient-centred user design in the design of certain technologies, and the promotion of digital skill training courses for patients.

Another important element indicated in chapter five is the importance of sustaining the role of a healthcare professional as a caregiver - those who support and guide patients through their care - or in other words maintaining the human-to-human element through digital solutions. Among facilitators, it was found that those digital health technologies, which supported communication between healthcare professionals and patients, centred around building connections or that built off

of an already established rapport (e.g., through familiarity from prior visits) were positively regarded as influencing their acceptance or led to better experiences of using such technologies.

Encouragingly, chapter five reported a greater frequency of positive perceptions as compared to negative ones on the perceived *impact* of digital health technologies on provider-patient relationships. These referred to perceptions that discussion could be promoted through shared data, and rapport, as well as patient reassurance enhanced through more frequent communication and monitoring. These largely align to findings by Qudah et al.'s review (2019) reporting that greater insight into patient data, through patient-reported outcomes from mhealth apps, allowed providers to focus their consultations on key areas of discussion [520]. This review also reported that communication features facilitated an emotional presence and connection between the patient and provider [520]. However, as indicated by Senek et al.'s review (2025) trust plays a fundamental role in the patient-provider relationship through digital health technologies and effort has to be made to address the sometimes-expressed feelings of depersonalization through remote-only care reported by patients and providers [521]. Overall, the findings are promising to indicate that instead of technologies replacing the caregiver and support role, they could improve patient-provider relationships if engaged and approached correctly, allowing for more personalised and guided care.

Lastly, besides fulfilling the caregiver role and human element, chapter five also highlighted the importance of digital health technologies in sustaining healthcare provider autonomy i.e., acknowledging their role as an autonomous medical professional. This refers to digital health technologies that can be adjusted and adapted based on providers' own clinical judgement. This need of autonomy is also apparent in prior findings in the literature regarding provider concerns of technologies (e.g., electronic health record systems) interfering with their professional autonomy of decision making or serving as management control mechanisms [522]. This highlights the growing need of designing tools that empower providers to support their work and equipping healthcare providers with the skills and capabilities to actively engage with digital health technologies [523].

The section below presents suggestions for the design and implementation of digital physical activity interventions for people with cardiovascular disease based on the synthesised findings of the previous chapters of this dissertation.

6.2.3 Recommendations for designing and implementing digital physical activity interventions for secondary prevention

Individuals with cardiovascular disease show particular needs and challenges to physical activity that require consideration in the design of digital physical activity interventions. As noted in this dissertation, there are key determinants of physical activity relevant for individuals with cardiovascular disease that should be regarded in the design of interventions. Additionally, there are specific demographic considerations to bear in mind throughout the design and implementation side of digital health technologies for the cardiac population. The following paragraphs will delve into recommendations regarding how i.e., what determinants should be best leveraged into the design of digital interventions for facilitating physical activity, and considerations for the implementation side of such interventions, based on patient and healthcare provider-reported findings.

This dissertation shed light on key psychological constructs important for physical activity engagement among people with cardiovascular disease (chapter two). These related to self-efficacy, intention,

psychological well-being, illness perception, negative emotion and autonomous motivation. Given that many of these constructs overlap with those of the general population, this dissertation addresses that several behavioural change techniques related to increased self-efficacy and physical activity in the general public - such as action planning, providing instruction, and reinforcing effort or progress towards behaviour [524] - can likely be applied into the design of digital physical activity interventions for populations with cardiovascular disease.

However, despite these overlapping constructs, individuals with cardiovascular disease often participated in physical activity with their cardiovascular health at the centre or modulating their engagement in physical activity (chapters two and three). This refers to participating in physical activity out of motivational reasons for improved cardiovascular health (e.g., heart strengthening) or re-gained independence; beliefs and attitudes of physical activity on their cardiovascular health relating to their engagement (i.e., whether it is viewed as beneficial or harmful); perceptions of control over their illness relating to physical activity; symptoms, such as pain influencing their participation. Thus, digital interventions which do not centre around these underlying cardiovascular health focuses into their design will likely be insufficient in addressing the needs of people with cardiovascular disease for physical activity promotion. Instead, interventions that encourage individual ability to overcome challenges and manage their cardiac condition may be beneficial in promoting physical activity. Such efforts can encourage confidence and empowerment and lead to potentially better adherence. Design features should, thus, focus on encouraging individual belief in their ability to sustain a heart-healthy lifestyle (i.e., self-efficacy), while navigating the challenges of a cardiac condition (e.g., medication side effects, pain, fatigue).

Moreover, as identified in this dissertation, kinesiophobia - an irrational fear of injury through physical activity - played a major barrier in physical activity engagement among individuals with cardiovascular disease. As this phenomenon is more pronounced in the cardiac community than other clinical and non-clinical populations [493], this suggests its need to be reflected in physical activity-promoting interventions for patients with cardiovascular disease. Therefore, interventions need to be sensitive to this belief and in turn address these fears and foster confidence in one's ability to participate in physical activity. Digital health interventions can uniquely address this fear through the provision of ongoing, tailored coaching and education beyond the extent of in-person consultations. This can increase confidence in disease understanding and physical activity, as well as reflection and empowerment [525,526] . Novel approaches such as artificial intelligence-powered health coaching [525] can offer personalised guidance immediately and autonomously without burdening healthcare professionals. However, this will require great reflection on how to balance autonomous capability and the human connection that is important for fostering provider-patient relationships [520,521].

This dissertation also provided insight into the role of autonomous motivation and patient-reported preferences for physical activity among individuals with cardiovascular disease (chapter three). These highlight additional design considerations for digital physical activity interventions in this population. Given the high interest in outdoor and home physical activities, digital interventions for patients with cardiovascular disease should provide tracking capabilities that encompass a wide range of activities including cycling, hiking and low-intensity home activities, such as gardening. Opportunities to track activities aligned to such preferences may encourage self-efficacy for achieving physical activity guidelines. Moreover, providing recommendations for physical activity adapted to their environment, such as easy home-based exercises or reminders for naturally integrating greater physical activity into their daily routine, e.g., taking the stairs over the elevator, could aide with promoting an overall healthier lifestyle. The use of just-in-time adaptive interventions - promoting physical activity at

favourable times based on the context - may serve as an approach to initiate cues and reminders at appropriate times for physical activity engagement in individuals' daily lives [527].

Moreover, in terms of personalised goals, digital tools should allow for the inclusion of more nuanced goals relating to quality-of-life and self-sufficiency, as these are important aspects expressed by patients with cardiovascular disease (chapter three). According to chapter three, patients did not express great interest in engaging in physical activity out of competitive reasons, so goals related to setting records or posting physical activity achievements used in traditional physical activity applications (e.g., Strava) may not be as applicable for individuals with cardiovascular disease. Instead reinforcing benefits of increased independence or improved cardiovascular health and quality of life, may align more greatly to patients' internalised goals. This could include informational reminders of measurable benefits of physical activity on cardiovascular health (e.g., corresponding to decreased risk, improved mental well-being), similar to that seen in smoking cessation applications (e.g., health progress based on number of smoke-free days) [528]. Overall, this lends itself into the importance of personalisation of digital physical activity interventions – where individuals can work towards goals that are aligned to their sense of self and interests. Design features, such as personalised goal setting, feedback and content could be applied to such interventions to promote more tailored approaches and thereby greater physical activity engagement [57].

Furthermore, as social support was observed to be positively related to engaging in physical activity among individuals with cardiovascular disease (chapter two), it may be beneficial to integrate social design features into digital physical activity interventions. For older individuals with cardiovascular disease, this could include opportunities to actively involve caregivers, spouses, or family members into the digital intervention. For younger adults, peers could serve as good source of support. In the case of a cardiac condition, this can be particularly beneficial in providing comfort to the individual that they are not navigating the condition alone.

In terms of concrete design features, this dissertation draws attention to specific relevant features from the perspectives of patients and healthcare providers. On the patient side, this refers to key tracking and recording abilities to help manage their cardiovascular and physical health (e.g., fitness, pulse measurement) (chapter four). As patients showed high motivation to engage in physical activity for their health, concrete features such as these can aide them in reaching their targets and encouraging confidence in their ability. In this dissertation, user-friendly design and simplistic communication features were underlined as potentially reenforcing the use of digital health technologies among patients (chapter four). This dissertation found similarities of digital communication preferences aligned to prior literature of older-aged preferences. As many individuals with cardiovascular disease are older-aged, this requires reflection into the design process of technologies to increase equitable access. On the healthcare professional side, design should follow their role as medical professionals (chapter five). This relates to fostering the patient-provider relationship and maintaining professional autonomy. The ability to personalise the technology and the use of two-way communication features may aide in this regard and encourage use by both patients and providers.

Although general recommendations are provided based on the scope of this dissertation, as healthcare providers and patient groups vary greatly based on their clinical context, this dissertation calls largely for the use of co-design in the development of digital physical activity interventions. Co-design is defined as "active collaboration between stakeholders in designing solutions to a prespecified problem" and focuses specifically on gathering user insights to inform strategies, along with shared responsibility in terms of decision-making and co-leading between stakeholders [529]. The use of co-design can better ensure that interventions take into account user needs and

preferences, along with their digital capabilities. In the field of cardiovascular disease, where healthcare providers showed concerns about patient digital skills (chapter five), co-design can encourage confidence that the tools are adapted to patient digital capabilities. Moreover, co-design with healthcare providers may increase confidence that their sense of autonomy is sustained, and potentially foster greater trust in the tool.

In this regard, this dissertation recommends utilising Noorbergen et al.'s (2021) contextualized framework and guidelines for co-designing mobile health (mHealth) systems as a framework for implementing co-design in a digital design process [299]. Here, Noorbergen et al.'s contextualised framework added dedicated 'prototyping' and 'implementation' phases to the already established Sanders and Stappers's co-design stages of 'pre-design', 'generative', 'evaluate' and 'post-design' [299,530]. In short, this refers to the addition of specific stages for the implementation side of mHealth systems (e.g., clinical context) and stages for higher fidelity prototyping. Noorbergen et al. suggested seven guidelines for co-designing in mHealth which include (1) understanding stakeholder vulnerabilities and diversity (i.e., understanding end-users vulnerabilities, such as health conditions of patients and selecting appropriate co-design tools and methods); (2) planning for and assessing health behaviour change by consulting behaviour change literature or experts in behaviour change relevant to the problem (here, it is worth noting that the use of core processes in applying Intervention Mapping may serve useful [531]); (3) identifying and involving co-design facilitators (i.e., select appropriate facilitators who can provide an authentic understanding); (4) immersing in the mHealth ecosystem; (5) identifying and involving post-design advocates of mHealth to support with the implementation; (6) applying health-specific evaluation criteria through feasibility testing (i.e., pilot testing and randomized controlled trials); (7) collecting and analysing usage data to understand impact (i.e., data to observe the impact on the system in post-design) [299].

Lastly, this dissertation provided insight into the implementation side of digital health technologies. Given that those of lower socioeconomic status and older age are of greater risk of cardiovascular disease [24], this underscores the importance of digital interventions to be implemented and promoted with these demographic groups in consideration. As shown in chapter four, the smartphone may be opportunistically targeted as a useful means of delivery, given its popularity and accessibility even among older-aged individuals. Simplistic apps or interventions using text messaging, calling, or email reminders may offer opportunities to engage with individuals with cardiovascular disease of diverse technical skills. To increase the equity of digital interventions it is, thus, critical to address aspects of digital literacy capabilities, language and health requirements, infrastructure and funding, resources, biases, representation and cost needed for engagement [532]. This also calls for a shift in responsibility of digital equity from a sheer individual-level to broader, systemic changes. To draw attention to this, Hollimon et al. (2025) proposed the *Rhizomatic Digital Ecosystem Framework* emphasising that digital inclusion must be addressed through five interdependent components: access, availability, adequacy, acceptability and affordability [533]. It recognizes that each component is interconnected to each other, and that policy initiatives must holistically target (individual and community) *access to* technologies, the *availability* of physical infrastructures, its *adequacy* (e.g., speed, connectivity) to meet the existing demands of internet services, technologies' *acceptability* by individuals through addressing socio-cultural barriers (incl. language needs), and its *affordability*, for example, through sustainable financial subsidises [533].

Besides such technological aspects, ensuring digital equity requires removing negative preconceived beliefs about certain groups' skills or perceptions of technologies. For instance, stereotypes and assumptions of older adults lacking technical capabilities or interest can contribute to ageism and digital exclusion of older-aged user groups [534]. To tackle this, changes, such as awareness-raising

and training need to be addressed at the micro- (individual), meso- (social interaction) and macro-level (societal) to encourage a positive framing of older adults, as well as efforts to empower older persons through designated interventions and promoting inclusive design [534].

On the healthcare provider side, the findings of this dissertation call for increased understanding of the clinical environment and integrating technology properly within such a setting e.g., including having adequate knowledge of the digital systems in place and the existing job responsibilities and roles of personnel. In this regard, it draws attention to greater effort needed in understanding the local context, where the implementation takes place, along with the surrounding regional and national context that may affect the local setting. To aide with this, guidance from the aforementioned NASSS framework, particularly those addressed in domain five 'organization' and domain six 'wider system' may serve useful [65]. For the domain 'organization' this includes assessing the capacity of the organization to innovate (incl. leadership and resources), their readiness for the technology, funding decisions, the extent of change needed to existing routines, and amount of work needed to implement the technology [65]. Knowledge of this and working locally with healthcare providers and managerial personnel can encourage a collaborative environment and provide an assessment if the technology is appropriate for such a context. If deemed so, it can aide in setting realistic expectations of the time commitment, workload and responsibilities involved, and how to sustain its implementation. For the domain 'wider system', this focuses on a greater understanding of the political, legal, economic, and regulatory landscape, and the surrounding sociocultural context that may impact adoption at the local, organizational level [65].

Additionally, to promote digital inclusion of healthcare providers, this will likely similarly require systematic factors, so that certain healthcare providers are not excluded from the opportunities of digital interventions. This could include, for instance, integrating digital skill development courses into healthcare education curricula to provide healthcare providers with the necessary skills to navigate digital innovations [519]. Overall, these findings from patients and healthcare providers highlight the importance of understanding the socio-environmental context and who these technologies are serving. Furthermore, it draws attention to the importance of ensuring equity of health technologies, so that certain groups are not disproportionately excluded from potential health benefits. In line with this, it is also critical that non-digital solutions for lifestyle changes are developed for those that generally dislike or struggle to use technologies, so that they are presented with the same opportunities as those digitally-engaged individuals.

6.2.4 Context of this dissertation: Intervention Mapping

This dissertation situates itself within the concept of Intervention Mapping. In short, Intervention Mapping is a well-established methodological framework in public health research that provides a systematic way to develop, implement and evaluate behavioural change interventions [535,536]. Here, this dissertation is situated primarily in the first and last steps of Intervention Mapping, namely (1) understanding stakeholder perspectives and (2) addressing implementation [535,536]. To provide recommendations for the design of (digital) physical activity interventions in cardiovascular disease prevention, this dissertation began with a systematic review to first assess the determinants (i.e., influencing factors) of physical inactivity in this population, and subsequently cross-sectional surveys to obtain patient-reported perspectives of physical activity needs and preferences, and opinions on digital technologies. Then, on the implementation side, a systematic review of healthcare provider attitudes on digital health intervention uptake in cardiac clinical care was conducted, to allow for insights into the implementation side of evidence-based digital interventions. From this, strategies to

increase uptake in clinical practice were provided. Overall, this dissertation falls in line within the Intervention Mapping framework by addressing key steps of Intervention Mapping.

This dissertation is particularly useful for those that take behavioural determinants as their conceptual starting point. Here intervention developers may directly target those determinants which emerge as strong indicators from this review, including determinants that are important for the general population, as well as determinants with specific relevance to the cardiac population.

Moreover, these aspects of needs assessment and understanding of the contextual environment of implementation are core concepts of the Ludwig Boltzmann Gesellschaft (LBG) with its focus on research driving a societal impact and bridging the gap between academia and implementation [537]. The Ludwig Boltzmann Gesellschaft was founded in 1961 and funds non-university specialised research institutes with a focus on collaboration between science and public sectors. The publications that constituted the scope of this dissertation stem out of my employment of one of such institutes, namely, the Ludwig Boltzmann Institute of Digital Health and Prevention (LBI-DHP) and contributes to the overall mission of the LBG by exploring a key societal issue of premature mortality due to cardiovascular disease and efforts to reduce these trends through behavioural change. Delving into this from the approach of systematic reviews and cross-sectional surveys allowed for both evidence-based conclusions and in-depth reflections based on patient-reported perspectives. This provided a detailed insight into potential design recommendations of (digital) physical activity interventions for patients with cardiovascular disease and reflections on how such interventions could be best implemented into clinical care.

6.2.5 Limitations of the studies in this dissertation and future directions

The studies that comprise this dissertation offer important insights, however, warrant important reflections when interpreting the results. Firstly, the two systematic reviews (determinants on physical activity and healthcare provider perspectives on the uptake of digital health interventions) include countries largely representative of the global north. Thus, these findings represent a rather homogenous group of individuals and may not be representative of countries primarily in the African, Latin American or Asian hemisphere. In terms of both determinants of physical activity and digital health interventions, the proposed suggestions and strategies here, thus, may not be fitting or tailored to these cultural differences. In an attempt to overcome this barrier, publication language was not limited nor were studies restricted based on country income level. Despite this, there is far more representation of Northern and specifically western countries.

Additionally, when interpreting the results of the determinants review, there was an observed unequal distribution of determinants across studies. Self-efficacy was the most explored determinant across studies leading to a wide representation across samples and an ability to compare its strength as a determinant more precisely. This trend was rather consistent for many of the cognitive and psychological determinants, showing that these are the most heavily explored determinants for this topic. Surprisingly, given the focus of intention on behaviour in the literature, intention was only represented in a handful of included studies in chapter two, suggesting further research is needed to explore its role on physical activity in the cardiac population. Moreover, environmental determinants showed overall low representation making interpretation of environmental effects on physical activity difficult. Thus, in general, there is a growing need to explore these less investigated determinants to understand how they may relate to physical activity. As indicated in chapter two, this refers to a need

to better understand how the factors of home exercise equipment, weather, insurance and the physical environment relate to physical activity in the cardiac population.

In terms of the chapter five, a critical limitation in its interpretation is the non-inclusion of low-income countries. In the scope of the systematic review search, no low-income countries were identified that met the inclusion criteria. This represents a general lack of studies investigating healthcare provider attitudes towards digital health interventions in low-income countries. This may be due to the digital infrastructure in low-income countries or a lack of funding for such interventions. This may represent a concerning potential digital divide due to socio-economic level. Moreover, it draws attention that the current findings from chapter five on barriers and facilitators of digital health uptake are assessed from the lens of middle- and high- income countries. To overcome this challenge, future directions should begin with assessing reasons for the lack of such studies in low-income countries and investigating their current digital landscape.

In terms of the cross-sectional studies in the Austrian context, one major limitation is related to the self-selected nature of the participants. Surveys were sent to the homes of former cardiac rehabilitation participants and returned on a voluntary basis. Thus, this may have led to higher responses from individuals naturally inclined to physical activity or digital tools. Attempts to lower this bias were addressed in a number of ways, by providing a paper-printed hard copy (with only an optional digital version) and sending the surveys through individuals' prior cardiac rehabilitation centres to foster trust in the inquirer and limit perception that the survey was promotional.

Lastly, this dissertation addresses potential constructs to target in behavioural change interventions based on the identified relevant determinants found. This calls for further exploration of the specific behaviour change techniques that best facilitate such constructs for behavioural change, such as self-efficacy [538]. In the context of cardiovascular disease, this can be beneficial for promoting strong evidence-based interventions for patients.

Despite these limitations, the studies of this dissertation provide important implications of relevant determinants and motivating reasons for physical activity among individuals with cardiovascular disease, the potential of digital health interventions for secondary prevention and physical activity maintenance, as well as implementation strategies of digital health interventions in the clinical context.

7. Concluding paragraph

This dissertation provides an overview of the need to increase physical activity interventions targeted towards individuals with cardiovascular disease. The low physical inactivity levels reported in secondary prevention are concerning for the cardiovascular health of individuals with cardiovascular disease. Although structured programmes, such as cardiovascular rehabilitation provide initial positive changes to physical activity, long-term adherence to physical activity remains a challenge. This dissertation highlights that physical activity interventions should target specific factors related to physical activity among individuals with cardiovascular disease. This refers specifically to addressing mental distress towards physical activity (e.g., kinesiophobia) and illness perception, along with known-psychological constructs for behaviour (e.g., self-efficacy, intention), that are related to the health condition of individuals. This also refers to the importance of promoting autonomous motivation specific to individual goals and interests. Patients with cardiovascular disease in this dissertation were found to engage in physical activity largely from motivation out of health-related goals (e.g., re-gained independence and cardiac strengthening), that should be reflected in the design of physical-activity promoting interventions. Furthermore, this dissertation explores the potential of digital health technologies for physical activity interventions and provides design recommendations of such interventions based on the main identified determinants for physical activity found. This dissertation further addresses how digital health interventions for this clinical population need to consider the typical demographic profile of individuals with cardiovascular disease, to ensure individuals of various backgrounds have equitable access to potential digital interventions. Lastly, this dissertation discusses how the implementation of digital health interventions requires implementation strategies at a multi-level approach, including the health system, users and technology. For such approaches, this dissertation calls for the use of user-centred design, shared decision-making and understanding the socio-cultural context of the intervention. Overall, this dissertation positions itself in the domain of Intervention Mapping, primary in the first and last steps. Namely, the initial design phase and the implementation considerations of digital physical activity interventions. Intervention developers may draw on these findings for the design and implementation of (digital) physical activity interventions for individuals with cardiovascular disease.

8. Impact paragraph

This dissertation addresses the growing concern of physical inactivity among individuals with cardiovascular disease in secondary prevention through a behavioural change and intervention implementation lens. Physical activity engagement (along with other healthy lifestyle behaviours) is critical for promoting overall health and preventing further adverse health outcomes (e.g., recurrent cardiac events, re-hospitalization). It plays a key role in lowering morbidity and mortality rates of cardiovascular disease, but frequent observations show that individuals struggle with establishing regular heart-healthy physical activity routines. This calls for an increased understanding of the influencing factors (i.e., determinants) of physical activity behaviour in this clinical population, and how interventions can be best designed and implemented to support a physically active lifestyle for individuals.

This dissertation identifies relevant determinants of physical activity through evidence-based, synthesized findings and patient-reported perspectives. Furthermore, it provides recommendations for the design of future (digital) interventions based on these identified factors and patient-reported digital technology use and perceptions. Finally, it addresses strategies for increasing the implementation of future or existing evidence-based digital health technologies in healthcare through collated findings of healthcare provider perceptions. The impact of this dissertation is outlined below in order of the different groups of people for which these findings may be useful for, namely, behavioural scientists, intervention developers, and implementers of digital health interventions.

For behavioural scientists in the field of physical activity behavioural change in secondary prevention, knowledge of relevant determinants and motivating reasons for physical activity can contribute to an increased understanding of physical activity behavioural engagement. This dissertation identifies certain determinants bearing particular importance among individuals with cardiovascular disease, including negative emotion (mostly kinesiophobia), illness perception, psychological wellbeing (incl. depression), prior exercise behaviour and motivation out of a desired improved cardiovascular health and quality-of-life. This highlights that individuals with cardiovascular disease may present specific determinants of physical activity that are less represented in the general public. This dissertation also identifies key determinants of physical activity which share relevance to those of the general population including: self-efficacy, exercise belief, education level, social support, intention, age, and autonomous motivation. Given that these present as consistent determinants across heterogenous timepoints (e.g., incl. months or years after cardiac rehabilitation, an acute event or diagnosis), it suggests their importance in physical activity behaviour in later, more maintenance stages of secondary prevention. Behavioural scientists may draw on these findings for future research to explore more greatly the potential causality of these identified determinants and physical activity behaviour using different study designs (e.g., longitudinal and experimental designs). Additionally, future research could focus on exploring the potential dynamic change of motivation for physical activity over the course of the patient journey to explore if motivation changes e.g., becomes more internalized in later compared to earlier stages of secondary prevention. This may provide increased insight into understanding the reasons behind non-adopters and adopters of maintained physical activity.

Intervention developers in secondary prevention of cardiovascular disease draw on evidence-based findings to design interventions. This dissertation shows that certain factors including self-efficacy, intention and autonomous motivation are relevant determinants even in later stages of prevention,

suggesting that these factors could be continuously targeted in both early and later stages of lifestyle behavioural change interventions. Additionally, the findings of negative emotion, psychosocial well-being and illness perception underscores that importance of addressing mental health features into the design of physical activity interventions for patients with cardiovascular disease. Furthermore, this dissertation highlights intrinsic motivational reasons (e.g., goals and preferences) for individual engagement in physical activity that could be targeted to better encourage activity. Besides specific features, this dissertation also addresses the importance of accessible design in digital health interventions to support the inclusion of individuals of various digital literacy levels and diverse socio-cultural backgrounds. This includes promoting user-friendly design and person-centred co-design.

Lastly, implementers of digital health interventions including policy makers in public health and secondary prevention of cardiovascular disease, healthcare providers and representatives of healthcare providers (e.g., senior managerial and operational staff) may draw on this dissertation for implementation strategies of evidence-based digital health technologies into healthcare. The findings of this dissertation point largely to a need to approach the implementation of digital health interventions from a multifaceted lens, i.e., the individuals (stakeholders), health system (incl. the environment), and the technology. This dissertation highlights that a current frequent gap in the adoption of digital health technologies is related to a low integration of technologies into the existing work environments (e.g., work responsibilities and routines), along with provider held beliefs. Healthcare providers' main barriers relate to a perceived increased workload, negative attitudes and low trust. As such, this dissertation calls for a greater understanding of the local context (incl. influencing regional and national factors) where the technologies are implemented. Suggestions for facilitating the uptake of evidence-based technologies include integrating technologies into existing systems, the use of co-design approaches, clear role and task distribution (e.g., inclusion of 'program champions') for sustainable integration, and training and education courses for healthcare providers and patients. On the patient side, policy makers may draw upon the components of this dissertation addressing the promotion of equitable access to digital health technologies. This dissertation addresses that traditionally vulnerable populations of digital exclusion (e.g., older adults and those of low socioeconomic status) are also those presenting the highest risk of cardiovascular disease. Here, the dissertation proposes efforts of greater inclusion through addressing systemic factors (e.g., access, cost, availability) and also developing non-digital solutions for those resistant or unable to use technologies.

Overall, this dissertation addresses a critical worldwide societal issue concerning the morbidity and mortality of cardiovascular disease. Given an increasing ageing population, rates of cardiovascular disease will continue to rise presenting a major challenge for healthcare. There will be an increased number of individuals present in a chronic stage of cardiovascular disease care and in need of continued behavioural support. Given the difficulties in adopting and maintaining behaviour change, interventions which are grounded in research are ever-more pertinent to support individuals in maintaining a heart-healthy lifestyle. This dissertation strives to positively impact patient care and patient outcomes by facilitating the development of future effective (digital) heath interventions for the secondary prevention of cardiovascular disease, and by facilitating the implementation of currently available evidence-based digital health interventions in healthcare practice. This dissertation adds to the growing body of knowledge and contributes to international initiatives for advancing cardiovascular health, including the European Union *Safe Hearts Plan* and the United Nations sustainable development goal 3.4 of reducing premature non-communicable disease mortality by one third by 2030.

9. Summary

The increasing burden of cardiovascular disease calls for greater secondary prevention and management strategies to reduce further adverse health consequences. A growing body of knowledge has drawn attention to the positive effects of regular heart-healthy physical activity on the cardiovascular health of individuals with cardiovascular disease. Despite this knowledge, far too few individuals with cardiovascular disease engage in regular physical activity. Even those who complete a structured cardiac rehabilitation programme often struggle to maintain an active lifestyle in the long-term. This draws attention to the need to better support individuals with cardiovascular disease in sustaining a physically active lifestyle through exploration into the determinants (i.e., influencing factors) of physical activity in this population and how interventions can be best designed and implemented for promoting physical activity behaviour.

In this dissertation, exploration into this stems from both a systematic synthesized approach and patient-reported perspectives to identify what determinants (i.e., factors) are most relevant and should be incorporated into physical activity-promoting interventions. Moreover, given the rise of digital health interventions, this dissertation also explores the potential and how digital health interventions may be best developed and implemented in healthcare based on patient-reported usage and perceptions, as well as collated findings from healthcare professional perspectives.

To explore this, this dissertation addresses the following two driving aims:

(1) To investigate and synthesize key determinants (i.e., promoting and hindering factors) of physical activity engagement among individuals with cardiovascular disease through:
    a. collated quantifiable association strength measures extracted from primary studies
    b. patient-reported perspectives of facilitators and barriers, as well as motivating reasons of physical activity
(2) To explore the potential of digital health interventions for promoting physical activity in cardiovascular disease secondary prevention through:
    a. patient-reported perspectives on the reasons for and against digital technology usage; insights into the desired features and means of digital technology-promoting physical activity interventions
    b. synthesized (quantitative and qualitative) findings of facilitating and hindering factors for the uptake of digital health interventions in clinical practice from healthcare professional perspectives, to provide strategies for increased uptake of evidence-based digital health interventions in healthcare

A summary of each chapter is presented below in alignment to the above-mentioned research aims.

Chapter one begins with a general introduction of the scope of cardiovascular disease and draws attention to its increasing prevalence and overall health burden worldwide. It highlights the global and European efforts to reduce the mortality and morbidity rates of cardiovascular disease and further addresses how healthy lifestyle behaviours are pertinent in reducing its adverse consequences. It stresses the critical role that physical activity plays as a key modifiable behavioural factor, but the concerning high levels of physical inactivity found among patients with cardiovascular disease, where physical activity is critical in preventing negative outcomes. It highlights a need to better understand the factors contributing to physical inactivity among individuals with cardiovascular disease given a gap in synthesized findings of the relevant determinants in this population. It draws upon the well-

researched area of determinants found in the general public through prior systematic reviews as a basis to build upon, but underlines that individuals with cardiovascular disease may present unique challenges based on their cardiac condition, warranting further investigation specific to this population. Among determinants, motivation for physical activity is as key factor to explore among patients with cardiovascular disease, as patients may present specific motivating reasons for physical activity unique to their condition that should be reflected in physical activity-promoting interventions. Here, self-determination theory is introduced as the framework applied to this dissertation to investigate and categorize patient motivation. Lastly, the introduction discusses the emergence of digital health interventions and their potential in improving clinical outcomes and behavioural change in cardiovascular disease prevention. It further addresses the current gaps in their uptake for patients and healthcare providers underscoring a need for greater insight into reasons behind low acceptability from these two stakeholder groups.

Chapter two begins with addressing the first aim of this dissertation, namely an investigation into the most prevalent determinants of physical activity among patients with cardiovascular disease. To investigate this, a systematic review was utilized as the best approach for addressing this aim, given its ability to collate association strength measures from determinants and physical activity behaviour across primary studies. This allows for a synthesis of determinants' importance based on the strength of association and directionality across a range of samples. Here, to categorize determinants, the OPTimAL ontology framework was utilized to allow for a systematic structurization, such that similar determinants were ordered to similar overarching themes (e.g., cognitive factors, psychological factors) allowing for improved comparison. Overall, 70 primary studies from 29 countries (2005-2025) were included resulting in 56 determinants. The determinants that are regarded as main facilitators of physical activity are self-efficacy and prior exercise behaviour followed by education level, social support, intention, exercise belief, illness perception, and psychological well-being. Negative emotion (mostly kinesiophobia) and older age were identified as the strongest indicators for negative physical activity behaviour.

Chapter three moves from an overall global view of determinants to a sample-specific analysis of determinants and motivation for physical activity in an Austrian sample of former cardiac rehabilitation participants. Here, a cross-sectional study was conducted and specifically targeted individuals who had completed a cardiac rehabilitation programme approximately three years prior to the study. This was purposely targeted to observe what determinants and motivating reasons relates to physical activity in long-term secondary prevention, i.e., self-management phase. Here, health, pain and motivation were found as main determinants of physical activity, with autonomous motivation relating to health-related goals and quality-of-life aspirations most prevalent. Furthermore, it was found that in this sample of predominately older-aged patients, there was an overall large preference for outdoor, aerobic, and individual physical activities. This study provided important considerations for creating physical activity-promoting interventions in such a population.

Chapter four turns to the second main aim of this dissertation, namely, the role of digital health technologies in cardiovascular disease prevention. It follows the same cross-sectional study design as the prior chapter, however, differs in the content of survey. Here, a different sample of former cardiac rehabilitation participants were asked about their usage of digital technologies in their daily lives, as well as for physical activity purposes and their reasons for and against technology usage, and desired features. Findings showed that digital technologies usage - especially the smartphone - was highly prevalent in patients' daily lives and to a large extent for physical activity purposes. Digital technologies were mostly used for information and more traditional communication aspects (e.g., email and calling), or pulse measurement and monitoring purposes for physical activity. Main reasons

against physical activity usage were perceived lack of need, lack of interest or poor usability. This study provided important insights into patient views and needs of digital technology for physical activity behaviour. Taken together, chapters three and four provide valuable primary data for the Austrian context, where such research has been largely unexplored.

Chapter five expands on this by exploring healthcare professional opinions on the barriers and facilitators for digital health technology uptake in cardiovascular disease healthcare. Here, a systematic review of 125 primary studies (2020-2024) with qualitative, quantitative, and mixed methods was conducted to synthesize healthcare provider perspectives on digital health technologies. These factors were coded and categorized to the World Heart Federation Roadmap domains: healthcare professionals, patients, technology and health systems. Overall, the most frequently reported barrier for healthcare providers was excessive workload (due to current workload or perceived added workload due to use of digital health interventions). Other barriers were individual factors relating to low trust and negative attitudes or concerns. On the other hand, perceived positive clinical impact, healthcare provider motivation and training were key-reported facilitators. Moreover, healthcare providers felt hindered to use digital health technologies because of perceived low patient access to technology and digital literacy levels, whereas perceived improvements in patient-centred care positively influenced use. For health systems, work structure, financing and policies were key factors. Lastly, on the technological side, usability, adaptability, technical stability, and integration with existing technical systems were important factors. Overall, this study reveals that uptake of digital health technologies for cardiovascular disease in healthcare is complex and effort needs to be focused on better assessing the local context, building trust, incorporating provider input, and transparency with digital health technologies.

Lastly, chapter six provides an in-depth discussion of the main findings from the previous studies and their overall implications within the scope of existing literature. Here, the discussion is structured by the two driving aims of this dissertation. The first part discusses the key determinants of physical activity behaviours identified among individuals of cardiovascular disease and provides recommendations based on these factors that should be targeted in the design of such interventions. It additionally draws on the motivational findings behind physical activity and how physical activity interventions could incorporate such motivating-reasons to drive patient autonomy and possibly greater behavioural outcome. The second part of this chapter focuses on the second aim of digital health interventions. Here, recommendations are provided to facilitate the design and implementation of digital interventions based on patient-reported perspectives on their needs, opinions and preferences. Recommendations are additionally provided for the implementation of evidence-based digital health interventions in healthcare by drawing on the collated perspectives of healthcare providers. Subsequently, a section of this chapter is devoted to synthesizing all the prior chapters together to provide concrete suggestions for the design and implementation of *digital* physical activity interventions for individuals with cardiovascular disease. Lastly, this chapter discusses how the dissertation situates itself in the concept of Intervention Mapping and provides its limitations and future directions.

10. Samenvatting

De toenemende ziektelast van cardiovasculaire aandoeningen vraagt om sterkere preventie- en managementstrategieën om de negatieve gezondheidseffecten te verminderen. Een groeiend inzicht in beïnvloedbare risicofactoren heeft de aandacht gevestigd op de positieve effecten die gezonde leefstijlgedragingen, zoals regelmatige hartgezonde lichaamsbeweging, kunnen hebben op cardiovasculaire gezondheidsuitkomsten. Voor personen met een cardiovasculaire aandoening is lichamelijke activiteit cruciaal voor het voorkomen van recidiverende 'events' en het bevorderen van positieve gezondheidsuitkomsten. Ondanks deze inzichten is slechts een klein deel van de bevolking regelmatig fysieke actief. Zelfs personen die een gestructureerd hartrevalidatieprogramma hebben afgerond, hebben vaak moeite om op de lange termijn een actieve leefstijl te behouden. Dit benadrukt de noodzaak om mensen met cardiovasculaire aandoeningen beter te ondersteunen bij het volhouden van een fysiek actieve leefstijl door inzicht te verkrijgen in de beïnvloedende factoren (d.w.z. determinanten) van lichamelijke activiteit binnen deze populatie en in hoe interventies het best ontworpen en geïmplementeerd kunnen worden om fysieke activiteit te bevorderen.

In dit proefschrift wordt deze problematiek onderzocht vanuit zowel een systematisch gesynthetiseerde benadering als vanuit patiënt-gerapporteerde perspectieven, met als doel te identificeren welke factoren (determinanten) relevant zijn en optimaal geïntegreerd dienen te worden in interventies die lichamelijke activiteit stimuleren. Daarnaast wordt, gezien de opkomst van digitale gezondheidsinterventies, ook het potentieel van dergelijke interventies onderzocht en hoe zij het best ontwikkeld en geïmplementeerd kunnen worden binnen de gezondheidszorg, op basis van patiënt-gerapporteerd gebruik en percepties, evenals samengevoegde bevindingen vanuit het perspectief van zorgprofessionals.

Om dit te onderzoeken richt dit proefschrift zich op twee centrale doelstellingen:

(1) Het onderzoeken en synthetiseren van belangrijke determinanten (d.w.z. bevorderende en belemmerende factoren) van deelname aan lichamelijke activiteit bij personen met cardiovasculaire aandoeningen door middel van:
   a.) samengevoegde kwantitatieve associatiematen afkomstig uit primaire studies;
   b.) patiënt-gerapporteerde perspectieven op facilitatoren, barrières en motiverende redenen voor lichamelijke activiteit.

(2) Het verkennen van het potentieel van digitale gezondheidsinterventies voor het bevorderen van lichamelijke activiteit in de secundaire preventie van cardiovasculaire aandoeningen door middel van:
   a.) patiënt-gerapporteerde perspectieven op redenen vóór en tegen het gebruik van digitale technologie, evenals inzichten in gewenste functies en vormen van digitale interventies ter bevordering van lichamelijke activiteit;
   b.) gesynthetiseerde (kwantitatieve en kwalitatieve) bevindingen over bevorderende en belemmerende factoren voor de adoptie van digitale gezondheidsinterventies vanuit het perspectief van zorgprofessionals, met als doel strategieën te formuleren voor een grotere implementatie van op evidentie gebaseerde digitale gezondheidsinterventies in de zorg.

Hieronder wordt per hoofdstuk een samenvatting gepresenteerd in lijn met de bovengenoemde onderzoeksdoelstellingen.

Hoofdstuk één start met een algemene inleiding over cardiovasculaire aandoeningen en vestigt de aandacht op de toenemende prevalentie en wereldwijde ziektelast. Het beschrijft mondiale en Europese inspanningen om mortaliteit en morbiditeit als gevolg van cardiovasculaire aandoeningen te reduceren en benadrukt het belang van gezonde leefstijlgedragingen bij het verminderen van negatieve gevolgen. Daarbij wordt de cruciale rol van lichamelijke activiteit als beïnvloedbare gedragsfactor benadrukt, evenals de zorgwekkend hoge mate van fysieke inactiviteit onder patiënten met cardiovasculaire aandoeningen, terwijl fysieke activiteit essentieel is voor het voorkomen van negatieve uitkomsten. Het hoofdstuk benadrukt de noodzaak om beter inzicht te krijgen in de factoren die bijdragen aan fysieke inactiviteit binnen deze populatie, gezien het gebrek aan gesynthetiseerde bevindingen over relevante determinanten. Er wordt voortgebouwd op bestaande bevindingen met betrekking tot de algemene bevolking, maar benadrukt ook dat patiënten met cardiovasculaire aandoeningen unieke uitdagingen kunnen ervaren die samenhangen met hun cardiale conditie. Motivatie voor lichamelijke activiteit wordt geïdentificeerd als een kernfactor, aangezien patiënten mogelijk specifieke, aandoening-gerelateerde motieven hebben die weerspiegeld moeten worden in interventies. De zelfdeterminatietheorie wordt geïntroduceerd als theoretisch kader voor het onderzoeken en categoriseren van motivatie. Tot slot wordt de opkomst van digitale gezondheidsinterventies besproken, evenals hun potentieel om klinische uitkomsten en gedragsverandering te verbeteren, en worden lacunes in acceptatie door zowel patiënten als zorgverleners belicht.

Hoofdstuk twee behandelt de eerste doelstelling van het proefschrift: het identificeren van de meest voorkomende determinanten van lichamelijke activiteit bij patiënten met cardiovasculaire aandoeningen. Hiervoor werd een systematische review uitgevoerd, waarmee associatiestatistieken tussen determinanten en lichamelijke activiteit uit primaire studies werden samengevoegd. Determinanten werden geclassificeerd met behulp van het OPTimAL-ontologiekader om een gestructureerde vergelijking mogelijk te maken. In totaal werden 70 primaire studies uit 29 landen (2005–2025) geïncludeerd, resulterend in 56 determinanten. De belangrijkste bevorderende factoren voor lichamelijke activiteit waren eigen-effectiviteit en eerder beweeggedrag, gevolgd door opleidingsniveau, sociale steun, intentie, beweegovertuigingen, ziekteperceptie en psychologisch welbevinden. Negatieve emoties (voornamelijk kinesiofobie) en hogere leeftijd bleken de sterkste indicatoren voor lage fysieke activiteit.

Hoofdstuk drie verschuift van een globale benadering naar een populatie-specifieke analyse van determinanten en motivatie voor lichamelijke activiteit in een Oostenrijkse steekproef van voormalige cardiale revalidatiepatiënten. In een cross-sectionele studie werden personen onderzocht die ongeveer drie jaar eerder een cardiaal revalidatieprogramma hadden afgerond, om determinanten in de context van langdurige secundaire preventie te analyseren. Gezondheid, pijn en motivatie kwamen naar voren als belangrijkste determinanten, waarbij autonome motivatie gerelateerd aan gezondheidsdoelen en kwaliteit van leven het meest voorkwam. Daarnaast bleek dat deze overwegend oudere populatie een sterke voorkeur had voor buitenactiviteiten, aerobe en individuele vormen van lichamelijke activiteit. Deze bevindingen bieden belangrijke aanknopingspunten voor interventieontwikkeling.

Hoofdstuk vier richt zich op de tweede hoofddoelstelling: de rol van digitale gezondheidstechnologieën in cardiovasculaire preventie. In een vergelijkbare cross-sectionele studie werd het gebruik van digitale technologieën in het dagelijks leven en voor lichamelijke activiteit

onderzocht. Het gebruik van digitale technologie, met name smartphones, bleek wijdverbreid, ook voor beweegdoeleinden. Technologie werd voornamelijk gebruikt voor informatie, communicatie (zoals e-mail en bellen) en het meten en monitoren van hartslag. Belangrijke redenen tegen gebruik waren een ervaren gebrek aan noodzaak, gebrek aan interesse en beperkte gebruiksvriendelijkheid. De bevindingen leveren waardevolle inzichten in de behoeften en percepties van patiënten. Samen bieden hoofdstuk drie en vier unieke primaire data voor de Oostenrijkse context.

Hoofdstuk vijf bouwt hierop voort door de opvattingen van zorgprofessionals te onderzoeken over belemmerende en bevorderende factoren voor de adoptie van digitale gezondheidstechnologieën binnen de cardiovasculaire zorg. Daartoe werd een systematische review uitgevoerd van 125 primaire studies (2020–2024) met kwalitatieve, kwantitatieve en mixed-methods onderzoeksopzetten, waarin perspectieven van zorgverleners op digitale gezondheidstechnologieën werden gesynthetiseerd. Deze factoren werden gecodeerd en geclassificeerd volgens de domeinen van de World Heart Federation Roadmap: zorgprofessionals, patiënten, technologie en zorgsystemen. In het algemeen was de meest frequent gerapporteerde barrière voor zorgprofessionals een hoge werkdruk, voortkomend uit de bestaande werklast of uit een verwachte toename als gevolg van het gebruik van digitale gezondheidsinterventies. Andere barrières betroffen individuele factoren, zoals een laag vertrouwen en negatieve attitudes of zorgen. Daartegenover stonden waargenomen positieve klinische effecten, motivatie van zorgprofessionals en scholing als belangrijke facilitatoren. Daarnaast gaven zorgprofessionals aan belemmerd te worden in het gebruik van digitale gezondheidstechnologieën door de veronderstelde beperkte toegang van patiënten tot technologie en een lage digitale geletterdheid, terwijl ervaren verbeteringen in patiëntgerichte zorg het gebruik juist bevorderden. Op het niveau van zorgsystemen speelden werkstructuur, financiering en beleid een centrale rol. Ten slotte waren aan de technologische kant gebruiksvriendelijkheid, aanpasbaarheid, technische stabiliteit en integratie met bestaande systemen belangrijke factoren. In het geheel laat deze studie zien dat de implementatie van digitale gezondheidstechnologieën voor cardiovasculaire aandoeningen complex is en dat inspanningen gericht moeten zijn op een betere beoordeling van de lokale context, het opbouwen van vertrouwen, het betrekken van zorgprofessionals en transparantie rondom digitale gezondheidstechnologieën.

Tot slot biedt hoofdstuk zes een diepgaande bespreking van de belangrijkste bevindingen uit de voorgaande studies en hun implicaties binnen het kader van de bestaande literatuur. De discussie is gestructureerd rond de twee centrale doelstellingen van dit proefschrift. Het eerste deel bespreekt de belangrijkste determinanten van lichamelijke activiteit die zijn geïdentificeerd bij personen met cardiovasculaire aandoeningen en formuleert aanbevelingen voor factoren die in het ontwerp van interventies gericht op lichamelijke activiteit zouden moeten worden meegenomen. Daarbij wordt ook ingegaan op de motiverende factoren achter lichamelijke activiteit en op hoe interventies deze motieven kunnen integreren om patiëntautonomie te bevorderen en mogelijk sterkere gedragsuitkomsten te realiseren. Het tweede deel richt zich op de tweede doelstelling, namelijk digitale gezondheidsinterventies. Hier worden aanbevelingen gedaan voor het faciliteren van het ontwerp en de implementatie van digitale interventies op basis van patiënt-gerapporteerde behoeften, opvattingen en voorkeuren. Daarnaast worden aanbevelingen geformuleerd voor de implementatie van op evidentie gebaseerde digitale gezondheidsinterventies in de zorg, gebaseerd op de samengevoegde perspectieven van zorgprofessionals. Vervolgens wordt een synthese van alle voorgaande hoofdstukken gepresenteerd, met concrete suggesties voor het ontwerp en de implementatie van *digitale* interventies ter bevordering van lichamelijke activiteit bij personen met cardiovasculaire aandoeningen. Afsluitend bespreekt dit hoofdstuk de positionering van het proefschrift binnen het concept van Intervention Mapping, evenals de beperkingen en richtingen voor toekomstig onderzoek.

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12. Appendices

The appendices for the chapters of this doctoral thesis can be found in a stored Open Science Framework (OSF) repository under:
https://osf.io/wvm6p/overview?view_only=b3a7526b06f341e9aab1a81bef04bd51

Curriculum Vitae

Hannah Christine McGowan was born on 24 January 1997 in Baltimore, Maryland, U.S.A. In 2018, she graduated from the University of Maryland, Baltimore County, where she completed a Bachelor of Science in Biological Sciences and a minor in Psychology. In 2021, she completed a Master of Science in Neuro-cognitive Psychology with a final grade of good at the Ludwig Maximilian University of Munich in Germany. From 2022 to 2025, Hannah worked as a researcher at the Ludwig Boltzmann Institute of Digital Health and Prevention in Salzburg, Austria on the projects described in this dissertation. Since 2024, she has been a PhD candidate at the Department of Health Promotion at the Care and Public Health Research Institute (CAPHRI) at Maastricht University where she completed her PhD projects and participated in higher educational courses.