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Change patterns and determinants of physical activity in people with cancer

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List of abbreviations

ACSM	American College of Sports Medicine
ANOVA	Analysis of variance
ASCO	American Society of Clinical Oncology
B	Unstandardized regression coefficient beta
BMI	Body mass index
CES	Cumulative effect size
χ^2	Chi-squared
CHAID	Chi-squared automated interaction detection
CI	Confidence interval
ES	Effect size
GSLTPAQ	Godin-Shepard Leisure-Time Physical Activity Questionnaire
HCP	Health care professionals
HR	Hazard ratio
LPA	Light-intensity physical activity
M	Mean
MASCC	Multinational Association of Supportive Care in Cancer
MD	Mean difference
Mdn	Median
METs	Metabolic equivalents of task values
MPA	Moderate-intensity physical activity
MVPA	Moderate-to-vigorous-intensity physical activity
ω^2	Omega-squared
OR	Odds ratio
QoL	Quality of life
PA	Physical activity
φ	Phi coefficient
PR	Prevalence ratio
r	Pearson’s r
RCT	Randomized controlled trial
RKI	Robert Koch Institute
SD	Standard deviation
U	Test statistic for the Mann-Whitney test
V	Cramer’s V
VPA	Vigorous-intensity physical activity
WHO	World Health Organization
z	Test statistic for the Wilcoxon signed-rank test

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1. Introduction

1.1. Physical activity in people with cancer

Due to a rapidly growing and aging population, the incidence of cancer is increasing worldwide. Recent statistics of 2020 have projected a number of 19.3 million new cancer cases, of which female breast cancer (11.7%) accounted for the most frequently diagnosed cancer type, followed by lung cancer (11.4%), colorectal cancer (10.0%), and prostate cancer (7.3%) (Sung et al. 2021). For Germany, the Robert Koch Institute (RKI) predicted a similar trend with the number of newly diagnosed cancer cases rising from 492,000 in 2016 to 510,000 in 2020, the latter including 69,700 female breast cancer, 61,200 prostate cancer, and 55,400 colorectal cancer cases (Robert Koch-Institut and Gesellschaft der epidemiologischen Krebsregister in Deutschland e.V. 2019). The increasing incidence leads to a higher absolute number of deaths from cancer. With an estimated number of almost ten million deaths in 2020, cancer counts as one of the leading causes of death worldwide (Sung et al. 2021). However, at the same time, improvements in early diagnostics and treatment of the disease lead to rising numbers of long-term cancer survivors. A global surveillance study of cancer survival for 37.5 million patients with 18 types of cancer from 71 countries showed that survival trends were generally increasing (Allemani et al. 2018). According to the RKI, survival rates have likewise been growing in Germany and are amounting to net 5-year survival rates of 87% for breast cancer, 89% for prostate cancer, 62% for male and 63% for female colorectal cancer (Robert Koch-Institut and Gesellschaft der epidemiologischen Krebsregister in Deutschland e.V. 2019).

The growing number of cancer survivors entails new demands for the long-term disease management, since many individuals with cancer suffer from treatment-related side-effects and their lasting health consequences. As shown in a large Australian population-based study, the number of cancer patients experiencing health problems significantly exceeds that of individuals without a history of cancer in terms of severe physical functioning limitations (prevalence ratio

(PR) = 1.28, 95% confidence interval (CI) [1.25, 1.32]), elevated psychological distress (PR = 1.05, 95% CI [1.02,1.08]), and poorer quality of life (QoL) (PR = 1.28, 95% CI [1.24, 1.32]) (Joshy et al. 2020). Physical limitations can thereby range from a loss in muscle strength and stamina to pain, dyspnea, or polyneuropathy, while psychological problems often include fatigue, sleeping disorders, anxiety, or depression (Arndt et al. 2017; Han et al. 2020; Schmidt et al. 2021; Stein et al. 2008; Zhang et al. 2020). Previous research has shown that for the majority of cancer patients these symptoms persist even years after the diagnosis and treatment (Schmidt et al. 2012; Schmidt et al. 2018; Stein et al. 2008). While 84% of breast and 89% of colorectal cancer patients indicated to experience side-effects during chemotherapy treatment (Pearce et al. 2017), more than 50% of individuals still suffered from at least three symptoms five to ten years after the cancer diagnosis (Götze et al. 2018). It appears evident that the high number and persistent duration of disease- and treatment-related symptoms can substantially contribute to a reduction in QoL. In this regard, a recent meta-analysis of 63 studies inferred that cancer patients' QoL was significantly impaired with regard to the subdomains physical health (cumulative effect size (CES) = -0.89, 95% CI [-1.47, -0.32]), mental health (CES = -0.87, 95% CI [-1.45, -0.29]), social health (CES = -0.68, 95% CI [-1.27, -0.08]), as well as cognitive health (CES = -0.05, 95% CI [-0.53, 0.44]) (Firkins et al. 2020). According to previous studies, almost 50% of the variance in cancer patients' QoL could be explained by fatigue, pain, psychological problems, and other treatment-related side effects (Arndt et al. 2006; Schmidt et al. 2018).

Overall, the high number of individuals living with long-lasting, burdening disease-related health issues and reduced QoL highlights the need for effective strategies for cancer patients to manage their symptoms in the long run. Self-management strategies, such as physical activity, nutrition, psychological support, or self-help groups, are considered as effective in improving the physical and psychological consequences of cancer treatment (Barlow et al. 2002; Coffey et al. 2016) and appear to be popular among cancer patients as shown in a study among 445 individuals in the United Kingdom, of which 92% indicated having undertaken some kind of self-management strategy (Shneerson et al. 2015). This dissertation sets particular focus on physical activity (PA), which has been revealed as one of the most commonly used self-management strategies among people with cancer (Shneerson et al. 2015; Sieverding et al. 2020). In its broadest sense, PA is defined as ‘any bodily movement produced by the skeletal muscles that results in energy expenditure’ (Caspersen et al. 1985, pg. 126). However, for this dissertation the focus is narrowed to leisure time PA that is performed during free time with the intent to improve one’s fitness, performance, or health in contrast to household and/or occupational activities (Courneya and Friedenreich 2011; Howley 2001). The following section will describe the beneficial effects of PA for the physical and psychological health of people with cancer.

1.2. Effects of physical activity on cancer-related outcomes

Research on PA among cancer patients has been evolving during the past 30 years. While in the 1960s and 1970s there was already evidence supporting the benefits of PA for other chronic diseases, e.g., cardiovascular diseases, the first investigations on PA in cancer patients were conducted in the late 1980s, albeit not consistently published before the late 1990s (Jones et al. 2017; MacVicar et al. 1989; Winningham et al. 1989). To date, the effects of PA on different health-related outcomes for individuals with cancer have been studied quite extensively. Overall, multiple clinical trials have generated solid and conclusive evidence for several positive effects of PA for cancer patients during and after cancer treatment. These are not limited to physical health benefits, such as improved physical functioning (Buffart et al. 2017), upper and lower body muscle strength, and aerobic fitness (Lee and Lee 2020; Segal et al. 2017; Singh et al. 2020; Sweegers et al. 2019; Zeng et al. 2019), but also include improvements in psychological health as shown by reductions in anxiety and depressive symptoms (Brown et al. 2012; Lee and Lee 2020; Singh et al. 2020; Zeng et al. 2019). Further strong evidence was provided for the reduction of treatment-related side-effects, comprising lower fatigue levels (Cramp and Byron-Daniel 2012; Lee and Lee 2020; Meneses-Echavez et al. 2015; Mustian et al. 2017; Nakano et al. 2018; van Vulpen et al.

2016) and reduced lymphedema (Baumann et al. 2018; Hasenoehrl et al. 2020; Rogan et al. 2016; Schmitz et al. 2010a). Beyond the improvement of specific disease- and treatment-related symptoms, PA is also considered as highly beneficial to counteract impairments in cancer patients' QoL (Lee and Lee 2020; Mishra et al. 2012; Segal et al. 2017; Singh et al. 2020; Soares Falcetta et al. 2018; Sweegers et al. 2018). An individual patient data meta-analysis of 34 randomized controlled trials (RCTs) including 4,519 patients with cancer concluded that compared with usual care, wait-list, or attention control groups, PA significantly improved patients' QoL (ß = 0.15, 95% CI [0.10, 0.20]), independent of their sociodemographic and medical characteristics or the type of PA (Buffart et al. 2017). Apart from these rather immediate positive effects on physical and psychological health outcomes, PA even seems to positively influence the course of the disease in terms of reduced risks of cancer recurrence (Cormie et al. 2017; Friedenreich et al. 2017; Lahart et al. 2015) and cancer-specific mortality (Lahart et al. 2015; Li et al. 2016; McTiernan et al. 2019; Patel et al. 2019; Schmid and Leitzmann 2014). In this regard, a recent meta-analysis of 136 studies suggested improved survival outcomes for PA performed before the diagnosis (hazard ratio (HR) = 0.82, 95% CI [0.79, 0.86]) as well as thereafter (HR = 0.63, 95% CI [0.53, 0.75]) for all cancer types combined. Particularly high effects emerged for breast (pre-diagnosis PA: HR = 0.86, 95% CI [0.78, 0.94]; post-diagnosis PA: HR = 0.63, 95% CI [0.50, 0.78]) and prostate cancer patients (pre-diagnosis PA: HR = 0.90, 95% CI [0.75, 1.08]; post-diagnosis PA: HR = 0.70, 95% CI [0.55, 0.90]), with a linear trend between pre- as well as post-diagnosis PA dose and cancer-specific mortality among breast cancer patients (Friedenreich et al. 2020).

Given the body of evidence, the health benefits associated with a physically active lifestyle for people with cancer are widely acknowledged. However, considering that patients' physical capabilities might be limited by the adverse effects of cancer treatment or other accompanying health conditions, it appears crucial that PA can be performed in a safe and feasible manner. In clinical studies, the safety of PA is commonly measured by the frequency and type of so-called adverse events, i.e., undesirable health-related or medical events occurring during or due to PA sessions. In 2018, the American College of Sports Medicine (ACSM) reviewed available literature on PA-related adverse events in RCTs and concluded that ‘exercise training and testing was generally safe for cancer survivors’ (Schmitz et al. 2019, pg. 2), albeit noting that medical clearance and adjustments of exercises might be necessary. While most evidence was based on studies among breast and prostate cancer patients, a recent pooled meta-analysis of 19 RCTs yielded that PA was also safe for colorectal cancer patients as in the analyzed studies, the risk of adverse events did not differ between PA intervention and control groups (Singh et al. 2020).

The increasing knowledge about the positive effects and safety of PA for cancer patients has contributed to a shift from the previously prevailing ‘rest-paradigm’, according to which people with cancer should avoid physical effort, to an ‘activity-paradigm’ that advises individuals to engage in activity (Ungar et al. 2019b). Accordingly, the ACSM has held two ‘Exercise and Cancer Roundtables’ with clinical and scientific experts to define specific exercise guidelines for cancer patients based on the expanding and refining evidence regarding efficacy and safety of PA. While in 2010, recommendations stated that cancer patients should perform at least 150 minutes of moderate-intensity PA (MPA) or 75 minutes of vigorous-intensity PA (VPA) per week (Schmitz et al. 2010b), the latest guidelines advise on at least 30 minutes of aerobic activities three times per week and 20 to 30 minutes of resistance exercises twice per week (Campbell et al. 2019). Apparently, the acknowledgement of PA as an effective self-management strategy for individuals with cancer does not seem to be limited to scientific circles and PA experts, but also begins to resonate with healthcare professionals (HCP) and cancer patients themselves. A study among 123 oncologists, for instance, revealed that 95% of participants agreed with the positive effects of PA on alleviating treatment-related side-effects (Hardcastle et al. 2018). Also, among breast cancer patients, exercise was viewed as a positive strategy offering multiple benefits, such as increased well-being, restored energy levels, and a feeling of empowerment (Lavallée et al. 2019). However, the positive attitude towards PA does not yet seem to be fully reflected in cancer patients’ actual PA behavior as the following section describes.

1.3. Changes in physical activity from pre- to post-diagnosis

It is conceivable that a life-threatening health problem such as a cancer diagnosis can elicit motivation to make positive lifestyle changes in hope of sustaining or improving one's health and well-being (Hawkins et al. 2010). The window following the adverse health-event has therefore been referred to as a 'teachable moment', in which individuals might be particularly amenable to adopt sufficient PA (Humpel et al. 2007; Lawson and Flocke 2009; Rabin 2009). However, there is little evidence that a cancer diagnosis actually serves as a cue to action for positive changes in PA behavior. Instead, studies have shown that people with cancer tend to decrease their activity levels after the diagnosis (Eng et al. 2018; Fassier et al. 2016; Huy et al. 2012; Schmidt et al. 2017), leading to a large number of insufficiently active individuals. In previous research, the proportion of cancer patients who, by self-report, complied with the recommended PA guidelines of 150 minutes moderate-to-vigorous PA (MVPA) per week varied from 7% to 45% (Avancini et al. 2020a; Eng et al. 2018; Forbes et al. 2014; Galvao et al. 2015; Gjerset et al. 2011; Halbert et al. 2021; Ramirez-Parada et al. 2019; Speed-Andrews et al. 2012). A recent study differentiating between guidelines for aerobic vs. resistance exercise found that 23.1% of cancer patients were performing at least 150 minutes of moderate-intensity or 75 minutes of vigorous-intensity aerobic activities per week, whereas only 14.5% were engaging in strengthening exercises twice per week. Recommendations for both aerobic and resistance exercise were met by even fewer individuals (10.4%) (Coletta et al. 2019). Similar numbers were reported in investigations using objective methods to measure PA behavior, i.e., accelerometry, according to which only 16% of breast cancer patients could be classified as sufficiently active (Boyle et al. 2016). For other cancer types, the proportion of individuals meeting PA guidelines based on objective measurements was even lower as reported by Thraen-Borowski et al. (2017): While among breast, prostate, and uterine cancer patients 11%-13% were considered as sufficiently active, only 2%-5% of cervix, colorectal, and melanoma patients complied with PA guidelines.

The empirical findings thus indicate that the majority of individuals with cancer do not seize the opportunity of making positive lifestyle changes with regard to PA after the cancer diagnosis. A more differentiated understanding of how individuals modify their PA behavior after being diagnosed with cancer might help to support them in taking advantage of the teachable moment. However, to date, detailed investigations regarding changes in different PA intensities as well as comparisons between different cancer types are lacking. It further appears meaningful to define specific pre- to post-diagnosis change patterns concerning the compliance with PA recommendations. In that respect, at least four possible change patterns can be defined: Individuals, who were meeting PA guidelines pre-diagnosis can either remain sufficiently active or decrease their PA to insufficient levels. Likewise, those who were not following PA recommendations before the diagnosis, can increase their PA to reach sufficient PA levels or remain insufficiently active after the diagnosis (Gjerset et al. 2011; Stone et al. 2019a). As patients who either remain inactive or decrease their PA levels after the diagnosis are more likely to encounter secondary health issues, targeted PA intervention strategies for these individuals need to be established. Identifying characteristics of cancer patients who experience difficulties being sufficiently active after the diagnosis and detecting external factors that exacerbate or facilitate their PA behavior may inform the development and implementation of such strategies. The next chapter will present previous research on factors that might affect cancer patients' post-diagnosis PA behavior.

1.4. Determinants of post-diagnosis physical activity

Supporting cancer patients in pursuing an active lifestyle could help to reduce their experience of disease- and treatment-related health problems. A comprehensive understanding of factors that influence PA after a cancer diagnosis may thereby provide important insights about which patients are at particular risk of insufficient activity and may further shed light on reasons for and strategies to overcome inactivity. The current dissertation aims to address this issue by focusing on the role of (1) patients' sociodemographic and medical characteristics, (2) their perception of structural barriers, and (3) physicians' PA counseling for post-diagnosis PA behavior.

1.4.1. Patients' sociodemographic and medical characteristics

Understanding which individuals, based on their sociodemographic or medical profile, have an increased likelihood to be (in)sufficiently active after the cancer diagnosis could enhance a more specific targeting of PA promotion strategies. Previous research has demonstrated different sociodemographic and medical characteristics to be associated with cancer patients' post-diagnosis PA, such as age (Buffart et al. 2012; Chung et al. 2013; Eng et al. 2018; Eyl et al. 2018; Forbes et al. 2014; Gjerset et al. 2011; Kampshoff et al. 2016; Lynch et al. 2016; Ramirez-Parada et al. 2019; Troeschel et al. 2018; van Putten et al. 2016), educational levels (Avancini et al. 2020a; Forbes et al. 2014; Gjerset et al. 2011; Peddle et al. 2008; Troeschel et al. 2018), BMI (Buffart et al. 2012; Coletta et al. 2019; Eyl et al. 2018; Forbes et al. 2014; Gjerset et al. 2011; Hawkes et al. 2015; Kampshoff et al. 2016; Lynch et al. 2016; Sabiston et al. 2014; Troeschel et al. 2018; van Putten et al. 2016), or co-morbidities (Boyle et al. 2016; Buffart et al. 2012; Eyl et al. 2018; McGowan et al. 2013b; Troeschel et al. 2018), but the associations varied across the different studies. A particular inconclusiveness was observed with regard to the impact of cancer treatment on post-diagnosis PA, as some studies found that patients receiving treatment performed less activity (Bock et al. 2013; Chung et al. 2013; Coletta et al. 2019), while others yielded no (Brunet et al. 2014; Kampshoff et al. 2016; Peddle et al. 2008; Ramirez-Parada et al. 2019; van Putten et al. 2016) or even a positive association (Buffart et al. 2012). In Table 1, an overview of previous studies examining sociodemographic and medical PA determinants is provided. The discernibly varying associations between studies could be attributable to their differing samples in terms of disease type and status, which hamper the comparability of results.

Table 1. Overview of previous studies investigating sociodemographic and medical determinants of physical activity (PA) in cancer patients

Study	Sample size and characteristics[a]	Physical activity measure *(Abbreviations explained in notes)*	Results
Boyle et al. 2016	Breast cancer *N* = 259 1-3 years post-diagnosis, currently not receiving chemo or radiation therapy	Objectively measured (Actigraph GT3X-Plus accelerometers) Classification as 'meeting PA guidelines' (≥150 min MVPA/week) or 'not meeting PA guidelines' (<150 min MVPA/week)	Patients with co-morbidities least likely to be meeting PA guidelines Patients with no co-morbidities, a university degree, and at least six hours MVPA/week pre-diagnosis most likely to be meeting PA guidelines
Brunet et al. 2014	Breast cancer *N* = 199 Having completed chemo and/or radiation therapy within previous 20 weeks	Self-reported (GLTEQ) at 5 timepoints Identification of PA trajectories over five months and classification as 'not meeting PA guidelines' (consistently inactive, decreasing levels, inactive with increasing levels, somewhat active) or 'meeting PA guidelines' (consistently sufficiently active)	Higher levels of depressive symptoms and fatigue decreased likelihood of meeting PA guidelines No association of age, time since treatment completion, number of treatment types, or number of physical symptoms and meeting PA guidelines
Coletta et al. 2019	Breast cancer *N* = 346 Having completed treatment *M* = 9 years post-diagnosis	Self-reported Classification as 'meeting aerobic guidelines' (150 min MPA/week or 75 min VPA/week or combination); 'meeting resistance guidelines' (2x/week strengthening exercises), 'meeting both guidelines'	History of radiation therapy and obesity significantly decreased likelihood of meeting aerobic guidelines Diagnosis of diabetes significantly decreased likelihood of meeting resistance guidelines
Kampshoff et al. 2016	Breast cancer *N* = 484 Having completed primary cancer treatment *M* = 47 months post-diagnosis	Objectively assessed (ActiTrainer accelerometers or Yamax Digi-Walker pedometers) in three studies Z-transformation of daily activity counts and daily steps across studies	Higher age and higher BMI significantly associated with lower PA No association between marital status, educational level, current work activity, treatment type, time since diagnosis, or co-morbidities and PA
Ramirez-Parada et al. 2019	Breast cancer *N* = 112 Receiving chemotherapy *M* = 16.7 months post-diagnosis	Self-reported (GLTEQ) Calculation of MVPA minutes and classification as 'no MVPA' (0 min/week), 'some MVPA' (1-149 min/week), or 'meeting guidelines' (≥150 min/week)	Association of higher age and longer time since diagnosis and not engaging in MVPA No association of educational level, marital status, disease stage, or radiation therapy and MVPA

(continued)

Table 1 (continued)

Study	Sample size and characteristics[a]	Physical activity measure *(Abbreviations explained in notes)*	Results
Sabiston et al. 2014	Breast cancer *N* = 177 Having completed primary treatment within previous 20 weeks *M* = 10.6 months post-diagnosis	Objectively measured (Actigraph GT3X accelerometers) at 5 timepoints within one year Calculation of weekly MVPA minutes	Association of a healthy BMI (<25 kg/m²) and more MVPA minutes at all follow-up time points
Hackshaw-McGeagh et al. 2015	Prostate cancer *N* = 511 At 9 months post-diagnosis	Self-reported (GSLTPAQ) Calculation of PA in MET-units, classification as 'sufficiently active' (≥14 MET-units/week) or 'insufficiently active' (<14 MET-units/week)	No significant association of age or marital status and being sufficiently active
Halbert et al. 2021	Prostate cancer *N* = 89 Having had radical prostatectomy 71% were ≤ 5 years post-diagnosis	Self-reported Categorization as 'meeting PA guidelines' (≥150 min PA/week) or 'not meeting guidelines' (<150 min PA/week)	Lower stage disease significantly increased likelihood of meeting PA guidelines No association of marital status, educational level, current work status, co-morbidities, or time since diagnosis and meeting guidelines post-diagnosis
Buffart et al. 2012	Colorectal cancer *N* = 1,371 Up to 10 years post-diagnosis *M* = 3.9 years post-diagnosis	Self-reported (EPIC PA Questionnaire) Calculation of weekly MVPA minutes (consisting of walking, bicycling, gardening, and sports)	Younger age, male sex, being employed, lower BMI, receiving chemotherapy, and no co-morbidities associated with higher MVPA No association of marital status or time since diagnosis and MVPA
Eyl et al. 2018	Colorectal cancer *N* = 1,343 At 5 years post-diagnosis	Self-reported (IPAQ short form) Calculation of MET-h/week	Younger age, male sex, lower BMI, <2 co-morbidities, and no cancer recurrence significantly associated with more MET-h/week No association between marital status, educational level, radiation therapy, chemotherapy, or cancer recurrence and MET-h/week

(continued)

Table 1 (continued)

Study	**Sample size and characteristics**[a]	**Physical activity measure** *(Abbreviations explained in notes)*	**Results**
Hawkes et al. 2015	Colorectal cancer *N* = 322 At 12 months post-diagnosis	Self-reported (GLTEQ-LSI) Classification as ‘sufficiently active’ (≥150 min MVPA/week) or ‘insufficiently active’ (<150 min MVPA/week)	Being retired and healthy BMI significantly associated with being sufficiently active No association of age, gender, marital status, educational level, radiation therapy, chemotherapy, or co-morbidities and sufficient activity
Lynch et al. 2016	Colorectal cancer *N* = 185 Having completed cancer treatment	Objectively measured (Actigraph GT3X plus accelerometer) Calculation of weekly MVPA minutes	Younger age, lower BMI, and being employed associated with MVPA No association of sex, marital status, educational level, time since diagnosis, cancer treatment, or number of co-morbidities associated with MVPA
Peddle et al. 2008	Colorectal cancer *N* = 413 ≥12 months post-treatment	Self-reported (GLTEQ-LSI) Classification as ‘no exercise' (0 min MVPA), ‘insufficiently active’ (1-149 min MVPA) or ‘meeting guidelines’ (>150 min MVPA)	Lower educational levels associated being insufficiently active No association between age, sex, employment status, marital status, metastases, cancer recurrence, time since diagnosis, or treatment type and meeting guidelines
Speed-Andrews et al. 2012	Colorectal cancer *N* = 600 Having completed adjuvant treatment *M* = 51 months post-diagnosis	Self-reported (GLTEQ-LSI) Classification as ‘completely sedentary’ (0 minutes PA), ‘insufficiently active’ (1-149 minutes PA), ‘within guidelines’ (150-299 minutes PA), ‘above guidelines’ (≥300 minutes PA)	Younger age, not being married, higher educational levels, being employed, no radiation therapy, and fewer co-morbidities significantly increased likelihood of meeting guidelines No association between sex, BMI, time since diagnosis, or chemotherapy and meeting guidelines
Van Putten et al. 2016	Colorectal cancer *N* = 1,375 Up to 10 years post-diagnosis *M* = 5.1 years post-diagnosis	Self-reported (EPIC PA Questionnaire) Calculation of weekly MVPA minutes (consisting of walking, bicycling, gardening, and sports)	Younger age, male sex, having a partner, and lower BMI significantly associated with higher MVPA No association between educational level, time since diagnosis, treatment type, or number of co-morbidities and MVPA

(continued)

Table 1 (continued)

Study	Sample size and characteristics[a]	Physical activity measure *(Abbreviations explained in notes)*	Results
Forbes et al. 2014	Breast cancer (BC), Prostate cancer (PC), Colorectal cancer (CC) (separately) N_{BC} = 248 N_{PC} = 253 N_{CC} = 240 *M* = 4.3 years post-diagnosis	Self-reported (GLTEQ-LSI) Classification as 'not meeting guidelines' (<150 min MVPA/week) or 'meeting guidelines' (>150 min MVPA/week)	<u>Breast cancer</u> Younger age, higher educational level, lower BMI, and fewer co-morbidities significantly associated with meeting guidelines No association of employment status, marital status, treatment type, current treatment status, cancer recurrence, or time since diagnosis and meeting guidelines <u>Prostate cancer</u> Younger age, having had surgery, no radiation therapy, no chemotherapy, no hormone therapy, and no current treatment significantly associated with meeting PA guidelines No association of marital status, educational level, employment status, BMI, time since diagnosis, or co-morbidities and meeting guidelines <u>Colorectal cancer</u> Higher educational levels significantly associated with meeting PA guidelines No association of age, sex, marital status, employment status, BMI, treatment type, current treatment status, cancer recurrence, time since diagnosis, or co-morbidities and meeting guidelines
Troeschel et al. 2018	Breast cancer, Prostate cancer Colorectal cancer *N* = 1,160 Having completed adjuvant treatment within previous 12 months	Self-reported Classification as 'inactive' (0 MET-h/week), 'insufficiently active' (0.01–8.74 MET h/week), '1 to <2 times recommended levels' (8.75–17.49 MET-h/week), or '≥2 times recommended levels' (≥ 17.49 MET-h/week)	Female sex, not being married, lower educational levels, and co-morbidities significantly increased likelihood of being inactive Older age, lower educational levels, not being married, and higher BMI significantly increased likelihood of being insufficiently active No association of cancer type, cancer stage, surgery, chemotherapy, or time since diagnosis and sufficient PA

(continued)

Table 1 (continued)

Study	Sample size and characteristics[a]	Physical activity measure *(Abbreviations explained in notes)*	Results
Eng et al. 2018	Various cancer types *N* = 1,003 Up to 10 years post-diagnosis	Self-reported Classification as 'not meeting guidelines' (<150 min MVPA/week) or 'meeting guidelines' (≥150 min MVPA/week)	Higher age and higher educational level significantly associated with not meeting guidelines among patients who were not meeting guidelines pre-diagnosis No association between sex, employment status, marital status, surgery, radiation therapy, or systemic therapy and meeting guidelines among both individuals who were and who were not meeting guidelines pre-diagnosis
Gjerset et al. 2011	Various cancer types *N* = 975 *Mdn* = 41 months post-diagnosis	Self-reported (GLTEQ-LSI) Classification as 'physically inactive' (<150 min MVPA/week) or 'physically active' (>150 min MVPA/week)	Younger age, lower BMI, higher educational levels, no co-morbidities, and no metastases significantly associated with being physically active No association of cancer type, marital status, employment status, time since diagnosis, treatment type, or disease stage and being physically active

Notes. EPIC: European Prospective Investigation into Cancer, GLTEQ: Godin Leisure-Time Exercise Questionnaire, GLTEQ-LSI: Godin Leisure-Time Exercise Questionnaire- Leisure Score Index, GSLTPAQ: Godin-Shepard Leisure-Time Physical Activity Questionnaire, IPAQ: International Physical Activity Questionnaire, PA: physical activity, MVPA: moderate-to-vigorous physical activity, MET: metabolic equivalent of task, *M*: mean, *Mdn*: median.
[a] Study sample described based on inclusion criteria regarding time since diagnosis or treatment. If timespan is not defined in inclusion criteria, mean time since diagnosis is reported, if available.

Since PA behavior as such seems to differ between cancer types (Blanchard et al. 2008; Kwon et al. 2012; LeMasters et al. 2014), sociodemographic and medical determinants of post-diagnosis PA might presumably also vary across cancer types. This assumption has not been sufficiently investigated so far, but preliminary findings of a study that directly compared PA determinants between breast, prostate, and colorectal cancer patients yielded first evidence that different factors might be associated with post-diagnosis PA for each cancer type (Forbes et al. 2014). As the interpretability of the results is however limited due to the use of only univariate statistical methods, it appears worthwhile to test the association between individual determinants and post-diagnosis PA in consideration of other sociodemographic and medical factors to allow a more reliable conclusion. Moreover, testing different combinations of single determinants with complementary methods could additionally enable the identification of subgroups that, based on their compound sociodemographic and medical profile, are most likely to be sufficiently or insufficiently active after the diagnosis.

Evaluating cancer patients' sociodemographic and medical characteristics as determinants for their PA behavior can be regarded as a first step towards a multidimensional evaluation of factors that are associated with post-diagnosis PA. In a second step, the light is shed on certain external factors that may influence the extent to which cancer patients engage in PA after the diagnosis, starting with the role of structural barriers for post-diagnosis PA in the next section.

1.4.2. Structural barriers for physical activity

Although the majority of cancer patients acknowledge an active lifestyle as being beneficial for their general health and recovery (Smith et al. 2017), the cancer diagnosis inevitably poses new challenges for engaging in PA. Not only decreases in physical fitness and functioning, fatigue, and mental preoccupation but also time restrictions due to medical appointments entail physical, psychological, and structural changes for the individual that might presumably be perceived as barriers for the pursuit of PA. In this regard, a systematic scoping review comprising 82 studies has identified three major barrier themes interfering with PA among people with cancer: (a) physiological barriers, such as treatment-related side-effects, fatigue, pain, and co-morbidities; (b) psychosocial and cultural barriers, such as low self-efficacy, lacking motivation and exercise discipline, or missing social support; and (c) economic and environmental barriers, i.e., structural barriers, such as financial issues, poor weather, inaccessible exercise facilities, and low availability of cancer-specific PA offers (Elshahat et al. 2021).

Previous research has mainly focused on the theme of physiological, i.e., disease- and treatment-related barriers, creating the impression that these factors pose a great challenge for PA after a cancer diagnosis (Craike et al. 2011; Fisher et al. 2016; Ng et al. 2021; Ottenbacher et al. 2015; Smaradottir et al. 2017). In a survey study among 456 cancer patients, for instance, illness or other health-related problems, joint stiffness, fatigue, and pain were rated as the most interfering barriers with more than 30% of patients across different cancer types and disease stages experiencing these issues (Blaney et al. 2013). A similar conclusion was drawn in systematic reviews of studies among breast cancer patients (Lavallée et al. 2019) and different cancer types (Clifford et al. 2018) that revealed treatment-related side-effects, fatigue, and pain as the most common barriers to PA. However, the reviews pointed out that structural barriers, such as a lack of information and knowledge as well as the distance to suitable exercise facilities or financial costs, were also perceived as impeding for cancer patients' PA. Further, it is remarkable that although structural barriers might be less prevalent, they nevertheless seem to play a major role for cancer patients' actual activity behavior. In this regard, Lynch et al. (2010) observed that while disease-specific factors were most commonly rated as barriers for PA, barriers regarding the physical environment were most closely associated with not achieving sufficient levels of PA at five months post-diagnosis (OR = 0.85, 95% CI [0.76, 0.94]). Another study evaluating personal, social, and structural barriers also yielded significant associations of structural barriers and post-diagnosis PA to the effect that breast and prostate cancer patients who experienced a lack of exercise facilities and no access to gym equipment reported significantly fewer PA minutes (all *p*-values < .05) (Ottenbacher et al. 2011).

However, in these studies items for structural barriers were mainly focused on the local environment, whereas a systematic assessment of more diverse structural barriers is still lacking. Given the seemingly strong association of structural barriers and post-diagnosis PA and considering that, compared to physiological barriers, structural barriers offer greater leverage for improvement, it seems worthwhile to gain a deeper understanding of their role for cancer patients'

PA. Aiming to counteract the perception of structural barriers, it firstly appears necessary to examine whether structural barriers are perceived as equally impeding by all cancer patients or whether some individuals might be more susceptible in this regard. Previous studies have suggested that the perception of barriers might in general differ between cancer types. Ottenbacher et al. (2011), for instance, revealed that breast cancer patients experienced a higher overall number of barriers than prostate cancer patients (mean difference (*MD*) = 1.1, $p < .01$) as well as greater endorsement for single barriers like 'responsibilities at home', 'not feeling self-conscious', or 'not liking to sweat' (all *p*-values < .05). Another study additionally found that breast cancer patients rated a lack of energy more often as a PA barrier than individuals with other cancer types (82.4% vs. 66.7%), whereas the latter felt more impeded by a lack of awareness about available exercise programs compared to people with breast cancer (50% vs. 41.2%) (Fernandez et al. 2015). Other sociodemographic and medical factors previously found to be associated with the perception of PA barriers comprised a younger age, lower educational level, shorter time since diagnosis, and having received surgery (all *p*-values < .05) (Romero et al., 2018). Factors that might specifically influence the perception of structural barriers have, however, been neglected so far.

Besides the evaluation of differences in the perception of structural barriers with regard to patient characteristics, a more detailed investigation of the presumably negative impact of structural barriers on post-diagnosis PA is required, first and foremost by looking at how different individual structural barriers contribute to insufficient activity behavior after the diagnosis. However, there are two possible change patterns resulting in insufficient post-diagnosis PA dependent on patients' pre-diagnosis PA, i.e., becoming vs. remaining insufficiently active. With previous PA behavior already having been identified as a predictor for the perception of structural barriers (Romero et al. 2018), it seems worthwhile to explore whether also the proposed association of structural barriers and insufficient post-diagnosis PA differs by patients' pre-diagnosis PA. Such a distinction might help to more specifically target PA interventions that aim to alleviate the impediment by structural barriers.

Although to date, the specific role of structural barriers has not been investigated in detail, it seems likely that they exacerbate the pursuit of PA for people with cancer. One possible strategy to minimize the perception of structural barriers could be a qualified exercise counseling, as the provided information might presumably counteract a lack of knowledge, e.g., with regard to appropriate PA programs or safety of exercising. The next chapter will specifically address the role of physicians' PA counseling in facilitating PA behavior after a cancer diagnosis.

1.4.3. Physical activity counseling by physicians

As described in the previous section, lacking knowledge about PA in the post-diagnosis setting is regarded as an obstacle for cancer patients to engage in PA. A systematic review explicitly emphasized a lack of information from HCP in this context (Clifford et al. 2018). Indeed, HCP appear to be particularly suited to provide lifestyle counseling to cancer patients due to regular appointments during cancer treatment and follow-up care as well as their image as authority figures (Hardcastle and Cohen 2017; Rabin 2009). The crucial role of HCP with regard to cancer patients' PA behavior becomes further apparent when examining existing literature on this subject. A large study by Williams et al. (2013) investigating the perspective of cancer patients and their social network on physicians' health behavior advice found that around 90% of cancer patients as well as their social network considered PA promotion by physicians as 'beneficial', 'encouraging', or 'helpful' and 85% agreed that it was the physicians' duty to provide exercise counseling. Beyond this, HCP were even revealed as patients' preferred source of information when it came to PA counseling. For instance, findings of a survey study among 392 people with cancer yielded that more than half of participants wished to receive exercise instructions from their oncologists (Avancini et al. 2020a) and even larger proportions were reported in a systematic review with 60%-80% of patients from different cancer types preferring their oncologist to inform them about PA (Elshahat et al. 2021).

Building upon the appraisal of physicians' counseling by cancer patients, two observational studies indicated that PA promotion by physicians could indeed help to improve patients' activity levels. A large cross-sectional study investigating whether the recall of receiving PA advice was associated with higher PA levels in a sample of 15,254 colorectal cancer patients showed that individuals who were given PA advice were 1.9 times more likely to be meeting PA guidelines than those indicating not having received this kind of exercise counseling (Fisher et al. 2015). This result was supported in a study among patients with different cancer types where among patients who reported having received an exercise recommendation, the proportion of inactive individuals was significantly lower and that of sufficiently active individuals significantly higher, compared to those indicating no PA counseling (Tarasenko et al. 2017). Furthermore, also an RCT investigating the effect of an exercise counseling intervention observed significantly higher PA levels *(MD* = 3.4 MET-h/week, 95% CI [0.7, 6.1], *p* = .011) as well as a significantly higher proportion of individuals meeting PA guidelines (*MD* = 10.7%, 95% CI [0.8, 20.3], *p* = .029) among participants who received an exercise recommendation from their oncologist compared to the control group (Jones et al. 2004). However, it has to be noted that almost a quarter of participants in the intervention group incorrectly remembered the counseling situation and reported that their physician had not provided any PA counseling. The positive effect of exercise counseling could further not be replicated in subsequent RCTs. Instead, results yielded no difference between an exercise recommendation group compared to the control group with regard to change in MET-h/week after four weeks (*MD* = 1.06, 95% CI [-1.65, 3.78]) (Park et al. 2015) or with regard to weekly MVPA minutes after 12 weeks (*MD* = 30, 95% CI [-4, 65]) (Vallance et al. 2007).

A possible explanation for these inconsistent findings could lie in a discrepancy between patients' perception of the counseling situation and the provided care, which further becomes apparent considering that although high numbers of physicians claim to promote PA towards their cancer patients, patients' reports reveal that they felt inadequately informed and desired more guidance. While 71.8% of physicians stated that they would recommend PA to a vignette patient in a fictional scenario (Ungar et al. 2019a) and more than 80% of physicians indicated to actually promote PA to their patients with cancer (Haussmann et al. 2018a), a contrasting impression emerged from the patients' perspective with studies revealing that only 30%-60% of people with cancer reported having discussed PA with their physician (Demark-Wahnefried et al. 2000; Fisher et al. 2015; Kenzik et al. 2016). The dissimilarity was confirmed in a study by Haussmann et al. (2021a), who directly compared patient- and physician-reported counseling by linking cancer patients' indications to those of their treating physicians, but found only poor agreements. The results give reason to assume that merely a short recommendation to exercise, as given in the described studies, may not be sufficient to lastingly increase patients' PA levels but that a more comprehensive counseling might be required to be memorable and consequently effective.

To test this hypothesis and get a better understanding of how cancer patients' perception of physicians' exercise counseling potentially relates to their PA behavior, a detailed approach to investigate the counseling situation is needed. One systematic approach for the assessment and delivery of comprehensive lifestyle counseling is the 5A framework, which was originally developed to be used in clinic-based smoking cessation programs (Glynn and Manley 1995), but is equally applicable to the promotion of other health behaviors, including PA. The 5A framework comprises five counseling steps that are meant to engage individuals to improve their behavior in the respective health domain: '(1) *assessing* […] status, ability, and readiness to change; (2) providing *advice* on possible changes relative to personalized benefits and recommended guidelines; (3) collaboratively *agreeing* with a patient on a plan of action and identifying personal barriers to the plan; (4) *assisting* participants in the identification of strategies to overcome personal barriers to behavior change; and (5) *arranging* follow-up assessment, feedback and support' (Estabrooks and Glasgow 2006, pg. 46). With regard to PA, a population-based survey among 1,141 adults pointed towards the effectiveness of the 5A approach as participants who were provided with an exercise plan by their primary care physician were twice as likely to increase PA compared to individuals who merely received PA advice (OR = 1.93, 95% CI [1.19, 3.15]).

For patients, who additionally discussed the exercise plan at follow-up visits, the likelihood of improving their PA was even higher as indicated by a nearly three-fold increase (OR = 2.84, 95% CI [1.78, 4.53]) (Weidinger et al. 2008).

Despite the recommendation of the American Society of Clinical Oncology (ASCO) to use the 5A framework for exercise counseling in people with cancer (Ligibel et al. 2019), its effectiveness has not been sufficiently investigated in this population. Moreover, factors that could influence the association of physicians' counseling and cancer patients' PA behavior have not yet been considered, although it has been suggested that patients with different preconditions require a different level of profoundness regarding PA counseling (Wolin et al. 2012). In this regard, it is conceivable that patients' previous experience with PA might be a crucial factor determining the success of PA counseling. While less experienced individuals may already benefit from recommendations to increase their motivation for exercise, previously active individuals could require a more profound counseling, addressing the issue of how and where to continue their PA in presence of disease-related barriers (Pinto et al. 1998). Whether or not these needs are met might conceivably influence patients' satisfaction with the provided care, which in turn could determine if the physician's PA promotion is actually translated into behavior. The satisfaction with counseling would therefore act as a mediator for the association between physicians' PA counseling and cancer patients' PA, particularly among previously active individuals.

1.5. Goals and objectives

With growing evidence regarding the efficacy and safety of PA, a physically active lifestyle is now considered as one of the most effective strategies for people with cancer in the management of adverse disease- and treatment-related health issues. Nevertheless, most individuals tend to remain insufficiently active or decrease their PA levels after being diagnosed with cancer and, thus, do not comply with recommended PA guidelines. Given the multiple benefits of PA for the physical and psychological health of cancer patients, it appears relevant to increase the number of physically active individuals. Aiming to develop and implement tailored PA intervention strategies, however, requires a comprehensive understanding of how a cancer diagnosis affects PA behavior. This comprises the questions of how individuals change their PA from pre- to post-diagnosis, which subgroups of cancer patients have an increased likelihood of being insufficiently active after the diagnosis, and to what extent certain external factors could prevent or facilitate PA behavior.

Although previous research has endeavored to address these issues, several questions remain unanswered. First and foremost, detailed information on pre- to post-diagnosis PA change patterns are missing, as so far, the focus has primarily been on changes in mean PA values for separate cancer types or averaged across different cancer types. Comparisons of change patterns with regard to different PA intensities as well as to different cancer types are yet to be conducted. Deeper insights into differences between cancer types are also needed with regard to patient characteristics that might determine whether or not individuals are sufficiently active after the diagnosis. Previous studies have yet identified several significant sociodemographic and medical determinants of post-diagnosis PA, discrepancies in the results however suggest that different predictors might be relevant depending on the cancer type. Looking at external factors that might impact cancer patients' PA behavior, evidence suggests that a large number of patients perceives disease- and treatment-related barriers as impeding their PA. In contrast, the theme of structural barriers has remained quite understudied, although first investigations suggest that particularly these kinds of barriers might be associated with the actual PA behavior. Besides the prevalence of different structural barriers, it is further unclear, whether certain individuals perceive these obstacles as more impeding than others and to what extent the different structural barriers are related to post-diagnosis PA, also considering that this association might differ depending on the individuals' previous PA behavior. A potential approach to alleviate the perception of structural barriers among cancer patients could be a comprehensive exercise counseling as physicians' PA promotion has been associated with increased PA levels after the cancer diagnosis. However, previous results appear inconsistent, potentially because not only detailed assessments of the counseling situation but also of potential influencing factors that underlie its association with patients' PA behavior were lacking.

Thus, the overarching goal of the current dissertation was to gain a comprehensive understanding of cancer patients' pre- to post-diagnosis PA change patterns as well as certain internal and external determinants of (in)sufficient post-diagnosis PA, by focusing on four specific objectives:

1. Describe pre- to post-diagnosis PA change patterns and work out differences between different cancer types

2. Determine sociodemographic and medical characteristics that are associated with post-diagnosis PA, compare determinants between different cancer types, and identify which combinations of determinants characterize patient subgroups that are most likely to be (in)sufficiently active

3. Examine the role of structural barriers for post-diagnosis PA by identifying which individuals experience stronger PA impediment and by investigating the association between structural barriers and post-diagnosis PA, also with regard to different pre-diagnosis PA levels

4. Investigate the association between physicians' PA counseling and patients' post-diagnosis PA and evaluate whether this association is mediated by patients' satisfaction with exercise counseling and moderated by patients' pre-diagnosis PA levels.

To obtain relevant and transferable knowledge, the research was conducted in a sample of breast, prostate, and colorectal cancer patients, as these reflect three of the largest cancer types for which the benefits of PA are well established. The presented methods and results are based on three first author publications (Depenbusch et al. 2020; Depenbusch et al. 2021; Steindorf et al. 2020), all of which were issued as part of the Momentum Project Heidelberg.

2. Methods

The following sections describe the eligibility criteria for study participants, recruitment procedures, study assessments, and statistical analyses. Parts of these sections correlate to publications that are associated with this dissertation (Depenbusch et al. 2020; Depenbusch et al. 2021; Steindorf et al. 2020).

The methods and results of the current dissertation are based on the Momentum Project Heidelberg, a project aiming to investigate social cognitions and norms towards PA among cancer patients and HCP. The Momentum Project got funded by the German Cancer Aid (110512, 110551, 111223) and was conducted between 03/2015 and 08/2018 as a cooperation between the Psychological Institute of Heidelberg University, German Cancer Research Center, National Center for Tumor Diseases Heidelberg, and University Hospital Heidelberg (Principal Investigators: Prof. Dr. Monika Sieverding, Prof. Dr. Karen Steindorf, and PD Dr. Joachim Wiskemann). The project is registered on Clinical Trials.gov (NCT02678832) and received ethical approval by the Ethics Commission of the Faculty of Behavioral and Cultural Studies of Heidelberg University (AZ Siev 2015/1-1 and AZ Siev 2016/1-2).

The Momentum Project was comprised of three studies:

1. A cross-sectional study among 917 selected HCP, i.e., general practitioners, specialized physicians, and oncology nurses, having regular contact with breast, prostate, and/or colorectal cancer patients. The study among HCP consisted of a qualitative interview study as well as a cross-sectional survey study to explore HCP' social cognitions regarding PA as a self-management strategy for cancer patients and their promotion practice in this regard.
2. A cross-sectional survey study among 1,299 breast, prostate, and colorectal cancer patients, examining cancer patients' social cognitions towards PA, their past and current

PA behavior as well as their perception of physicians' attitude and counseling with regard to PA.

3. A longitudinal follow-up study among 134 breast, prostate, and colorectal cancer patients comprising four timepoints, i.e., immediately before or at the beginning of treatment, two timepoints during treatment, and after three months follow-up. Besides assessments similar to those of the cross-sectional survey study, the longitudinal study included two 7-day periods of objective ambulatory PA measurement, i.e., one week after baseline and one week before the 3-month follow-up assessment.

The current dissertation focuses on project part 2, the cross-sectional study among cancer patients, which was conducted between 01/2017 and 05/2018. Participants and procedures as well as assessments of the survey study will be described in more detail in the following section. Subsequently, the statistical analyses of the acquired data will be explained separately for each objective of the dissertation.

2.1. Participants and procedures

Patients were eligible for study participation if 1) they were ≥ 18 years old, 2) they were diagnosed with breast, prostate, or colorectal cancer, 3) the latest diagnosis of the primary tumor, recurrence, or metastases was no longer than 2.5 years ago, 4) they were currently receiving, had already received, or were planned to receive cancer treatment, i.e., surgery, chemotherapy, and/or radiation therapy, and 5) they were capable of standing and walking without assistive devices.

Participants were mainly recruited through the cancer registry of the German federal state Baden-Württemberg. The cancer registry maintains data of all cancer patients residing in the region and includes information about the occurrence, therapy, and course of the cancer disease. Eligible patients were contacted via postal mail and asked whether they were willing to participate in the study. Those who were interested could either directly participate via a link in an online version of the study or fill in a consent form, allowing the cancer registry to forward their contact details to the study team, in order to receive a paper-and-pencil questionnaire package. The package consisted of the paper-and-pencil survey, two copies of the informed consent, a form offering to request information resources about self-management strategies, and an addressed and stamped return envelope. Another recruitment channel was established via physicians working in outpatient care, who had previously participated in the Momentum study for HCP and agreed to be contacted by the study team again. In addition, study personnel directly recruited participants at an information event for cancer patients and at a meeting of a prostate cancer self-help group. The online survey was further promoted in five self-help group associations and six online portals for cancer patients via internal mailing lists, websites, and social media platforms. Lastly, the study was announced in the local newspaper.

2.2. Assessments

All data were assessed as self-report in the paper-and-pencil questionnaire or the congruent online version. Items and scales of the questionnaire were based on both validated instruments and self-developed items and were pre-tested in two pilot studies including a qualitative study with semi-structured interviews among 18 people with cancer as well as a quantitative pre-test among 85 individuals of the target group. The following scales and items are relevant for the analyses in the context of this dissertation:

- **Sociodemographic data:** Patients were asked to indicate their age, sex, height and weight, highest educational level (no degree, lower secondary education degree, secondary education degree, diploma qualifying for university, or university degree), current work status (homemaker, retired, on sick-leave, unemployed, currently working, or student), and their marital status (single, married or in a firm relationship, divorced, or widowed).

- **Medical data:** Medical characteristics included the cancer type of the primary tumor and the date of diagnosis, whether metastases or cancer recurrence had been diagnosed and if so, the date of diagnosis. Regarding cancer treatment, participants were asked to choose all applicable treatments from a list containing surgery, chemotherapy, radiation therapy, immunotherapy, and hormone therapy. For each applicable therapy, treatment status had to be specified as planned, ongoing, or completed, in case of the latter also requesting the date of completion. The same structure was used to register participation in rehabilitation measures. For the assessment of co-morbidities, patients were asked to indicate all applicable from a list of eleven co-morbidities, adapted from the Charlson co-morbidity index (Charlson et al. 1987).
- **Physical activity:** An adapted version of the Godin-Shepard Leisure-Time Physical Activity Questionnaire (GSLTPAQ) was used to acquire PA data (Godin 2011). Patients were asked to indicate their weekly minutes of light-intensity PA (LPA), moderate-intensity PA (MPA), and vigorous-intensity PA (VPA) for both the time pre-diagnosis and post-diagnosis, i.e., during the last week. Participants were instructed to only refer to intentional PA that was perceived as somewhat exhausting, excluding slow walks or household chores. For each activity intensity, a short description was given with LPA being defined as ‘minimal physical effort, e.g., going for a walk or light yoga’; MPA as ‘getting out of breath, e.g., (Nordic-)walking, regular cycling, slow swimming, or gymnastics’; and VPA as ‘heart beats fast, e.g., running, playing soccer, fast swimming, or sportive cycling’.
- **Structural barriers for physical activity:** Items for the assessment of perceived structural barriers for PA were developed based on the qualitative and quantitative Momentum studies for HCP (Haussmann et al. 2018a; Haussmann et al. 2018b). Patients were asked to what extent the following seven structural conditions impeded them from regularly performing PA: (1) lack of information material regarding PA for people with cancer, (2) lack of PA offers specifically for people with cancer, (3) lack of PA offers overall, (4) lack of possibility to clarify if one is medically suitable for PA, (5) lack of a contact person who is specialized in exercise

oncology counseling and treatment, (6) lack of therapeutic programs that are reimbursed by health care insurances, and (7) lack of parks, walking, running and cycling paths, or public pools in the neighborhood (Spittaels et al. 2010). Answer options were displayed on a 4-point Likert scale with 0 = ‘not at all’, 1 = ‘slightly’, 2 = ‘strongly’, 3 = ‘very strongly’.

- **Physical activity counseling by physicians:** For the items concerning PA counseling by physicians, patients were asked to refer to the physician who they considered as their most important contact person regarding their cancer treatment or, if they did not have one most important contact person, to the physician who had carried out the most recent treatment counseling. A list was provided to indicate, which specialization the physician could be assigned to including general practitioner, oncologist, gynecologist, urologist, gastroenterologist, surgeon, and radiation therapist. The perception of PA counseling by this physician was assessed in accordance to the 5A framework (Estabrooks and Glasgow 2006). To complete the list of possible counseling scenarios, three self-generated items from the Momentum study among HCP (1-3) were added to the five original 5A items (4-8). Patients were asked to recall which of the counseling steps their physician had completed with multiple answers possible: (1) *advised against* PA, (2) *did not address* PA and neither made positive nor negative statements, (3) gave me some *advice* after *I had addressed* PA first, (4) *assessed* my current PA, (5) gave me specific *advice on his/her initiative*, (6) *agreed* with me on PA-related goals or developed a specific plan together with me, (7) *assisted* me in achieving the PA goals, e.g., by making referrals, and/or (8) repeatedly addressed PA and *arranged* to follow-up with the implementation of his/her recommendation. Subsequently, patients were queried how satisfied they were with their physician’s exercise counseling on a 5-point Likert scale from 1 = ‘very unsatisfied’ to 5 = ‘very satisfied’.

2.3. Data analyses

To adequately analyze the data with respect to the stated objectives, meaningful variables were computed and different statistical tests run as described below. Statistical analyses were conducted as complete case analyses, leading to slightly different datasets per objective. All statistical analyses were carried out with IBM SPSS version 25.0. A significance level of $\alpha = .05$ was considered statistically significant.

For the description of the **study population**, means (*M*s) and standard deviations (*SD*s) for metric and counts and percentages for categorical variables were used. Sociodemographic and medical characteristics were determined for the overall study sample as well as separately for each cancer type. Height and weight were used to calculate body mass index (BMI) as kg/m². Time since diagnosis was derived from patients' reported date of diagnosis and the date of survey completion. To obtain sufficient sample sizes for categorical variables, answer options were grouped into meaningful categories as follows:

- *Educational level:* 0 = 'Lower': no degree or (lower-) secondary education degree; 1 = 'Higher': diploma qualifying for university or university degree.
- *Current work status*: 0 = 'Currently not working': homemaker, retired, on sick-leave, or unemployed; 1 = 'Currently working': currently working or student.
- *Marital status*: 0 = 'Single': single, divorced, or widowed; 1 = 'In relationship': married or in a firm relationship.
- *Rehabilitation*: 0 = 'No': no participation in rehabilitation measure or rehabilitation measure planned; 1 = 'Yes': rehabilitation measure completed or currently participating in rehabilitation measure.
- *Co-morbidities*: 0 = 'None': no co-morbidities; 1 = '≥ 1': one or more co-morbidities.

- *Current treatment status*: 0 = ‘No treatment’: currently not receiving chemotherapy, radiation therapy, and/or hormone therapy; 1 = ‘Receiving treatment’: currently receiving chemotherapy, radiation therapy, and/or hormone therapy.
- *Treatment type*: 0 = ‘No’: not having received this treatment or treatment planned; 1 = ‘Yes’: treatment completed or currently receiving this treatment. This categorization applied to each chemotherapy, radiation therapy, and hormone therapy. Due to the small proportion of patients having received or currently receiving immunotherapy (N = 60, 4.7%; breast cancer: n = 49, 7.8%; prostate cancer: n = 1, 0.3%; colorectal cancer: n = 10, 3.1%) and the high proportion of patients having had surgery (N = 1,120, 0.5%; breast cancer: n = 547, 99.3%; prostate cancer: n = 249, 99.2%; colorectal cancer: n = 297, 100%), these variables were not further considered in the following analyses.

Differences between cancer types regarding metric sociodemographic and medical variables were identified using robust Welch-ANOVAs with Games-Howell post-hoc tests, since Levene’s test revealed lacking homogeneity of variances for these variables. Omega-squared (ω^2) was calculated to determine corresponding effect sizes with .01 being considered as a small, .06 as a medium, and .14 as a large effect (Kirk 1996). For categorical variables, group differences were analyzed with chi-square (χ^2) tests and further described by Cramer’s V as an effect size measure. Values of .10, .30, and .50 indicated small, medium, and large effects, respectively (Cohen 1992).

To analyze **PA levels**, *M*s and *SD*s of each LPA, MPA, and VPA minutes were defined for the overall sample and each cancer type. According to the World Health Organization (WHO), an average volume of 150-300 minutes MPA or 75-150 minutes VPA per week or an equivalent combination of moderate-to-vigorous PA (MVPA) produces the greatest health benefits (Bull et al. 2020). Therefore, MVPA minutes were calculated as [MPA min/week + 2*VPA min/week] for both pre- and post-diagnosis PA. In accordance with renowned PA guidelines (Schmitz et al. 2010b), participants were then either classified as ‘sufficiently active’, i.e., meeting PA guidelines (≥ 150 min MVPA/week) or as ‘insufficiently active’, i.e., not meeting PA guidelines (< 150 min MVPA/week) for both timepoints. It has to be noted that the current classification was based on the 2010 ACSM recommendations (Schmitz et al. 2010b), that, compared to the most recent guidelines (Campbell et al. 2019), do not distinguish between aerobic and resistance exercises, but have nevertheless been predominantly referred to in previous literature (e.g., Boyle et al. 2016; Eng et al. 2018; Forbes et al. 2014; Halbert et al. 2021; Hawkes et al. 2015; Ramirez-Parada et al. 2019). Based on this classification, four potential pre- to post- diagnosis change patterns were derived: (1) ‘maintainers’, i.e., participants who were meeting PA guidelines pre-diagnosis and post-diagnosis, (2) ‘decreasers’, i.e., participants who were meeting PA guidelines pre-diagnosis but not post-diagnosis, (3) ‘increasers’, i.e., participants who were not meeting PA guidelines pre-diagnosis but post-diagnosis, and (4) ‘consistently inactives’, i.e., participants who were not meeting PA guidelines pre-diagnosis or post-diagnosis. Counts and percentages were used to describe the number of participants meeting PA guidelines at each timepoint as well as the distribution of the four PA change patterns in the overall sample and for each cancer type.

With regard to objective 1, **changes in PA from pre- to post-diagnosis** were analyzed in terms of LPA, MPA, and VPA minutes and the percentage of participants meeting PA guidelines in the overall sample as well as separately for each cancer type. Since none of the PA variables was normally distributed as indicated by Shapiro-Wilk tests, the significance of changes in PA minutes from pre- to post-diagnosis was evaluated with Wilcoxon signed-rank tests using the test statistic *z*. Pearson’s correlation coefficient *r* was calculated to describe effect sizes in this regard. To test the significance of changes in the percentage of participants meeting PA guidelines, McNemar tests were used. The results were described by the test statistic χ^2 and further classified by the effect size measure Phi (φ). Differences between cancer types regarding PA minutes were analyzed with Kruskal-Wallis tests, followed by post hoc pairwise comparisons with Mann-Whitney tests using the test statistic *U* and involving Bonferroni correction. The corresponding effect sizes were described with Pearson’s *r*. Chi-square tests were conducted to identify differences between cancer types regarding the percentage of participants meeting PA guidelines as well as the distribution of the four PA change patterns with φ serving as an indicator of the effect size. In accordance with Cohen (1992), effect sizes of .10 were interpreted as small, .30 as medium, and .50 as large effects for both *r* and φ.

To address objective 2, **sociodemographic and medical determinants** of sufficient post-diagnosis PA were evaluated by estimating odds ratios (ORs) with 95% confidence intervals (CIs) in logistic regression analyses. Separate analyses were conducted for the overall sample and each cancer type, each for which meeting PA guidelines post-diagnosis served as the outcome variable, meeting guidelines pre-diagnosis was entered as a predictor in a first block, and sociodemographic and medical variables in a second and third block, respectively. Since two of the three cancer types are gender-specific, sex was not incorporated as an explanatory variable in the models. To nevertheless distinguish the effect of cancer type and sex in the analysis for the overall sample, cancer type was specified as breast cancer, prostate cancer, colorectal cancer in women, and colorectal cancer in men. Building upon this, a classification tree analysis using chi-squared automated interaction detection (CHAID) was performed to identify population subgroups that were more or less likely to meet PA guidelines post-diagnosis. Classification tree analyses describe a nonparametric statistical method to model the relationship between an outcome variable and the interaction of predictor variables by segmenting the data into mutually exclusive subgroups that best describe the outcome. In a first step, the most discriminating predictor, i.e., the variable with the strongest influence on the outcome, is detected and divided into meaningful subgroups. In following steps, each subgroup is then evaluated independently for the next best predictor and split accordingly until no further split can be made. The resulting terminal nodes of the classification tree thus present a unique combination of variables that are most informative for the outcome variable (Boslaugh et al. 2004; Dominick et al. 2015; Frank et al. 2008; Kass 1980). For the current analysis, predictors that were significantly associated with sufficient post-diagnosis PA in the preceding logistic regression analysis among the overall sample were considered for

CHAID analysis. At each level of the classification tree, merging and/or re-splitting of independent predictor variable categories was allowed at a significance level of $p < .05$ with Bonferroni correction for multiple comparisons. Each variable split required a minimum of 100 participants and each terminal node a minimum of 50 participants.

For objective 3 regarding **structural barriers to PA**, descriptive statistics were used to report the impediment for PA by the seven queried structural barriers. To calculate the number of perceived structural barriers, answer scales were dichotomized as 0 = 'not at all' vs. 1 = 'slightly', 'strongly', or 'very strongly' and values were added up across the seven barriers. In case of missing values, the number of barriers was calculated based on the answers of available barrier variables. Sociodemographic and medical determinants of the perception of structural barriers were examined using separate linear regression analyses for each structural barrier and the number of structural barriers. Each model contained a different barrier as a continuous outcome variable and age, sex, educational level, current work status, cancer type, time since diagnosis, current treatment status, treatment types, co-morbidities, and physician's PA counseling as predictor variables. To test the association of structural barriers and post-diagnosis PA, ORs and 95% CIs were estimated by multiple logistic regression analysis. As the nature of barriers is to impede, rather than enhance a behavior, insufficient post-diagnosis PA, i.e., *not* meeting PA guidelines, was defined as the outcome variable. Aiming to avoid confounding effects, separate regression models were calculated for each structural barrier, all of which were adjusted for age, sex, BMI, educational level, cancer type, time since diagnosis, co-morbidities, sufficient pre-diagnosis PA, and physician's PA counseling. Subsequently, differences in the hypothesized association of structural barriers and insufficient post-diagnosis PA between the two possible PA changes patterns, i.e., *remaining* vs. *becoming* insufficiently active, were explored. For this purpose, the sample was split according to whether or not patients were sufficiently active pre-diagnosis and the above-described logistic regression analyses were re-run for each split sample.

For the analysis of objective 4 on **PA counseling** by physicians, meaningful categories of the eight queried counseling steps (‘advise against PA’, ‘not address PA’, ‘advise after I had addressed PA’, ‘assess current PA’, ‘advise on own initiative’, ‘agree on PA-related goals’, ‘assist in achieving PA goals’, ‘arrange follow-up‘) were generated: The counseling steps ‘advise against PA’ and ‘not addressing PA’ were combined as ‘no counseling’, as both display undesirable counseling behaviors. Further, the two ‘advise’ items (‘advise after I had addressed PA’ and ‘advise on his/her initiative’) were summarized, since they contain the same counseling technique, irrespective of who initiated the conversation. This resulted in six categories, namely ‘no counseling’, ‘assess’, ‘advise’, ‘agree’, ‘assist’, and ‘arrange’. Due to a heterogenous response pattern regarding completed 5A steps (Table 2), a weighted sum score (‘5A score’) was derived to depict the comprehensiveness of PA counseling. Based on the assumption that higher 5A steps are more profound with regard to content and time-consumption, ascending factors were assigned to each counseling step (from 0 for ‘no counseling’ to 5 for ‘arrange’) and summed up across all steps. The resulting scale with a maximum of 15 was then divided by three in order to return to a scale ranging from 0 to 5. If, for example, 5A steps ‘assess’ and ‘advise’ were completed, but not ‘no counseling’, ‘agree’, ‘assist’, and ‘arrange’, the respective 5A score would be (0*0 + 1*1 + 1*2 + 0*3 + 0*4 + 0*5) / 3 = 1. A higher 5A score indicated a more comprehensive exercise counseling. Descriptive statistics were used to examine the frequency of each counseling step as well as *M*s and *SD*s of the 5A score and satisfaction with PA counseling. ANOVAs were conducted to check whether the 5A score or satisfaction with PA counseling differed between cancer types or between physicians’ specializations. Given a lacking homogeneity of variances for the satisfaction variable, a robust Welch-ANOVA with Games-Howell post-hoc test was used. Additionally, ω^2 was calculated as an indicator of the effect size for group differences. As proposed by Kirk (1996), effect sizes of .01 were considered as small, .06 as medium, and .14 as large effects.

Table 2. Response patterns regarding completed 5A steps for physical activity counseling[†]

	Assess	Advise	Agree	Assist	Arrange	N	%
0						183 [a]	18.3
1	x					98	9.8
2		x				291	29.0
3			x			8	0.8
4				x		6	0.6
5					x	2	0.2
6	x	x				226	22.6
7	x		x			2	0.2
8	x			x		3	0.3
9	x				x	8	0.8
10		x	x			10	1.0
11		x		x		18	1.8
12		x			x	26	2.6
13			x	x		1	0.1
14			x		x	0	0.0
15				x	x	2	0.2
16	x	x	x			15	1.5
17	x	x		x		20	2.0
18	x	x			x	48	4.8
19	x		x	x		0	0.0
20	x		x		x	2	0.2
21	x			x	x	1	0.1
22		x	x	x		1	0.1
23		x	x		x	0	0.0
24		x		x	x	2	0.2
25			x	x	x	0	0.0
26	x	x	x	x		1	0.1
27	x	x	x		x	6	0.6
28	x	x		x	x	11	1.1
29	x			x	x	0	0.0
30		x	x	x	x	2	0.2
31	x	x	x	x	x	9	0.9

Notes. N = 1,002.
[a] Eight participants of 191 who indicated 'no counseling' (cf. Table 12), but also indicated other counseling steps are counted in the respective combination of other counseling steps.
[†] Adapted from Haussmann et al. (2021).

To analyze the relationship between PA counseling and post-diagnosis PA in consideration of patients' satisfaction with PA counseling and their pre-diagnosis PA, a moderated mediation model was built and tested using the PROCESS macro for SPSS (v.3.4, Hayes 2019). PROCESS is a regression-based analysis tool estimating and probing interactions and conditional indirect effects of moderated mediation models (Hayes and Rockwood 2020). For the current analysis, the proposed indirect effect of the predictor 5A score on the outcome post-diagnosis MVPA through the mediator satisfaction with PA counseling was tested at different levels of the moderator pre-diagnosis MVPA (Figure 1).

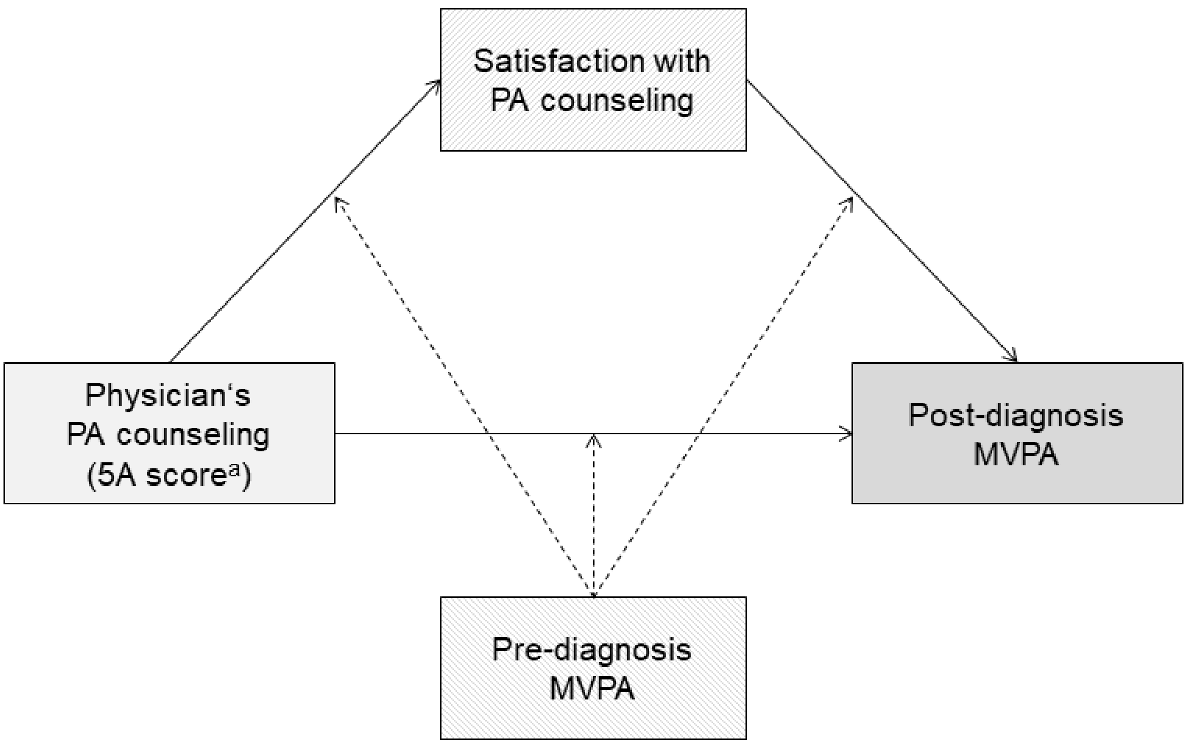

Figure 1. Conceptual research model with the association between physicians' physical activity (PA) counseling and patients' post-diagnosis PA being mediated by satisfaction with PA counseling and moderated by pre-diagnosis PA

Notes. PA: physical activity, MVPA: moderate-to-vigorous physical activity. Dotted lines indicate a potential moderating effect. Modified from Depenbusch et al. (2020).
[a]Weighted sumscore of 5A counseling steps, ranging from 0 to 5.

As shown in Figure 2, the analysis was carried out with three models: (1) The moderating effect of pre-diagnosis PA on the association between 5A score and satisfaction with PA counseling was probed (Figure 2a), (2) it was examined whether the associations between 5A score and post-diagnosis MVPA as well as satisfaction with PA counseling and post-diagnosis MVPA were moderated by pre-diagnosis MVPA (Figure 2b), and (3) the full model including the indirect effect of 5A score on post-diagnosis MVPA through the mediator satisfaction was tested at different levels of the moderator pre-diagnosis MVPA (Figure 2c).

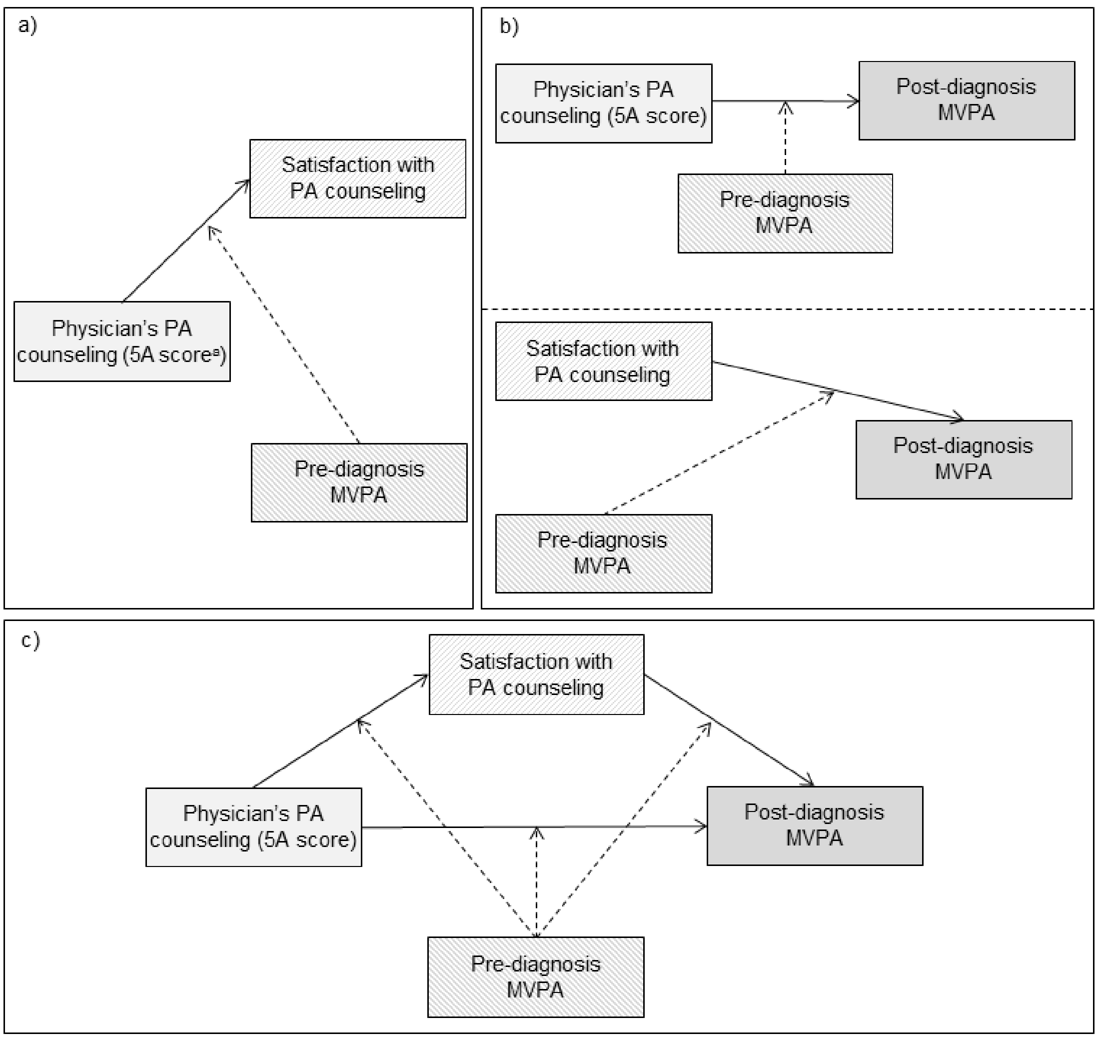

Figure 2. Stepwise models to analyze the moderated mediation of the association between physicians' physical activity (PA) counseling and patients' post-diagnosis PA

Notes. PA: physical activity, MVPA: moderate-to-vigorous physical activity. Dotted lines indicate a potential moderating effect.
[a]Weighted sumscore of 5A counseling steps, ranging from 0 to 5.

Since a large proportion of participants did not perform any MVPA or indicated only few MVPA minutes, the MVPA variable yielded a right skewed distribution with a large clump at zero, which precluded its direct use as a continuous variable. As a solution, the above shown three models were each analyzed in two consecutive phases (Chang and Pocock 2000; Min and Agresti 2002). Phase 1 aimed to evaluate if PA counseling had an effect on whether participants performed any post-diagnosis MVPA. The MVPA variable was therefore dichotomized as 0 = '0 min post-diagnosis MVPA' vs. 1 = '≥ 1 min post-diagnosis MVPA'. Given the binary outcome variable, the conditional process analysis was conducted as a logistic regression-based analysis. The moderator pre-diagnosis PA was entered as a dichotomous variable corresponding to the measurement level of the outcome variable, i.e., 0 min pre-diagnosis MVPA vs. ≥ 1 min pre-diagnosis MVPA, allowing to test the direct and indirect effect of PA counseling on whether participants performed any post-diagnosis MVPA separately for these two subgroups. Phase 2 included only participants with ≥ 1 min post-diagnosis MVPA to further investigate whether PA counseling was associated with the amount of MVPA minutes among active individuals. Here, post-diagnosis MVPA minutes were used as a continuous outcome variable and thus, a linear regression-based conditional process analysis was performed. The moderator variable pre-diagnosis MVPA was likewise defined as a continuous variable and the direct and indirect effects of PA counseling were tested separately for participants with 'low', 'medium', or 'high' pre-diagnosis MVPA, as specified by the 16^{th}, 50^{th}, and 84^{th} percentile ($M \pm 1$ *SD*) of the sample distribution, respectively. For this second phase, a normal distribution of residuals was achieved by log-transforming the MVPA variables. The conditional process analyses were adjusted for sociodemographic and medical covariates, i.e., age, sex, education level, BMI, cancer type, and time since diagnosis. All continuous variables forming interactions were mean-centered to allow for interpretable parameter estimates. 95% confidence intervals were calculated for the estimated direct and indirect effects and probed by generating 10,000 bootstrapped samples.

3. Results

The next sections will present the results of the data analyses regarding the four objectives of the dissertation. Parts of the presented results resemble publications that are associated with this dissertation (Depenbusch et al. 2020; Depenbusch et al. 2021; Steindorf et al. 2020). The results section will begin with the description of the recruitment flow and study population.

3.1. Description of study population

The recruitment flow of the cross-sectional Momentum study among cancer patients is presented in Figure 3. A total of 3,915 cancer patients were contacted via the cancer registry Baden-Württemberg, of which 22 were deceased and 5 letters were returned to sender. Of the remaining 3,888 contacted individuals, 798 initially agreed to participate in the paper-and-pencil study and 639 eventually returned the questionnaire. Further, 822 paper-and-pencil questionnaires were handed out by physicians and 61 by study personnel, of which 74 and 30 were returned, respectively. Taken together, from a total of 1,681 distributed questionnaires, 743 were returned, resulting in a return rate of 44.2% for the paper-and-pencil survey. In addition, 699 patients participated in the online version of the questionnaire, of which 238 indicated having been contacted by the cancer registry, 15 by physicians, 3 by study personnel, and 299 by other advertisement, while 144 did not indicate how they had learned about the study. A total of 60 surveys (*N* = 7 paper-and-pencil, *N* = 53 online) were excluded since they contained only sociodemographic data or were identified as double entries, and 83 participants (*N* = 40 paper-and-pencil, *N* = 43 online) did not fulfill the inclusion criteria, leading to the final sample of 1,299 participants (*N* = 696 paper-and-pencil and *N* = 603 online).

Descriptive statistics of the study population can be found in Table 3. The sample consisted of 631 breast cancer (48.6%), 344 prostate cancer (24.9%), and 324 colorectal cancer patients (26.5%), who were on average 60 years old (*SD* = 12.5) and at 58% female. The mean time since the latest diagnosis was 14.9 months (*SD* = 7.6), only a minority of which referred to metastases or cancer recurrence (20.2% and 11.3%, respectively). 41.4% of participants were receiving chemo, radiation, and/or hormone therapy at the time of survey completion.

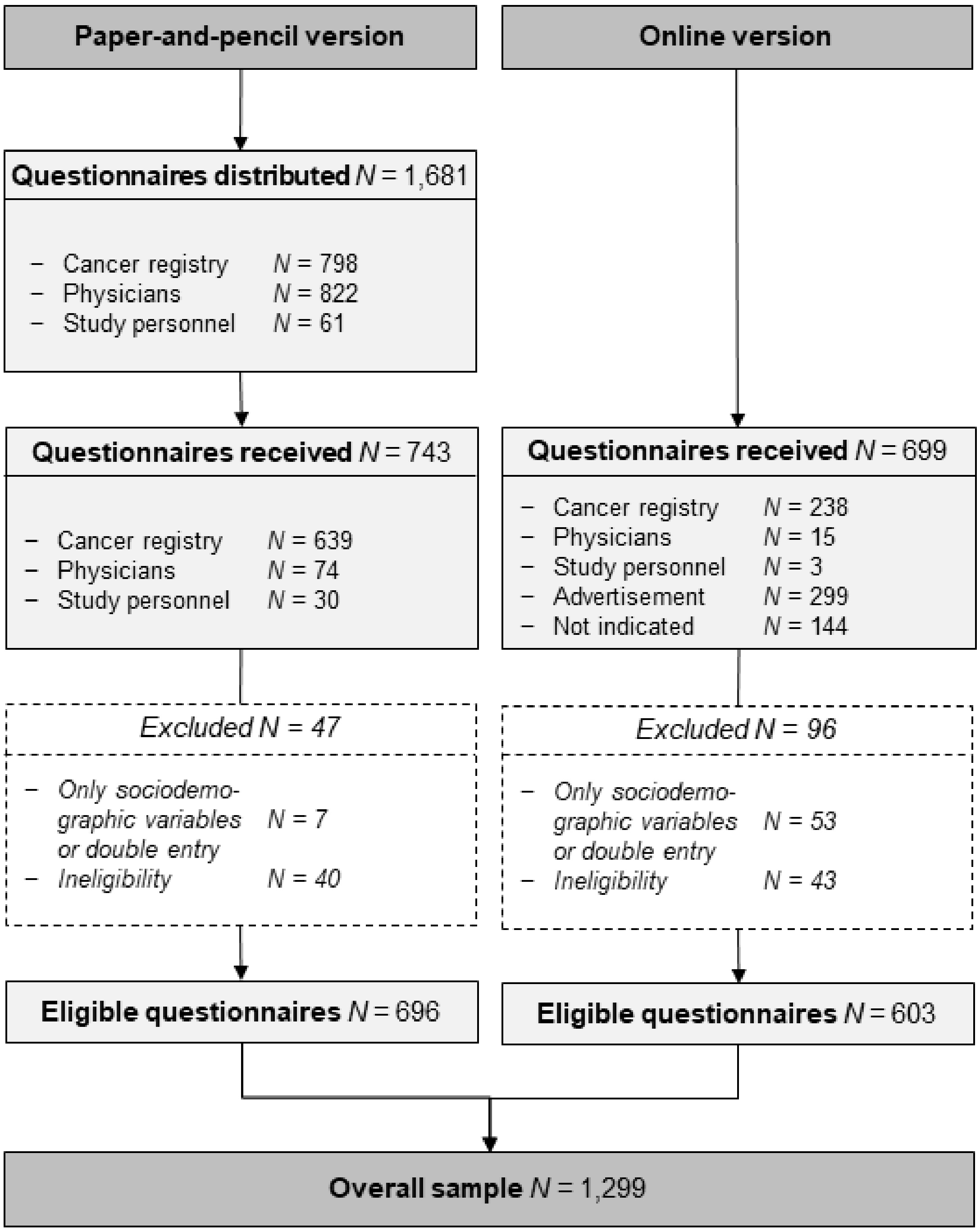

Figure 3. Recruitment flow

Note. Modified from Steindorf et al. (2020).

Table 3. Descriptive statistics of sociodemographic and medical characteristics, overall and by cancer type[†]

	Overall sample		Breast cancer		Prostate cancer		Colorectal cancer	
	M or *N*	*SD* or %	*M* or *N*	*SD* or %	*M* or *N*	*SD* or %	*M* or *N*	*SD* or %
Age [years][a]	60.0	12.5	54.1	11.9	68.6	7.3	62.2	12.0
BMI [kg/m²][a]	26.4	4.8	26.0	5.3	27.2	3.7	26.4	4.7
Sex								
Female	754	58.1%	625	99.2%	0	0.0%	129	39.8%
Male	543	41.9%	5	0.8%	343	100.0%	195	60.2%
Educational level[b]								
Lower	736	57.8%	333	53.7%	190	56.2%	213	67.4%
Higher	538	42.2%	287	46.3%	148	43.8%	103	32.6%
Current work status[c]								
Currently not working	844	67.6%	329	54.1%	281	83.1%	234	77.2%
Currently working	405	32.4%	279	45.9%	57	16.9%	69	22.8%
Marital status[d]								
Single	251	19.5%	148	23.6%	35	10.3%	68	21.2%
In relationship	1037	80.5%	478	76.4%	305	89.7%	254	78.9%
Time since diagnosis [months][a]	14.9	7.6	14.7	7.4	16.1	7.3	14.1	8.1
Metastases								
No	1032	79.8%	520	82.5%	284	83.5%	228	70.4%
Yes	262	20.2%	110	17.5%	56	16.5%	96	29.6%
Cancer recurrence								
No	1111	88.7%	567	91.0%	285	87.7%	259	84.9%
Yes	142	11.3%	56	9.0%	40	12.3%	46	15.1%
Co-morbidities								
None	549	44.6%	296	49.3%	111	33.9%	142	46.6%
≥1	683	55.4%	304	50.7%	216	66.1%	163	53.4%
Current treatment status[e]								
No treatment	735	58.6%	242	39.7%	258	77.9%	235	75.1%
Receiving treatment	519	41.4%	368	60.3%	73	22.1%	78	24.9%
Chemotherapy[f]								
No	726	57.0%	303	48.5%	300	89.3%	123	39.3%
Yes	548	43.0%	322	51.5%	36	10.7%	190	60.7%
Radiation therapy[f]								
No	559	43.8%	140	22.5%	191	57.0%	228	71.5%
Yes	717	56.2%	482	77.5%	144	43.0%	91	28.5%
Hormone therapy[f]								
No	843	66.6%	285	46.5%	245	74.0%	313	97.5%
Yes	422	33.4%	328	53.5%	86	26.0%	8	2.5%
Rehabilitation[f]								
No	556	43.6%	280	45.2%	109	32.4%	167	52.2%
Yes	720	56.4%	340	54.8%	227	67.6%	153	47.8%

Notes. Overall sample size *N* = 1,299, breast cancer: *n* = 631, prostate cancer: *n* = 344, colorectal cancer *n* = 324. Numbers in cells may not add up to total *N* due to missing data. Percentages were calculated based on complete cases. *M:* mean, *SD:* standard deviation.

[a] Displayed as mean *(M)* and standard deviation (*SD).*

[b] *Lower*: no degree or (lower-) secondary education degree; *Higher:* diploma qualifying for university or university degree.

[c] *Currently not working:* homemaker, retired, on sick-leave, or unemployed; *Currently working*: currently working or student.

[d] *Single:* single, divorced, or widowed; *In relationship*: married or in a firm relationship.

[e] Includes treatment types chemotherapy, radiation therapy, and hormone therapy.

[f] *No*: Not having received this treatment or treatment planned; *Yes*: treatment completed or currently receiving this treatment.

[†] Modified from Steindorf et al. (2020).

ANOVAs and chi-square tests revealed that sociodemographic and medical characteristics differed between cancer types with prostate cancer patients being significantly older ($F_{(2,744)}$ = 278.28, $p < .001$, $\omega^2 = .43$), having a higher BMI ($F_{(2,749)}$ = 8.31, $p < .001$, $\omega^2 = .02$), longer time since diagnosis ($F_{(2,697)}$ = 6.74, $p = .001$, $\omega^2 = .02$), and a higher proportion of patients reporting co-morbidities ($\chi^2 = 20.94$, $p < .001$, $V = .13$) than breast and colorectal cancer patients. Further differences between cancer types are presented in Table 4.

Table 4. Differences in sociodemographic and medical characteristics between cancer types

	Statistical test of group differences			Significant group differences between
	F or χ^2	*p*	ω^2 or *V*	
Age [years][a]	278.28	< .001	.43	PC > BC, PC > CC, CC > BC
BMI [kg/m²][a]	8.31	< .001	.02	PC > BC
Education: Higher	16.55	< .001	.11	BC > CC, PC > CC
Current work status: Currently working[c]	100.53	< .001	.28	BC > PC, BC > CC
Marital status: In relationship[d]	25.75	< .001	.14	PC > BC, PC > CC
Time since diagnosis [months][a]	6.74	.001	.02	PC > BC, PC > CC
Metastases: Yes	23.70	< .001	.14	CC > BC, CC > PC
Cancer recurrence: Yes	7.98	.018	.08	CC > BC
Co-morbidities: ≥1	20.94	< .001	.13	PC > BC, PC > CC
Current treatment status: Receiving treatment[e]	176.20	< .001	.38	BC > PC, BC >CC
Chemotherapy: Yes[f]	201.41	< .001	.40	CC > BC, CC > PC, BC > PC
Radiotherapy: Yes[f]	237.55	< .001	.43	BC > PC, BC > CC, PC > CC
Hormone therapy: Yes[f]	257.61	< .001	.45	BC > PC, BC > CC, PC > CC
Rehabilitation: Yes[f]	27.23	< .001	.15	PC > BC, PC > CC

Notes. *N* = 1,299. Number of analyzed datasets might deviate due to complete case analyses. Statistical test of group differences carried out with robust Welch-ANOVAs for metric and chi-square tests for categorical variables.
> indicates higher mean value for metric variables or higher proportion for categorical variables.
[a] Group differences displayed as *F*-ratio, effect size displayed as ω^2.
[b] Diploma qualifying for university or university degree (compared to no degree or (lower-) secondary education degree).
[c] Currently working or student (compared to homemaker, retired, on sick-leave, or unemployed).
[d] Married or in a firm relationship (compared to single, divorced, or widowed).
[e] Includes treatment types chemotherapy, radiation therapy, and hormone therapy.
[f] Treatment completed or currently receiving this treatment (compared to not having received this treatment or treatment planned).

In the following sections, the results on cancer patients' pre- to post-diagnosis change in PA levels including differences between cancer types will be presented separately with regard to PA minutes (section 3.2.1) and the classification of PA change patterns (section 3.2.2).

3.2. Physical activity levels and changes from pre- to post-diagnosis

3.2.1. Physical activity minutes and differences between cancer types

The first objective of this dissertation was to identify pre- to post-diagnosis PA change patterns and to investigate differences between individuals with breast, prostate, and colorectal cancer in this regard. Table 5 describes the self-reported pre- and post-diagnosis PA levels separately for the three activity intensities and separately for each cancer type. The respective number of analyzed observations for each cell can be found below the table. The analyses of change in PA levels from before to after the diagnosis revealed an overall reduction in PA minutes with Wilcoxon signed-rank tests yielding statistical significance for the decrease in MPA minutes from 124.1 min/week pre-diagnosis (*SD* = 167.3) to 113.3 min/week post-diagnosis (*SD* = 153.0) ($z = -2.56$, $p = .011$, $r = -.08$) and VPA minutes from 90.7 min/week pre-diagnosis (*SD* = 169.9) to 62.0 min/week post-diagnosis (*SD* = 121.4) ($z = -8.73$, $p < .001$, $r = -.26$), which was further reflected in a significantly lower proportion of individuals meeting PA guidelines post-diagnosis (53.4%) compared to pre-diagnosis (62.0%) ($\chi^2_{(1,\, N = 1{,}108)} = 28.20$, $p < .001$, $\varphi = .16$).

However, starting at varying PA levels before the diagnosis, each cancer type displayed a unique change pattern. Prostate cancer patients reported the strongest reduction in PA, as demonstrated by statistically significant decreases in PA minutes with small to medium effect sizes for all activity intensities (LPA: $z = -3.33$, $p = .001$, $r = -.24$; MPA: $z = -3.79$, $p < .001$, $r = -.22$; VPA: $z = -6.50$, $p < .001$, $r = -.38$) as well as a significant reduction in the number of sufficiently active individuals (71.9% pre- vs. 51.8% post-diagnosis; $\chi^2_{(1,\, N = 296)} = 46.41$, $p < .001$, $\varphi = .40$).

Table 5. Self-reported pre- and post-diagnosis physical activity (PA) levels (min/week), overall and by cancer type[†]

	Overall sample (N = 1,119)		Breast cancer (BC) (n = 553)		Prostate cancer (PC) (n = 299)		Colorectal cancer (CC) (n = 267)		Statistical test of group differences[e]		Significant group differences between
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*p*	*d*	
Light PA											
Pre-diagnosis[a]	171.2	210.6	133.5	144.7	241.1	295.2	186.5	215.6	<.001	0.39	BC-PC, BC-CC, PC-CC
Post-diagnosis[b]	167.8	191.4	142.5	144.8	200.4	237.2 ↓**	192.2	222.4	.012	0.18	BC-PC, BC-CC
Moderate PA											
Pre-diagnosis[c]	124.1	167.3	102.5	133.5	155.7	196.8	133.5	187.8	.001	0.21	BC-PC
Post-diagnosis	113.3	153.0 ↓*	103.9	125.7	125.6	174.1 ↓***	118.9	176.8 ↓**	.647	0.06	
Vigorous PA											
Pre-diagnosis[c]	90.7	169.9	70.7	110.0	113.2	190.7	107.3	232.5	.008	0.17	BC-PC
Post-diagnosis	62.0	121.4 ↓***	57.5	87.1 ↓**	73.9	156.1 ↓***	57.8	136.7 ↓***	.022	0.14	BC-CC
Meeting PA guidelines[d]	*N*	%	*N*	%	*N*	%	*N*	%	*p*	*V*	
Pre-diagnosis[c]	702	62.0	317	56.4	217	71.9	168	62.5	<.001	.13	BC-PC, PC-CC
Post-diagnosis	597	53.4 ↓***	318	57.5	155	51.8 ↓***	124	46.4 ↓***	.010	.09	BC-CC

Notes. *M:* mean, *SD:* standard deviation. ↓ indicates a significant decrease in PA from pre- to post-diagnosis, * $p < .05$, ** $p < .01$, *** $p < .001$.

[a] Overall sample size $N = 848$, BC: $n = 453$, PC: $n = 202$, CC: $n = 193$.

[b] Overall sample size $N = 869$, BC: $n = 460$, PC: $n = 207$, CC: $n = 202$.

[c] Overall sample size $N = 1{,}133$, BC: $n = 562$, PC: $n = 302$, CC: $n = 269$.

[d] Participants performing ≥ 150 minutes moderate-to-vigorous PA/week.

[e] Statistical tests of group differences were carried out with non-parametric tests that are based on mean ranks of PA.

[†] Modified from Steindorf et al. (2020).

For colorectal cancer patients, the analyses revealed a significant reduction in MPA (z = -2.65, p = .008, r = -.16) and in VPA (z = -5.89, p < .001, r = -.36) with small and medium effect sizes, respectively. Accordingly, this also led to a significant decrease in the proportion of participants complying with PA guidelines from 62.5% pre- to 46.4% post-diagnosis ($\chi^2_{(1,\ N\ =\ 262)}$ = 22.55, p < .001, φ = .29). Breast cancer patients in contrast had a yet significant but only small-sized decrease in VPA (z = -3.38, p = .001, r = -.14) and seemed to shift their activity behavior after the diagnosis from vigorous to lighter-intensity activities as suggested by descriptive increases in LPA and MPA post-diagnosis.

Looking at differences in PA levels between the cancer types, Kruskal-Wallis tests detected significant pre-diagnosis group differences for MPA and VPA minutes, which however attenuated after the diagnosis. Further elaborating these differences with Mann-Whitney tests for pairwise comparisons showed that prostate cancer patients had significantly higher mean ranks of pre-diagnosis MPA (U = 71847.50, z = -3.76, p < .001, r = -.21) and VPA (U = 74828.00, z = -3.00, p = .003, r = -.10) than breast cancer patients, which were, however, no longer significantly differing after the diagnosis (MPA: U = 80527.00, z = -0.63, p = .527, r = -.02; VPA: U = 80674.00, z = -0.62, p = .533, r = -.02). The marginally significant pre-diagnosis difference between colorectal and breast cancer patients regarding VPA even reversed, with breast cancer patients showing significantly higher mean VPA ranks than colorectal cancer patients post-diagnosis (U = 65630.50, z = -2.78, p = .005, r = -.10). While breast cancer patients had the lowest proportion of participants meeting guidelines PA pre-diagnosis, their number of sufficiently active participants exceeded that of prostate cancer patients descriptively and that of colorectal cancer patients significantly after the diagnosis ($\chi^2_{(1,\ N = 553)}$ = 8.87, p = .003, φ = -.10).

3.2.2. Classification of change patterns and differences between cancer types

As described in the methods section 2.3, patients were categorized into four PA change patterns, i.e., 'maintainers', 'decreasers', 'increasers', and 'consistently inactives'. The distribution of these four change patterns is shown in Figure 4.

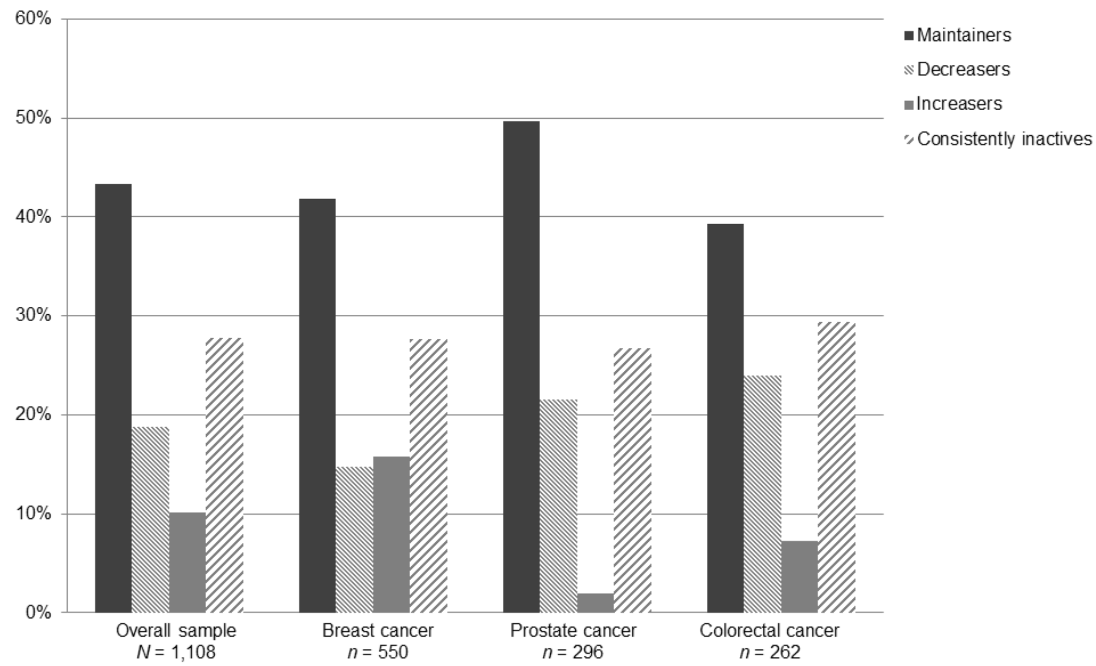

Figure 4. Distribution of physical activity (PA) change patterns from pre- to post-diagnosis, overall and by cancer type

Note. Modified from Steindorf et al. (2020).

In the overall sample of 1,108 participants, 43.3% of individuals were classified as 'maintainers'. Although accounting for the highest share among each cancer type, the proportion of 'maintainers' was significantly larger among prostate cancer patients compared to breast ($\chi^2_{(1,\ N = 846)} = 4.79$, $p = .029$, $\varphi = 0.08$) and colorectal cancer patients ($\chi^2_{(1,\ N = 558)} = 6.02$, $p = .014$, $\varphi = .10$) (Table 6). 18.8% of the overall sample fell into the category of 'decreasers'. Chi-square tests revealed that this change pattern applied more often to prostate ($\chi^2_{(1,\ N = 846)} = 6.44$, $p = .011$, $\varphi = .09$) and colorectal cancer patients ($\chi^2_{(1,\ N = 812)} = 10.56$, $p = .001$, $\varphi = .11$) compared to breast cancer patients. 'Increasers' accounted for 10.1% with significantly higher proportions among breast compared to prostate ($\chi^2_{(1,\ N\ =\ 846)}$ = 37.41, p < .001, φ = -.21) and colorectal cancer patients ($\chi^2_{(1,\ N\ =\ 812)}$ = 11.47, p = .001, φ = -.12). 27.8% of the overall sample were categorized as ‘consistently inactives’ with no significant differences between cancer types (all *p*-values > .05).

Table 6. Pairwise comparisons of the distribution of physical activity change patterns between cancer types

	Comparison between											
	Prostate cancer (*N* = 296) Breast cancer (*N* = 550)				Colorectal cancer (*N* = 262) Breast cancer (*N* = 550)				Prostate cancer (*N* = 296) Colorectal cancer (*N* = 262)			
	χ^2	df	*p*	φ	χ^2	df	*p*	φ	χ^2	df	*p*	φ
Maintainers[a]	4.79	1	**.029**	**.08**	0.46	1	.497	-.02	6.02	1	**.014**	**.10**
Decreasers[b]	6.44	1	**.011**	**.09**	10.56	1	**.001**	**.11**	0.47	1	.495	-.03
Increasers[c]	37.41	1	**<.001**	**-.21**	11.47	1	**.001**	**-.12**	8.87	1	**.003**	**-.13**
Consistently inactives[d]	0.09	1	.768	-.01	0.27	1	.604	.02	0.50	1	.478	-.03

Notes. Bold values indicate p < .05.
[a] Participants meeting physical activity (PA) guidelines, i.e., ≥ 150 minutes moderate-to-vigorous PA (MVPA), pre- and post-diagnosis.
[b] Participants meeting PA guidelines pre-diagnosis but not post-diagnosis.
[c] Participants not meeting PA guidelines pre-diagnosis but post-diagnosis.
[d] Participants not meeting PA guidelines pre-diagnosis or post-diagnosis.

The next sections will report on the results regarding factors that might influence cancer patients’ PA behavior after the diagnosis, ranging from the individuals’ sociodemographic and medical characteristics (section 3.3.1), to structural barriers (section 3.3.2) and physicians’ PA counseling (section 3.3.3).

3.3. Determinants of post-diagnosis physical activity

3.3.1. Patients’ sociodemographic and medical characteristics

As a second objective, the dissertation aimed to determine which sociodemographic and medical characteristics were associated with sufficient post-diagnosis PA, to evaluate whether these determinants differed between cancer types, and, in a subsequent step, to identify distinct combinations of determinants characterizing patient subgroups that were most likely to be (in)sufficiently active.

Logistic regression analyses were performed to detect significant determinants of sufficient post-diagnosis PA, i.e., meeting PA guidelines, in the overall sample comprising 912 participants, and separately for each cancer type (breast cancer: n = 457, prostate cancer: n = 241, colorectal cancer n = 214) (Table 7). The analyses revealed cancer type as a significant predictor of sufficient post-diagnosis PA with breast cancer patients being 2.4 and 1.9 more likely to be meeting PA guidelines than prostate (OR = 0.40, 95% CI [0.25, 0.65], p < .001) and female colorectal cancer patients (OR = 0.52, 95% CI [0.29, 0.94], p = .031), respectively. Moreover, sufficient pre-diagnosis PA (OR = 6.34, 95% CI [4.58, 8.77], p <. 001), higher educational levels (OR = 1.48, 95% CI [1.08, 2.02], p = .014), a lower BMI (OR = 0.95, 95% CI [0.92, 0.98], p = .001), longer time since diagnosis (OR = 1.03, 95% CI [1.00, 1.05], p = .021), participation in rehabilitation measures (OR = 1.58, 95% CI [1.14, 2.19], p = .006), no co-morbidities (OR = 0.65, 95% CI [0.47, 0.89], p = .005), and not having received chemotherapy (OR = 0.59, 95% CI [0.41, 0.86], p = 0.05) significantly increased the likelihood of meeting PA guidelines post-diagnosis.

Furthermore, subgroup analyses yielded differences in determinants between cancer types. Among breast cancer patients, those who were complying with PA guidelines before the diagnosis (OR = 3.82, 95% CI [2.48, 5.88], p < .001), had higher educational levels (OR = 1.86, 95% CI [1.20, 2.90], p = .006), a lower BMI (OR = 0.95, 95% CI [0.91, 1.00], p =.028), metastatic disease (OR = 1.89, 95% CI [1.00, 3.55], p = .049), and no co-morbidities (OR = 0.51, 95% CI [0.33, 0.81], p = .004) were more likely to be sufficiently active post-diagnosis. In contrast, for prostate cancer patients, sufficient pre-diagnosis PA (OR = 24.88, 95% CI [9.61, 64.44], p < .001), currently receiving treatment (OR = 7.51, 95% CI [1.91, 29.47], p = .004), and not having received chemotherapy (OR = 0.12, 95% CI [0.03, 0.47], p = .003), and/or hormone therapy (OR = 0.22, 95% CI [0.07, 0.72], p = .013) were significantly associated with meeting PA guidelines post-diagnosis. Among colorectal cancer patients, meeting PA guidelines pre-diagnosis was the only significant predictor of sufficient post-diagnosis PA (OR = 9.85, 95% CI [4.70, 20.65], p < .001).

Table 7. Logistic regression results on sociodemographic and medical determinants of sufficient post-diagnosis physical activity (PA), overall and by cancer type †

		Total (*N* = 912)			Breast cancer (*n* = 457)			Prostate cancer (*n* = 241)			Colorectal cancer (*n* = 214)		
		OR	[95% CI]	*p*	OR	[95% CI]	*p*	OR	[95% CI]	*p*	OR	[95% CI]	*p*
Meeting guideline	No	Reference			Reference			Reference			Reference		
pre-diagnosis [a]	Yes	6.34	[4.58, 8.77]	**<.001**	3.82	[2.48, 5.88]	**<.001**	24.88	[9.61, 64.44]	**<.001**	9.85	[4.70, 20.65]	**<.001**
Age	Per 1 year	1.01	[0.99, 1.02]	.481	1.00	[0.98, 1.02]	.960	0.99	[0.94, 1.05]	.783	1.03	[0.99, 1.06]	.120
Educational level[b]	Lower	Reference			Reference			Reference			Reference		
	Higher	1.48	[1.08, 2.02]	**.014**	1.86	[1.20, 2.90]	**.006**	1.03	[0.51, 2.09]	.931	1.38	[0.69, 2.75]	.362
Current work status[c]	Currently not working	Reference			Reference			Reference			Reference		
	Currently working	1.25	[0.86, 1.81]	.242	1.42	[0.89, 2.27]	.144	0.63	[0.22, 1.79]	.389	1.46	[0.62, 3.45]	.383
Marital status[d]	Single	Reference			Reference			Reference			Reference		
	In relationship	1.45	[0.96, 2.16]	.072	1.63	[0.98, 2.72]	.060	1.70	[0.44, 6.56]	.441	1.03	[0.45, 2.36]	.949
BMI	Per 1 kg/m²	0.95	[0.92, 0.98]	**.001**	0.95	[0.91, 1.00]	**.028**	0.96	[0.88, 1.06]	.443	0.93	[0.86, 1.00]	.060
Cancer type by sex	Breast	Reference											
	Prostate	0.40	[0.25, 0.65]	**<.001**	-	-	-	-	-	-	-	-	-
	Colorectal, female	0.52	[0.29, 0.94]	**.031**	-	-	-	-	-	-	Reference		
	Colorectal, male	0.66	[0.39, 1.14]	.135	-	-	-	-	-	-	1.10	[0.53, 2.30]	.796
Metastases	No	Reference			Reference			Reference			Reference		
	Yes	1.11	[0.71, 1.72]	.654	1.89	[1.00, 3.55]	**.049**	1.22	[0.38, 3.93]	.739	0.73	[0.28, 1.94]	.503
Cancer recurrence	No	Reference			Reference			Reference			Reference		
	Yes	0.65	[0.40, 1.07]	.091	0.68	[0.33, 1.43]	.312	0.77	[0.26, 2.34]	.469	0.69	[0.25, 1.94]	.485
Time since diagnosis	Per 1 month	1.03	[1.00, 1.05]	**.021**	1.02	[0.98, 1.06]	.324	1.02	[0.97, 1.08]	.447	1.04	[0.99, 1.10]	.105
Rehabilitation[e]	No	Reference			Reference			Reference			Reference		
	Yes	1.58	[1.14, 2.19]	**.006**	1.20	[0.74, 1.95]	.464	1.30	[0.60, 2.82]	.512	1.86	[0.94, 3.69]	.074
Co-morbidities	None	Reference			Reference			Reference			Reference		
	≥ 1	0.65	[0.47, 0.89]	**.007**	0.51	[0.33, 0.81]	**.004**	0.61	[0.30, 1.25]	.177	0.89	[0.44, 1.80]	.753

(continued)

Table 7 (continued)

		Total (N = 912)			Breast cancer (n = 457)			Prostate cancer (n = 241)			Colorectal cancer (n = 214)		
		OR	[95% CI]	p	OR	[95% CI]	p	OR	[95% CI]	p	OR	[95% CI]	p
Current treatment status[f]	No treatment	Reference			Reference			Reference			Reference		
	Receiving treatment	1.10	[0.67, 1.83]	.699	0.65	[0.29, 1.44]	.289	7.51	[1.91, 29.47]	**.004**	0.75	[0.28, 2.04]	.571
Chemotherapy[e]	No	Reference			Reference			Reference			Reference		
	Yes	0.59	[0.41, 0.86]	**.005**	0.66	[0.41, 1.08]	.096	0.12	[0.03, 0.47]	**.003**	1.11	[0.51, 2.38]	.797
Radiation therapy[e]	No	Reference			Reference			Reference			Reference		
	Yes	0.83	[0.58, 1.19]	.313	1.01	[0.56, 1.79]	.986	0.76	[0.36, 1.60]	.476	0.59	[0.27, 1.32]	.201
Hormone therapy[e]	No	Reference			Reference			Reference					
	Yes	1.12	[0.66, 1.89]	.675	2.13	[0.95, 4.75]	.066	0.22	[0.07, 0.72]	**.013**	-	-	-

Notes. Dependent variable 'meeting PA guidelines post-diagnosis', i.e., ≥ 150 minutes moderate-to-vigorous PA (MVPA) per week. Bold values indicate p < .05. OR*:* odds ratio, CI: 95% confidence interval.

[a] Participants performing ≥ 150 min MVPA/week pre-diagnosis.

[b] *Lower*: no degree or (lower-) secondary education degree; *Higher:* diploma qualifying for university or university degree.

[c] *Currently not working:* homemaker, retired, on sick-leave, or unemployed; *Currently working*: currently working or student.

[d] *Single:* single, divorced, or widowed; *In relationship*: married or in a firm relationship.

[e] *No*: not having received this treatment or treatment planned; *Yes*: treatment completed or currently receiving this treatment.

[f] Includes treatment types chemotherapy, radiation therapy, and hormone therapy.

[†] Modified from Steindorf et al. (2020).

Building upon the logistic regression analysis, a classification tree analysis was conducted to identify subgroups of patients that, based on their combination of sociodemographic and medical characteristics, had the highest or lowest likelihood to comply with PA guidelines post-diagnosis. Figure 5 displays the resulting regression tree. In the stepwise approach, compliance with PA guidelines before the diagnosis turned out as the most discriminating predictor for sufficient post-diagnosis PA levels ($\chi^2_{(1,\ N\ =\ 912)} = 141.49$, $p < .001$) and the overall sample was subdivided accordingly. Among the subgroup of previously sufficiently active individuals, the sample was split by patients' time since diagnosis ($\chi^2_{(1,\ N\ =\ 563)} = 17.37$, $p < .001$). Those who were diagnosed more than nine months ago and had higher educational levels were most likely to maintain sufficient activity levels with 80.7% of patients still meeting PA guidelines ('maintainers'), whereas those with a diagnosis less than nine months ago and chemotherapy treatment were most likely to decrease their PA levels ('decreasers'). Among the subgroup of previously insufficiently active individuals, cancer type emerged as the most discriminating factor ($\chi^2_{(2,\ N\ =\ 349)} = 32.15$, $p < .001$), revealing that prostate cancer patients were most likely to remain insufficiently active post-diagnosis with only 8.8% meeting PA guidelines ('consistently inactives'). In contrast, previously insufficiently breast cancer patients with no co-morbidities had the highest likelihood of increasing their PA to sufficient levels after the diagnosis ('increasers').

3.3.2. Structural barriers for physical activity

The third objective of this dissertation was to evaluate the role of structural barriers for post-diagnosis PA. First, descriptive statistics will describe to what extent cancer patients perceived structural barriers as impeding for their PA. Subsequently, results on determinants of the perception of structural barriers and the association between structural barriers and post-diagnosis PA behavior, also with regard to different pre- to post-diagnosis change patterns, will be presented. Since all analyses were carried out separately for each structural barrier, the number of participants slightly differed between the analyzed models.

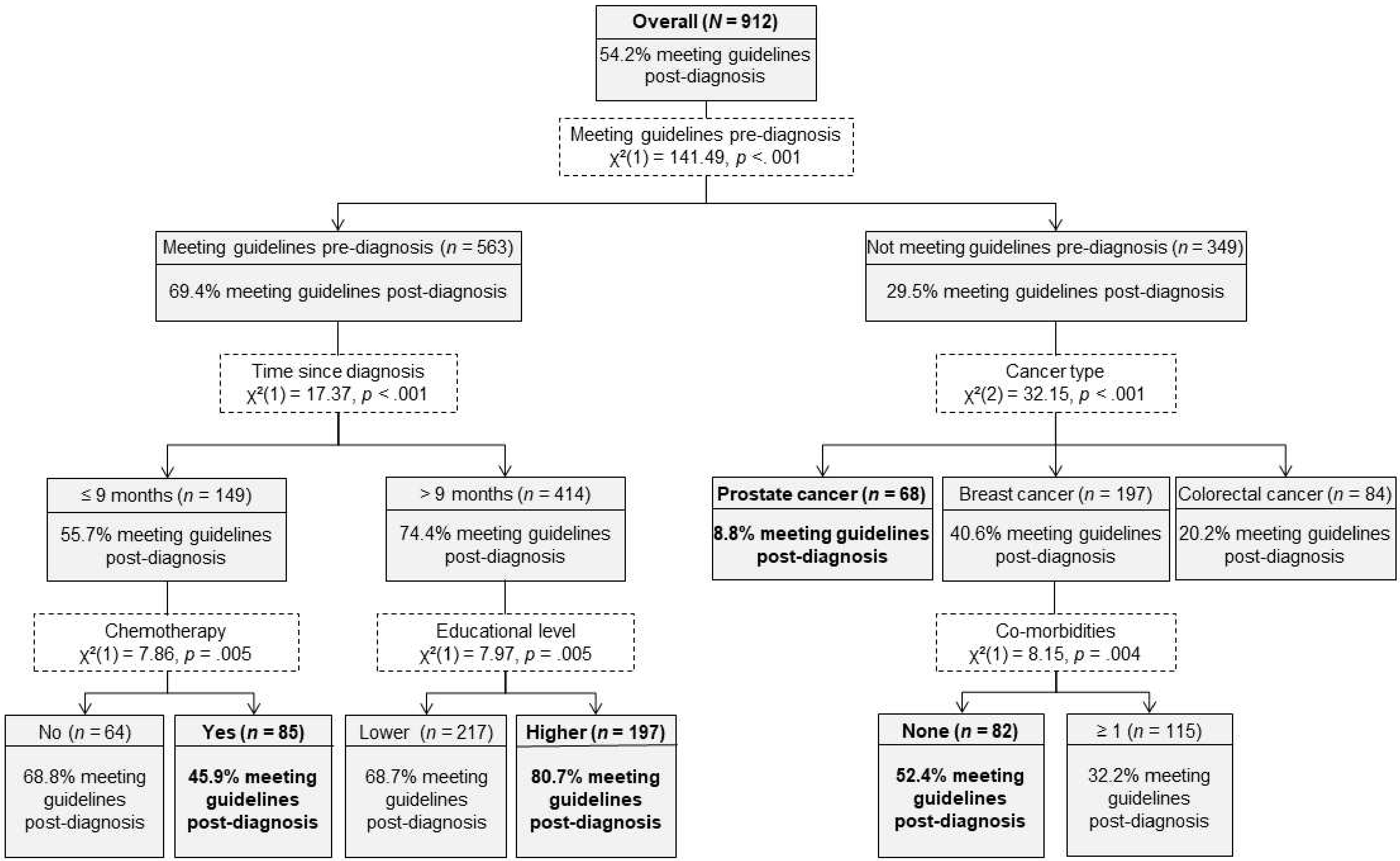

Figure 5. Classification tree analysis for identification of subgroups more or less likely to be meeting physical activity guidelines post-diagnosis

Notes. 'Meeting guidelines' defined as ≥ 150 minutes moderate-to-vigorous physical activity per week. Modified from Steindorf et al. (2020).

Descriptive statistics

Descriptive statistics for the extent of PA impediment by the seven queried structural barriers can be found in Table 8 and Figure 6. The number of analyzed observations in this context varied from 1,130 to 1,154; the overall number of perceived barriers was calculated for 1,180 individuals. The barrier 'lack of reimbursement for PA programs' turned out as the most frequently endorsed barrier (57.9% based on the dichotomized variable), also yielding the highest mean value for PA impediment (*M* = 2.08, *SD* = 1.10), followed by 'lack of an expert contact person' (53.2%, *M* = 1.89, *SD* = 1.00), and 'lack of PA offers specifically for people with cancer' (48.3%, *M* = 1.80, *SD* = 0.98). In contrast, only 29.8% and 18.5% of patients reported impediment by barriers 'lack of PA offers overall' and 'lack of parks, paths, or pools in the neighborhood', respectively. Based on the dichotomized variables, the average number of perceived barriers was 2.8 (*SD* = 2.4) with more than 70% of patients feeling impeded by at least one barrier.

Table 8. Descriptive statistics of perceived structural barriers to physical activity (PA)[†]

	Not at all		Slightly		Strongly		Very strongly		*M*, *SD*[a]	
Lack of	*N*	%	*N*	%	*N*	%	*N*	%	*M*	*SD*
Information material	679	58.8	308	26.7	113	9.8	54	4.7	1.60	0.85
PA offers for people with cancer	592	51.7	283	24.7	176	15.4	95	8.3	1.80	0.98
PA offers overall	793	70.2	223	19.7	88	7.8	26	2.3	1.42	0.73
Possibility for medical clearance	666	58.6	276	24.3	126	11.1	69	5.3	1.65	0.90
Expert contact person	533	46.8	303	26.6	197	17.3	105	9.2	1.89	1.00
Reimbursement for PA programs	482	42.1	256	22.4	236	20.6	170	14.9	2.08	1.10
Parks, paths, or pools in neighborhood	936	81.5	143	12.5	44	3.8	25	2.2	1.27	0.64

Notes. *N* = 1,180. Numbers in cells may not add up to total *N* due to missing data. Percentages were calculated based on complete cases. *M*: mean, *SD*: standard deviation, PA: physical activity.
[a] based on 4-point Likert Scale with 0 = 'not at all', 1 = 'slightly', 2 = 'strongly', 3 = 'very strongly'.
[†] Modified from Depenbusch et al. (2021).

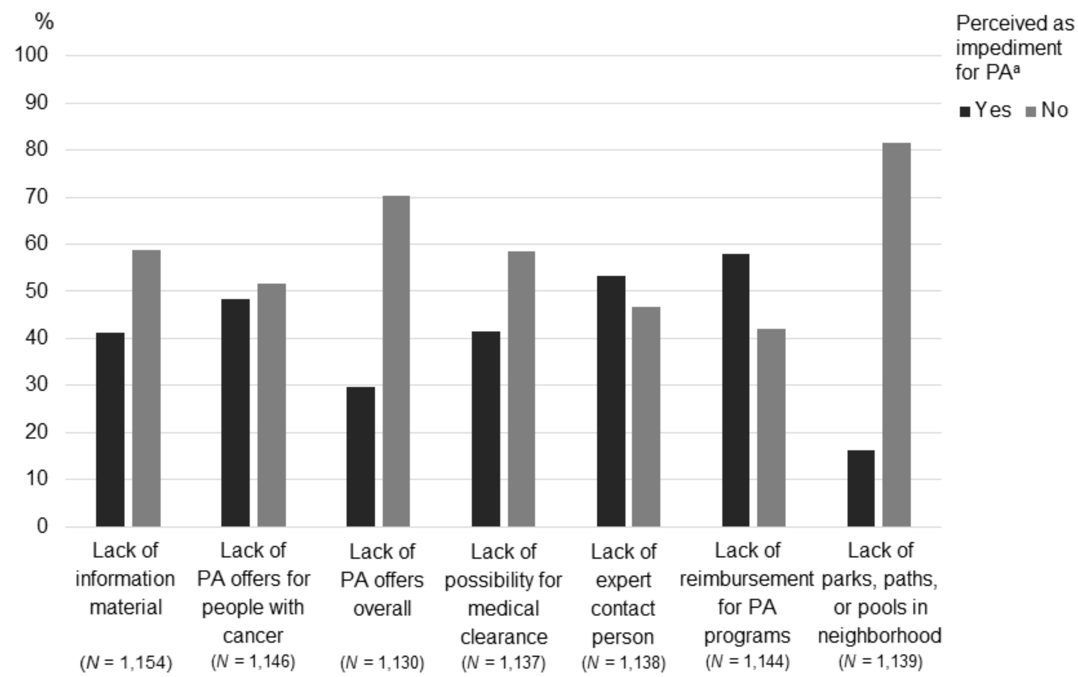

Figure 6. Frequencies of participants perceiving impediment for physical activity (PA) by structural barriers

Notes. PA: physical activity. Modified from Depenbusch et al. (2021).
[a] based on dichotomized barrier variable with 0 = ‘not at all’; 1 = ‘slightly’, ‘strongly’, or ‘very strongly’.

Determinants of the perception of structural barriers

Linear regression analyses were conducted to identify which individuals, based on their sociodemographic and medical characteristics, perceived stronger impediment by each structural barrier and an overall higher number of barriers (Table 9). Dependent on the number of individuals providing complete data on the respective variables, the regression models were based on 948 to 984 observations. The analyses revealed a younger age, lower educational level, no current work activity, and a higher BMI as significant predictors of a stronger impediment by five to six structural barriers as well as a higher number of perceived barriers (all *p*-values $< .05$). Further, patients' sex was significantly associated with the perception of the structural barriers ‘lack of PA offers for people with cancer’ (unstandardized regression coefficient beta (*B*) = -.26, $p = .039$) and ‘lack of reimbursement for PA programs’ (*B* = -.29, $p = .037$) with female participants feeling more strongly impeded than male ones.

Table 9. Linear regression results on sociodemographic and medical determinants of perceiving impediment by structural barriers to physical activity (PA)†

	Lack of information material (*N* = 967)		Lack of PA offers for people with cancer (*N* = 964)		Lack of PA offers overall (*N* = 948)		Lack of possibility for medical clearance (*N* = 957)		Lack of expert contact person (*N* = 952)		Lack of reimbursement for PA programs (*N* = 956)		Lack of parks, paths, or pools in neighborhood (*N = 964*)		Number of barriers (*N* = 984)	
	B	*p*	*B*	*p*	*B*	*p*	*B*	*p*	*B*	*p*	*B*	*p*	*B*	*p*	*B*	*p*
Age [per year]	**-.01**	**.001**	**-.02**	**<.001**	**-.01**	**<.001**	**-.01**	**.001**	**-.02**	**<.001**	**-.02**	**<.001**	.00	.236	**-.05**	**<.001**
Sex[a]	-.21	.061	**-.26**	**.039**	-.08	.412	-.05	.666	-.14	.283	**-.29**	**.037**	-.03	.696	-.52	.084
BMI [per 1 kg/m²]	**.02**	**.010**	**.02**	**.023**	**.02**	**<.001**	.00	.515	.01	.215	**.02**	**.019**	**.01**	**.022**	**.06**	**<.001**
Educational level[b]	**-.11**	**.046**	**-.16**	**.010**	**-.13**	**.006**	**-.19**	**.002**	**-.15**	**.026**	**-.23**	**<.001**	-.03	.445	**-.48**	**.002**
Current work status[c]	**-.14**	**.046**	**-.33**	**<.001**	**-.15**	**.010**	**-.21**	**.003**	**-.24**	**.003**	**-.21**	**.017**	-.04	.413	**-.65**	**<.001**
Cancer type																
Colorectal[d]	.15	.154	-.02	.842	.17	.056	.04	.745	.13	.298	.06	.670	-.02	.758	.33	.239
Prostate[e]	.25	.058	.09	.564	**.23**	**.044**	.14	.342	.26	.097	.22	.187	-.03	.747	.63	.078
Time since diagnosis [per month]	-.01	.171	.00	.935	.00	.228	-.01	.207	-.01	.191	.00	.929	-.00	.393	-.01	.230
Current treatment[f]	.09	.339	.13	.220	.05	.501	.12	.231	.16	.134	.22	.056	.04	.572	.46	.059
Chemotherapy[g]	-.03	.658	.07	.324	.02	.701	.06	.363	.04	.564	-.05	.575	.01	.868	-.04	.835
Radiation therapy[g]	.04	.547	.04	.550	**.15**	**.007**	**.19**	**.005**	.12	.102	.16	.054	.08	.111	**.47**	**.007**
Hormone therapy[g]	-.05	.582	-.07	.532	.03	.695	-.08	.446	-.11	.337	-.15	.206	-.02	.810	-.34	.217
Co-morbidities[h]	.07	.202	**.19**	**.004**	.09	.081	**.14**	**.028**	**.16**	**.024**	**.16**	**.033**	.05	.279	**.38**	**.015**
5A score for PA counseling[i]	**-.08**	**.009**	-.04	.210	.01	.838	**-.08**	**.015**	**-.12**	**.001**	-.02	.682	.00	.925	-.13	.106

Notes. Bold values indicate $p < .05$. *B:* unstandardized regression coefficient beta.
[a] 0 = female; 1 = male.
[b] 0 = *Lower*: no degree or (lower-) secondary education degree; 1 = *Higher*: diploma qualifying for university or university degree.
[c] 0 = *Currently not working*: homemaker, retired, on sick-leave, or unemployed; 1 = *Currently working*: currently working or student.
[d] Cancer type, dummy-coded. 0 = breast cancer, prostate cancer; 1 = colorectal cancer.
[e] Cancer type, dummy-coded. 0= breast cancer, colorectal cancer; 1 = prostate cancer.
[f] 0 = *No treatment*: currently not receiving chemo, radiation, and/or hormone therapy; 1 = *Receiving treatment:* currently receiving chemo, radiation, or hormone therapy.
[g] 0 = *No:* not having received this treatment or treatment planned; 1 = *Yes*: treatment completed or currently receiving this treatment.
[h] 0 = *None:* no co-morbidities; 1 = ≥1: one or more co-morbidities.
[i] Weighted sumscore for physicians' PA counseling based on 5A framework, higher values indicate more comprehensive counseling.
† Modified from Depenbusch et al. (2021).

With regard to medical factors, co-morbidities emerged as a significant predictor of higher impediment by four structural barriers (all *p*-values < .05) as well as a higher number of barriers (B = .38, p = .015). Having received radiation therapy was moreover significantly associated with a 'lack of PA programs overall' (B = .15, p = .007), a 'lack of possibility for medical clearance for PA' (B = .19, p = .005) and a higher number of barriers (B = .47, p = .007). Finally, patients reporting less comprehensive exercise counseling indicated significantly higher PA impediment by a 'lack of information material' (B = -.08, p = .009), a 'lack of possibility for medical clearance' (B = -.08, p = .015), and a 'lack of an expert contact person' (B = -.12, p = .001).

Association of structural barriers and insufficient post-diagnosis physical activity

To evaluate the association between the perception of structural barriers and insufficient post-diagnosis PA, i.e., *not* meeting PA guidelines, separate logistic regression models for each of the seven structural barriers as well as the number of barriers were analyzed, including data of 940 to 973 individuals. Results are displayed in Table 10. Overall, patients who reported higher PA impediment by structural barriers had a significantly increased likelihood of being insufficiently active after the diagnosis, above and beyond the effect of established PA determinants. The strongest association emerged for the barrier 'lack of information material' with a 38% higher likelihood of not meeting PA guidelines post-diagnosis for each increase in level of perceived impediment (OR = 1.38, 95% CI [1.15,1.65], p < .001). For the other structural barriers, every level of perceived impediment significantly increased the likelihood of insufficient post-diagnosis PA by 16% to 30% (all *p*-values < .05), except for the barrier 'lack of parks, paths, or pools in the neighborhood', which yielded no significant association. The model for the number of perceived barriers further revealed that with every additionally perceived barrier, the likelihood of not meeting PA guidelines post-diagnosis was increased by 14% (OR = 1.14, 95% CI [1.07,1.21], p < .001).

Table 10. Logistic regression results on the impact of structural barriers on insufficient post-diagnosis physical activity (PA)[†]

		Model for barrier: Lack of information material (*N* = 960)			**Model for barrier: Lack of PA offers for people with cancer** (*N* = 954)			**Model for barrier: Lack of PA offers overall** (*N* = 940)			**Model for barrier: Lack of possibility for medical clearance** (*N* = 950)		
		OR	CI	*p*	OR	CI	*p*	OR	CI	*p*	OR	CI	*p*
Structural barrier[a]	Per 1 step	**1.38**	**[1.15, 1.65]**	**<.001**	**1.21**	**[1.04, 1.42]**	**.016**	**1.27**	**[1.02, 1.58]**	**.032**	**1.22**	**[1.03, 1.43]**	**.019**
Age	Per 1 year	1.00	[0.98, 1.01]	.779	1.00	[0.98, 1.01]	.805	1.00	[0.98, 1.01]	.657	1.00	[0.98, 1.01]	.675
Sex	Female	Reference			Reference			Reference			Reference		
	Male	0.73	[0.40, 1.33]	.303	0.74	[0.41, 1.34]	.323	0.73	[0.40, 1.32]	.296	0.71	[0.39, 1.30]	.267
BMI	Per 1 kg/m²	1.06	[1.02, 1.09]	.001	1.06	[1.02, 1.09]	.001	1.05	[1.02, 1.09]	.003	1.06	[1.02, 1.09]	.001
Educational level[b]	Lower	Reference			Reference			Reference			Reference		
	Higher	0.67	[0.49, 0.91]	.009	0.67	[0.50, 0.91]	.010	0.68	[0.51, 0.93]	.014	0.68	[0.50, 0.92]	.012
Cancer type	Breast	Reference			Reference			Reference			Reference		
	Colorectal	2.66	[1.59, 4.45]	<.001	2.74	[1.64, 4.55]	<.001	2.55	[1.53, 4.27]	<.001	2.70	[1.62, 4.51]	<.001
	Prostate	2.90	[1.44, 5.83]	.003	3.09	[1.55, 6.18]	.001	2.79	[1.39, 5.62]	.004	2.99	[1.49, 6.00]	.002
Time since diagnosis	Per 1 month	0.97	[0.95, 0.98]	<.001	0.96	[0.94, 0.98]	<.001	0.96	[0.94, 0.98]	<.001	0.96	[0.94, 0.98]	<.001
Co-morbidities	None	Reference			Reference			Reference			Reference		
	≥1	1.44	[1.05, 1.96]	.023	1.40	[1.03, 1.92]	.034	1.41	[1.03, 1.92]	.033	1.44	[1.05, 1.97]	.022
Pre-diagnosis MVPA	0-149 min/week	Reference			Reference			Reference			Reference		
	≥150 min/week	6.50	[4.73, 8.93]	<.001	6.08	[4.43, 8.34]	<.001	6.05	[4.41, 8.31]	<.001	6.21	[4.53, 8.52]	<.001
5A score[c]	Per 1 step	0.72	[0.61, 0.85]	<.001	0.70	[0.60, 0.82]	<.001	0.70	[0.60, 0.83]	<.001	0.70	[0.60, 0.83]	<.001

(continued)

Table 10 (continued)

		Model for barrier: Lack of expert contact person (*N* = 944)			**Model for barrier: Lack of reimbursement for PA programs** (*N* = 948)			**Model for barrier: Lack of parks, paths, or pools in neighborhood** (*N* = 952)			**Model for barrier: Lack of number of barriers** (*N* = 973)		
		OR	CI	*p*	OR	CI	*p*	OR	CI	*p*	OR	CI	*p*
Structural barrier[a]	Per 1 step	**1.30**	**[1.12, 1.51]**	**.001**	**1.16**	**[1.00, 1.33]**	**.043**	1.21	[0.95, 1.55]	.119	**1.14**	**[1.07, 1.21]**	**<.001**
Age	Per 1 year	1.00	[0.98, 1.03]	.821	1.00	[0.98, 1.01]	.907	1.00	[0.98, 1.01]	.591	1.00	[0.99, 1.02]	.987
Sex	Female	Reference			Reference			Reference			Reference		
	Male	0.67	[0.37, 1.23]	.194	0.68	[0.38, 1.25]	.214	0.70	[0.39, 1.26]	.237	0.75	[0.41, 1.36]	.341
BMI	Per 1kg/m²	1.06	[1.02, 1.09]	.001	1.06	[1.02, 1.09]	.001	1.06	[1.02, 1.09]	.001	1.05	[1.02, 1.08]	.004
Educational level[b]	Lower	Reference			Reference			Reference			Reference		
	Higher	0.66	[0.49, 0.89]	.007	0.68	[0.51, 0.93]	0.14	0.66	[0.49, 0.90]	.008	0.68	[0.50, 0.92]	.013
Cancer type	Breast	Reference			Reference			Reference			Reference		
	Colorectal	2.79	[1.66, 4.70]	<.001	2.82	[1.69, 4.72]	<.001	2.64	[1.59, 4.39]	<.001	2.63	[1.58, 4.38]	<.001
	Prostate	3.21	[1.58, 6.50]	.001	3.08	[1.54, 6.18]	.002	2.94	[1.47, 5.86]	.002	2.88	[1.44, 5.77]	.003
Time since diagnosis	Per 1 month	0.97	[0.95, 0.99]	.001	0.96	[0.94, 0.98]	<.001	0.96	[0.94, 0.98]	<.001	0.96	[0.95, 0.98]	<.001
Co-morbidities	None	Reference			Reference			Reference			Reference		
	≥1	1.44	[1.05, 1.97]	.023	1.41	[1.03, 1.92]	.033	1.45	[1.06, 1.98]	.020	1.36	[1.00, 1.86]	.053
Pre-diagnosis MVPA	0-149 min/week	Reference			Reference			Reference			Reference		
	≥150 min/week	6.37	[4.63, 8.78]	<.001	6.21	[4.53, 8.53]	<.001	6.19	[4.52, 8.50]	<.001	6.38	[4.66, 8.75]	<.001
5A score[c]	Per 1 step	0.72	[0.61, 0.85]	<.001	0.69	[0.59, 0.82]	<.001	0.71	[0.60, 0.83]	<.001	0.70	[0.60, 0.83]	<.001

Notes. Separate regression models for each structural barrier. Dependent variable 'insufficient post-diagnosis PA', i.e., not meeting PA guidelines of 150 minutes moderate-to-vigorous PA (MVPA) per week. Bold values indicate $p < .05$. OR: Odds ratio. CI: 95% confidence interval. PA: physical activity.

[a] Structural barrier as indicated in column heading, higher values indicate higher perceived impediment for PA.

[b] *Lower*: no degree or (lower-) secondary education degree; *Higher:* diploma qualifying for university or university degree.

[c] Weighted sumscore for PA counseling based on 5A framework, higher values indicate more comprehensive counseling.

† Modified from Depenbusch et al. (2021).

Subsequently, subgroup analyses defined by whether or not individuals were meeting PA guidelines pre-diagnosis were conducted to investigate if the associations of structural barriers and insufficient post-diagnosis PA applied equally to the two possible change patterns of insufficient post-diagnosis PA, i.e., becoming vs. remaining insufficiently active. As shown in Table 11, the associations indeed differed between the two PA change patterns. Looking at the subgroup of previously sufficiently active individuals, those perceiving stronger impediment by structural barriers were significantly more likely to become insufficiently active after the diagnosis with each level of impediment increasing the likelihood of not meeting PA guidelines by 20% to 39% for five of the seven barriers (all *p*-values < .05). Further, as indicated by the regression model for the number of barriers, each additionally perceived barrier increased the likelihood of becoming insufficiently active by 16% (OR = 1.16, 95% CI [1.07,1.26], *p* < .001). In contrast, among previously insufficiently active individuals, the analyses yielded no significant association between any of the structural barriers or the number of perceived barriers and the change pattern of remaining insufficiently active after the diagnosis (all *p*-values > .05).

Table 11. Logistic regression results on the impact of structural barriers on insufficient post-diagnosis physical activity (PA), separately for both possible PA change patterns[†]

	Becoming insufficiently active[a]				**Remaining insufficiently active**[b]			
Lack of	*N*	OR	CI	*p*	*N*	OR	CI	*p*
Information material	599	**1.37**	**(1.01; 1.71)**	**.005**	361	1.34	(0.98; 1.84)	.068
PA offers for people with cancer	597	**1.22**	**(1.00; 1.49)**	**.048**	357	1.21	(0.93; 1.56)	.157
PA offers overall	587	**1.32**	**(1.00; 1.74)**	**.047**	353	1.18	(0.83; 1.69)	.359
Possibility for medical clearance	593	0.85	(0.69; 1.04)	.108	357	1.30	(0.98; 1.73)	.071
Expert contact person	590	**1.39**	**(1.16; 1.67)**	**<.001**	354	1.14	(0.87; 1.49)	.336
Reimbursement for PA programs	596	**1.20**	**(1.01; 1.43)**	**.044**	352	1.10	(0.86; 1.40)	.449
Parks, paths, or pools in neighborhood	595	1.35	(0.97; 1.89)	.078	357	1.19	(0.83; 1.70)	.338
Number of barriers	609	**1.16**	**(1.07; 1.26)**	**<.001**	364	1.10	(0.97; 1.24)	.137

Notes. Separate regression models for each structural barrier. Dependent variable 'insufficient post-diagnosis PA', i.e., not meeting PA guidelines of 150 minutes moderate-to-vigorous PA (MVPA) per week. All models were adjusted for age, sex, BMI, educational level, cancer type, time since diagnosis, co-morbidities, and 5A score for PA counseling. Bold values indicate *p* < .05. OR: Odds ratio, CI: 95% confidence interval, PA: physical activity.
[a] Subgroup analysis for participants meeting PA guidelines pre-diagnosis (≥ 150 min MVPA/week).
[b] Subgroup analysis for participants not meeting PA guidelines pre-diagnosis (< 150 min MVPA/week).
[†] Modified from Depenbusch et al. (2021).

3.3.3. Physical activity counseling by physicians

The fourth and last objective of the dissertation focused on physicians' PA counseling as a potential facilitator to PA after the cancer diagnosis. Descriptive statistics of counseling-related variables will be presented, followed by results on the impact of PA counseling on cancer patients' post-diagnosis PA. For the analyses, data of 1,002 participants were available.

Descriptive statistics

Descriptive statistics for variables concerning PA counseling are displayed in Table 12. Oncologists were most frequently rated as patients' most important medical contact person (28.0%), followed by gynecologists (26.4%), urologists (21.2%) and general practitioners (15.4%). Surgeons, gastroenterologists and radiation therapists were only mentioned by 2%-4% of participants.

Table 12. Descriptive statistics of variables related to physicians' physical activity (PA) counseling

	N	%
Most important contact person		
General practitioner	131	15.4%
Oncologist	238	28.0%
Gynecologist	225	26.4%
Urologist	180	21.1%
Gastroenterologist	16	1.9%
Surgeon	36	4.2%
Radiation therapist	25	2.9%
Physicians' exercise counseling (5A framework)[a]		
No counseling	191	19.1%
Assess	450	44.9%
Advice	686	68.5%
Agree	57	5.7%
Assist	77	7.7%
Arrange	119	11.9%
Satisfaction with PA counseling[b]		
Very unsatisfied	32	3.2%
Unsatisfied	79	7.9%
Partly satisfied	226	22.6%
Satisfied	458	45.7%
Very satisfied	207	20.7%

Notes. N = 1,002. Numbers in cells do not add up to total N due to missing data or possibility of multiple answers. Percentages were calculated based on complete cases. M: mean, SD: standard deviation.
[a] Multiple answers possible.
[b] M = 3.7, SD = 0.9.

Regarding frequencies of the 5A counseling steps, 19.1% reported not having received PA counseling, whereas 44.9% and 68.5% stated that their physician had ‘assessed’ and/or ‘advised’ PA, respectively. With less than 12%, the 5A steps ‘agree’, ‘assist’, and ‘arrange’ were, in contrast, only rarely mentioned. The average 5A score was 1.0 (SD = 0.9) and did not differ between cancer types ($F_{(2,999)}$ = 0.74, p = .479, ω^2 = .00) or physician’s specialization ($F_{(6,844)}$ = 1.41, p = .207, ω^2 = .00). The majority of patients was satisfied (45.7%) or very satisfied (20.7%) with their physician’s PA counseling, while taken together only 11.1% indicated to be unsatisfied or very unsatisfied. Welch-ANOVAs yielded statistically significant differences regarding satisfaction with PA counseling between cancer types ($F_{(2,548)}$ = 4.04, p = .018, ω^2 = .01) with Games-Howell post-hoc tests showing that colorectal cancer patients reported significantly higher satisfaction levels than breast cancer patients (MD = 0.18, p = .045). The satisfaction levels further differed with regard to physician’s specialization ($F_{(6,115)}$ = 3.57, p = .003, ω^2 = .12) in the way that participants rating surgeons as their most important contact person indicated significantly higher satisfaction levels than those referring to oncologists (MD = 0.47, p = .016) or gynecologists (MD = 0.53, p = .005).

Association of physical activity counseling and post-diagnosis physical activity

The impact of physicians’ PA counseling on patients’ post-diagnosis MVPA was investigated using a conditional process analysis, that tested a mediation of the proposed association by satisfaction with PA counseling and a moderation by patients’ pre-diagnosis MVPA (cf. Figure 1). As described in the methods section 2.3, the analysis was carried out in three models (cf. Figure 2), each consisting of two phases that examined the association of the 5A score on 1) whether patients performed any MVPA after the diagnosis and 2) the amount of MVPA among active individuals.

The first model analyzed the association of 5A score and satisfaction with PA counseling at different levels of pre-diagnosis MVPA (Table 13).

Table 13. The moderating effects of pre-diagnosis moderate-to-vigorous physical activity (MVPA) on satisfaction with physical activity (PA) counseling and on post-diagnosis MVPA[†]

	Outcome							
	Satisfaction				**Post-diagnosis MVPA**			
	B	*SE*	*p*	95% CI	*B*	*SE*	*p*	95% CI
Phase 1 (logistic regression)[a]								
5A Score[c]	0.44	0.03	**<.001**	[0.38, 0.50]	0.25	0.15	.101	[-0.05, 0.55]
Satisfaction[d]	----	----	----	---- ----	0.23	0.11	**.048**	[0.00, 0.45]
Pre-diagnosis MVPA	0.01	0.09	.942	[-0.18, 0.19]	2.83	0.25	**<.001**	[2.34, 3.32]
5A Score x Pre-diagnosis MVPA	-0.01	0.09	.933	[-0.19, 0.17]	-0.50	0.31	.101	[-1.10, 0.10]
Satisfaction x Pre-diagnosis MVPA	----	----	----	---- ----	0.88	0.25	**<.001**	[0.39, 1.37]
	$R^2 = 0.19$, $F_{(9,992)} = 24.443$, $p < .001$				$R^2 = 0.33$, $\chi^2(11) = 212.67$, $p < .001$			
Phase 2 (linear regression)[b]								
5A Score	0.42	0.03	**<.001**	[0.35, 0.49]	0.06	0.04	.101	[-0.01, 0.13]
Satisfaction	----	----	----	---- ----	0.02	0.04	.651	[-0.06, 0.09]
Pre-diagnosis MVPA	0.05	0.02	**.045**	[0.00, 0.09]	0.21	0.03	**<.001**	[0.15, 0.26]
5A Score x Pre-diagnosis MVPA	-0.00	0.02	.960	[-0.04, 0.04]	-0.05	0.02	**.039**	[-0.10, 0.00]
Satisfaction x Pre-diagnosis MVPA	----	----	----	---- ----	0.07	0.03	**.011**	[0.02, 0.12]
	$R^2 = 0.19$, $F_{(9,835)} = 21.34$, $p < .001$				$R^2 = 0.14$, $F_{(11,833)} = 8.06$, $p < .001$			

Notes. Bold values indicate $p < .05$. *B*: unstandardized regression coefficient beta, *SE:* standard error, CI: 95% confidence interval, MVPA: moderate-to-vigorous physical activity. All analyses were adjusted for age, sex, educational level, BMI, cancer type, and time since diagnosis. Continuous variables building interactions terms were mean-centered. For linear regression analyses, a heteroscedasticity-consistent standard estimator was used.

[a] *N* = 1,002. Pre- and post-diagnosis MVPA were entered as binary variables, coded as 0 = '0 min MVPA'; 1 = '≥ 1 min MVPA'.

[b] Only cases with ≥ 1 min post-diagnosis MVPA, *N* = 845. Pre- and post-diagnosis MVPA were entered as continuous, log-transformed variables.

[c] Weighted sumscore of 5A counseling steps, ranging from 0 to 5.

[d] Satisfaction with exercise counseling, Likert scale from 1 = 'very unsatisfied' to 5 = 'very satisfied'.

[†] Modified from Depenbusch et al. (2020).

The results showed that a higher 5A score was significantly associated with higher satisfaction levels in both phases (phase 1: $B = 0.44$, 95% CI [0.38, 0.50], $p < .001$; phase 2: $B = 0.42$, 95% CI [0.35, 0.49], $p < .001$), irrespective of individuals' pre-diagnosis MVPA (phase 1: $p = .933$; phase 2: $p = .960$)

In the second model, the direct association between 5A score and post-diagnosis MVPA was tested at different levels of pre-diagnosis MVPA. The analyses revealed that the association of 5A score and post-diagnosis MVPA differed depending on patients' pre-diagnosis MVPA (Figure 7a/7b). In phase 1, previously inactive individuals with a higher 5A score were significantly more likely to perform any MVPA post-diagnosis ($B = 0.69$, 95% CI [0.19, 1.19], $p = .007$), whereas for previously active individuals, a higher 5A score did not increase the likelihood of performing any MVPA post-diagnosis ($B = 0.19$, 95% CI [-0.14, 0.52], $p = .264$). Accordingly, in phase 2, the 5A score was only significantly associated with post-diagnosis MVPA minutes among individuals with low pre-diagnosis MVPA values ($B = 0.11$, 95% CI [0.02, 0.20], $p = .014$), but not among individuals with medium ($B = 0.04$, 95% CI [-0.03, 0.12], $p = .237$) or high pre-diagnosis MVPA levels ($B = 0.00$, 95% CI [-0.09, 0.09], $p = .962$). Also, the effect of satisfaction with PA counseling on post-diagnosis MVPA differed by individuals' pre-diagnosis MVPA (Figure 7c/7d). In phase 1, higher satisfaction levels were significantly associated with an increased likelihood to perform any MVPA post-diagnosis among previously active individuals ($B = 0.33$, 95% CI [0.08, 0.58], $p = .009$), but not among previously inactive individuals ($B = -0.54$, 95% CI [-0.97, -0.12], $p = .013$). Corresponding to this, phase 2 revealed a significant association between higher satisfaction levels and more MVPA minutes for previously highly active individuals ($B = 0.10$, 95% CI [0.01, 0.19], $p = .037$), but not for individuals with medium ($B = 0.04$, 95% CI [-0.04, 0.11], $p = .305$) or low pre-diagnosis MVPA values ($B = -0.05$, 95% CI [-0.15, 0.04], $p = .267$).

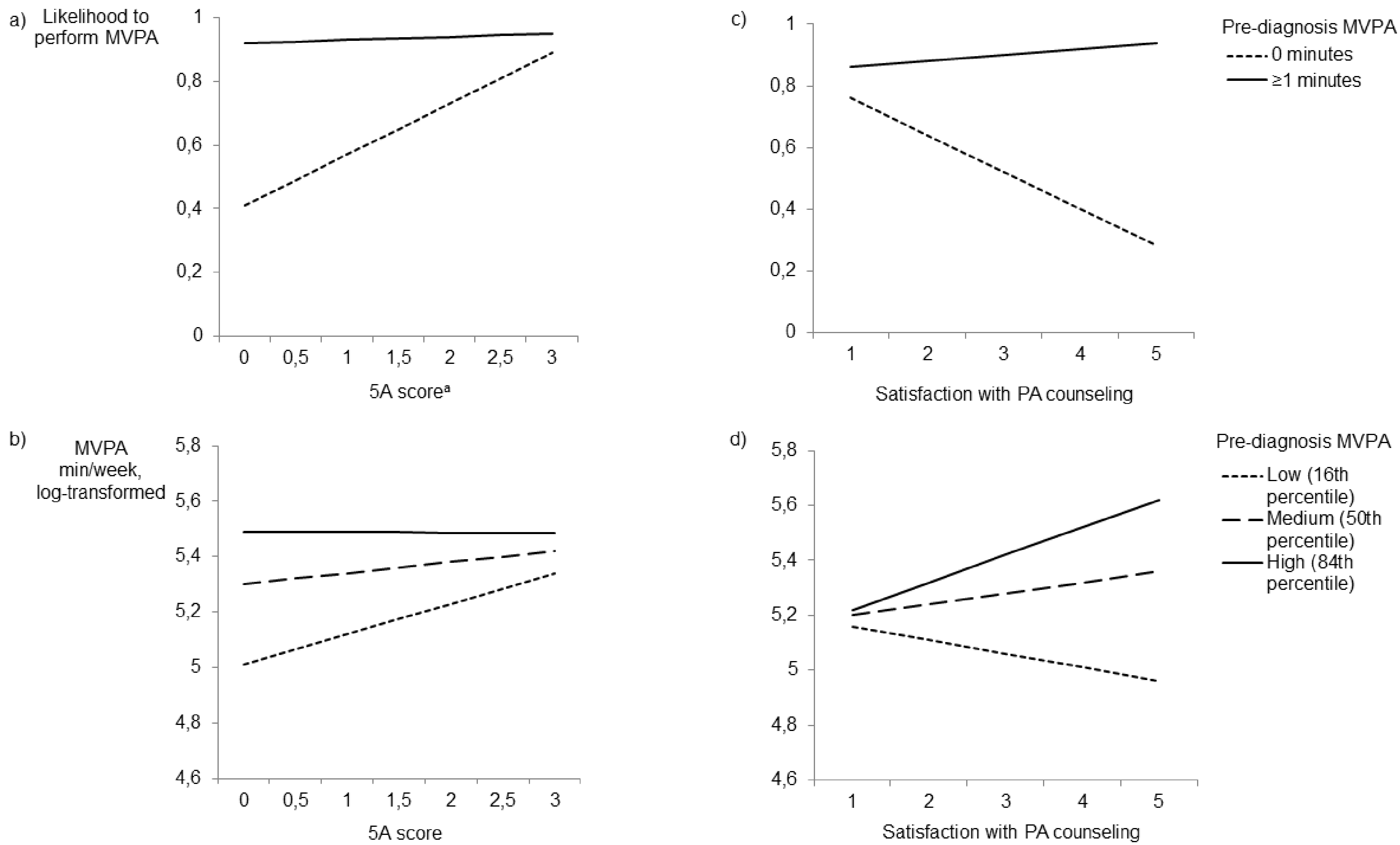

Figure 7. Association of exercise counseling and satisfaction with exercise counseling with post-diagnosis physical activity (PA) at different levels of pre-diagnosis PA

Notes. PA: physical activity, MVPA: moderate-to-vigorous physical activity. Modified from Depenbusch et al. (2020).
[a]Weighted sumscore of 5A counseling steps, ranging from 0 to 5.

In the third model, the full moderated mediation model was evaluated and the proposed pathways indeed confirmed, as shown in Table 14. The results yielded a direct impact of 5A score on whether individuals performed any MVPA post-diagnosis among previously inactive individuals (phase 1: $B = 0.69$, 95% CI [0.19, 1.19], $p = .007$) as well as on post-diagnosis MVPA minutes for the group with the lowest pre-diagnosis MVPA (phase 2: $B = 0.11$, 95% CI [0.02, 0.20], $p = .014$). In contrast, satisfaction with counseling mediated the effect of the 5A score on the likelihood of performing any post-diagnosis MVPA among previously active individuals (phase 1: $B = 0.42$, 95% BootCI [0.04, 0.25]) and on post-diagnosis MVPA minutes among group with the highest pre-diagnosis MVPA (phase 2: $B = 0.04$, 95% BootCI [0.01, 0.08]).

Table 14. Conditional direct and indirect effects of physical activity (PA) counseling on post-diagnosis moderate-to-vigorous PA (MVPA) at different levels of pre-diagnosis MVPA[†]

	Conditional direct effect				Conditional indirect effect[a]		
Moderator value [pre-diagnosis MVPA]	*B*	*SE*	*p*	95% CI	*B*	Boot *SE*	Boot 95% CI
Phase 1							
0 min pre-diagnosis MVPA	0.69	0.26	**.007**	**[0.19, 1.19]**	-0.24	0.11	[-0.50, -0.07]
≥1 min pre-diagnosis MVPA	0.19	0.17	.264	[-0.14, 0.52]	0.14	0.05	**[0.04, 0.25]**
Phase 2							
Low MVPA levels [16th percentile]	0.11	0.05	**.014**	**[0.02, 0.20]**	-0.02	0.02	[-0.06, 0.02]
Medium MVPA levels [50th percentile]	0.04	0.04	.237	[-0.03, 0.12]	0.02	0.02	[-0.01, 0.05]
High MVPA levels [84th percentile]	-0.00	0.05	.962	[-0.09, 0.09]	0.04	0.02	**[0.01, 0.08]**

Notes. $N = 1{,}002$. Bold values indicate $p < .05$. *B:* unstandardized regression coefficient beta, *SE:* standard error, CI: 95% confidence interval, MVPA: moderate-to-vigorous physical activity. All analyses were adjusted for age, sex, educational level, BMI, cancer type, and time since diagnosis. Continuous variables building interactions terms were mean-centered. For linear regression analyses, a heteroscedasticity-consistent standard estimator was used.
[a] Indirect effect of PA counseling on post-diagnosis MVPA through satisfaction with PA counseling.
[†] Modified from Depenbusch et al. (2020).

4. Discussion

The present dissertation provides valuable new insights into change patterns and determinants of physical activity in people with cancer. Although research on PA among people with cancer has evolved over the past decades and empirical evidence suggests numerous health benefits of PA after a cancer diagnosis, majority of individuals with cancer do not perform sufficient levels of activity. Despite prior efforts to investigate how a cancer diagnosis affects PA behavior, several questions have still remained unanswered. As described in the introduction, previous studies have assessed the change in PA from pre- to post-diagnosis and identified sociodemographic and medical determinants as well as external factors that seem to impact PA behavior after the diagnosis. However, detailed analyses of change patterns with regard to different PA intensities and cancer types are lacking, just as more comprehensive investigations of influencing factors, including their potentially underlying mechanisms. The current dissertation aimed to address these shortcomings and to gain a more profound understanding by analyzing unresolved research questions in a large sample of breast, prostate, and colorectal cancer patients using solid methodological approaches. The results yielded that an encouragingly high number of cancer patients reported sufficient post-diagnosis PA levels, thereby emphasizing the relevance of individuals' previous PA behavior. Nevertheless, certain subgroups were identified that, based on their sociodemographic and medical profile, had an increased likelihood of becoming or remaining insufficiently active after the diagnosis. Further, the analyses demonstrated that structural barriers might exacerbate, while physicians' exercise counseling may facilitate post-diagnosis PA behavior, both effects for which pre-diagnosis PA behavior appeared to play a moderating role.

The following sections are going to discuss the results of the dissertation regarding PA change patterns and determinants by evaluating the findings against the backdrop of existing literature and drawing inferences not only for future research but also for their implementation into clinical practice. Parts of this discussion resemble publications associated with the dissertation (Depenbusch et al. 2020; Depenbusch et al. 2021; Steindorf et al. 2020).

4.1. Changes in physical activity from pre- to post-diagnosis

Previous research examining changes in PA behavior from before to after a cancer diagnosis came to the predominant consensus that most individuals decrease their PA levels (Eng et al. 2018; Fassier et al. 2016; Huy et al. 2012; Schmidt et al. 2017). This was partially confirmed in the current analysis as overall participants reported significantly lower post-diagnosis PA levels with a particularly strong decrease of higher-intensity activities, which accordingly led to a smaller proportion of individuals meeting PA guidelines. However, with almost 55% of participants meeting PA guidelines after the diagnosis, the number of sufficiently active cancer patients was encouragingly high. In contrast to the observation of generally insufficient activity behavior in prior research (Avancini et al. 2020a; Eng et al. 2018; Galvao et al. 2015; Ramirez-Parada et al. 2019), a few more recent studies pointed to similarly high PA levels with more than 50% of individuals being classified as sufficiently active (Dibble et al. 2021; Price et al. 2021; Tollosa et al. 2019). The classification and evaluation of the four PA change patterns (‘maintainers’, ‘decreasers’, ‘increasers’, and ‘consistently inactives’) enabled to further refine PA trajectories and revealed that most of the individuals who were sufficiently active after the diagnosis had already complied with PA guidelines before the diagnosis, i.e., were categorized as ‘maintainers’. The fact that consistently inactive individuals accounted for the second largest share after ‘maintainers’ implies that majority of individuals do not change their PA behavior from pre- to post-diagnosis but either maintains their high activity levels or remains insufficiently active. This strengthens findings of previous research in which a comparable distribution of change patterns was reported, although in the current study the percentages were higher for ‘maintainers’ (43% vs. 26-33%) and lower for ‘consistently inactives’ (28% vs. 40-45%) (Gjerset et al. 2011; Stone et al. 2019a). The considerably high PA levels in the current study might reflect the previously mentioned paradigm shift towards more positive views on PA. Recent analyses on patients' attitudes towards PA in the same study sample indeed confirmed that patients' agreement with statements reflecting the activity-paradigm was significantly higher than with those referring to the rest-paradigm (Haussmann et al. submitted). Similarly, positive attitudes were reported in a study among 905 people with cancer with 80% disagreeing that cancer patients should not be physically active and more than 60% approving that PA could make them feel better and help them in coping with the disease (Höh et al. 2018). If this increased awareness about the benefits of PA for cancer patients has contributed to desirable improvements in PA behavior, it appears worthwhile to identify and strengthen its reinforcing sources. In this regard, the importance of HCP' PA counseling has been widely acknowledged in the literature and particularly physicians seem to realize some form of PA counseling in their clinical routine more and more frequently as results of the Momentum study among HCP have shown (Haussmann et al. 2018a). The actual impact of physicians' PA counseling for cancer patients' post-diagnosis PA will be discussed in greater detail in section 4.2.3. Beyond the potential to provide information in the context of medical care, the internet seems to gain increasing popularity as an education tool for people with cancer. This was, for instance, shown in a recent study, where 35% of patients who had sought out information about PA named the internet as their primary source (Höh et al. 2018). Apparently, the internet displays a promising medium for easily accessible and up-to-date information that can facilitate patient empowerment (Kuijpers et al. 2013; Prochaska et al. 2017; Sawesi et al. 2016) and its great potential has been underlined during the 2019 Annual Meeting of the Multinational Association of Supportive Care in Cancer (MASCC) (Chan et al. 2020). However, given that cancer patients still often seem to feel insecure about information from the internet (Höh et al. 2018), it should be further explored how such information need to be designed and promoted to convey trustworthiness and consequently help to improve patients' activity behavior.

In advantage to previous research on PA in patients with cancer, the current study allowed a direct comparison of pre- to post-diagnosis change trajectories between individuals with breast, prostate, and colorectal cancer and indeed detected differences in their activity behavior. While prostate cancer patients strongly decreased their PA irrespective of intensity, colorectal cancer patients indicated to perform significantly less MVPA post-diagnosis. For both cancer types, the decline resulted in a substantially lower number of individuals complying with PA guidelines after the diagnosis. A different trajectory emerged for breast cancer patients, who seemed to shift their PA behavior from vigorous- to lighter-intensity activities after the diagnosis and were the only group with a descriptively increased proportion of patients meeting PA guidelines. This difference was also reflected in the distribution of the four change patterns with prostate and colorectal cancer patients having higher proportions of 'decreasers' than breast cancer patients, who in contrast had a higher share of 'increasers'. The findings are in line with previous research that highlighted positive behavior changes among breast cancer patients in general (Steinhilper et al. 2013) as well as in comparison to other cancer types (Fassier et al. 2016; Hawkins et al. 2010). However, it has to be noted that prostate and colorectal cancer patients already reported significantly more PA concerning the time before the diagnosis not only in the current but also in prior studies (Demark-Wahnefried et al. 2000; Kwon et al. 2012). As higher initial values naturally allow more room for decrease, the findings could be attributable to the statistical phenomenon of regression to the mean (Davis 1976) as previously described in a study yielding comparable results (Fassier et al. 2016). Research using objective measurements of PA could therefore help to verify to what extent the proposed differences in PA levels between cancer types actually reflect behavioral differences or are attributable to potential biases in self-reports.

The investigation and discussion of change in PA levels after the cancer diagnosis lay a foundation for the identification of factors that determine post-diagnosis PA behavior. In the following sections, results on PA determinants will be discussed, also with regard to differences between cancer types and potentially modifying factors. First, the discussion focuses on findings regarding sociodemographic and medical determinants (section 4.2.1), before results regarding structural barriers and physicians' exercise counseling are going to be discussed in section 4.2.2 and 4.2.3, respectively.

4.2. Determinants of post-diagnosis physical activity

4.2.1. Patients' sociodemographic and medical characteristics

To determine, which individuals are most likely to be (in)sufficiently active after the cancer diagnosis, sociodemographic and medical characteristics associated with post-diagnosis PA were analyzed in the overall sample as well as for each cancer type. The analyses among all participants confirmed the seemingly positive behavior change among breast cancer patients by showing that individuals with breast cancer were more likely to be meeting PA guidelines post-diagnosis than prostate and female colorectal cancer patients. Since breast and prostate cancer constitute gender-specific diagnoses, a potential confounding of the association by sex cannot be completely excluded. However, the significant difference between women with breast and women with colorectal cancer indicates that the effect can at least partially be explained by cancer type. Adjustments of the analysis for other potentially confounding factors that are distinctive for each cancer type, such as age, disease stage, or treatment type and status, further strengthen the assumption. Whether or not patients were sufficiently active pre-diagnosis turned out as the strongest predictor of the compliance with PA guidelines after the diagnosis. This is consistent with previous research among breast cancer patients (Anderson et al. 2017; Boyle et al. 2016; Schmidt et al. 2017), colorectal cancer patients (Hawkes et al. 2015), and a sample of patients undergoing chemotherapy (Midtgaard et al. 2009). The undeniable relevance of pre-diagnosis PA behavior stresses the need not only to improve PA behavior in the oncology setting but to already strive for greater PA promotion in the general public. Given that physically active individuals have a significantly reduced risk to develop cancer (Matthews et al. 2020; McTiernan et al. 2019; Patel et al. 2019), improving pre-diagnosis PA does not only appear beneficial for cancer patients after the diagnosis, but could more importantly contribute to a reduction of cancer incidences in the first place.

Besides being the strongest predictor of post-diagnosis PA, sufficient pre-diagnosis activity levels were further the only factor that was significantly associated with post-diagnosis PA across all three cancer types. Other determinants in contrast differed between cancer types, which might be attributable to their unique sociodemographic profiles as well as standard treatment procedures. For instance, BMI was only significantly negatively linked to post-diagnosis PA among individuals with breast cancer. This is in line with previous research highlighting the role of BMI for PA among breast cancer patients (Coletta et al. 2019; Kampshoff et al. 2016; Sabiston et al. 2014; Stone et al. 2019b) as well as with a study that detected a similar difference in the association between cancer types (Forbes et al. 2014). A possible explanation could be that weight gain and changes in body composition are highly prevalent among breast cancer patients during and after chemo- and hormone therapy (Ee et al. 2020; Sheean et al. 2012; van den Berg et al. 2017; Vance et al. 2011), both treatments which were significantly more often indicated by participants with breast than by those with prostate or colorectal cancer in the current study. Beyond a direct impact on PA engagement, the role of the BMI for patients' psychological well-being could have also contributed to differing associations between cancer types. This hypothesis is based on two studies among breast cancer patients showing that an unfavorable body composition was directly linked to a poorer body image and body-related shame, which in turn negatively affected PA behavior (Castonguay et al. 2017; Fazzino et al. 2017). Interestingly, having co-morbidities also only decreased the likelihood of being sufficiently active among breast cancer patients. As their overall number of co-morbidities was comparable to that of colorectal and even lower than that of prostate cancer patients, it is conceivable that rather the type than the number of health conditions played a relevant role for the pursuit of post-diagnosis PA. In this regard, breast cancer patients reported to suffer from depressive symptoms more often than prostate and colorectal cancer patients. Depressive disorders have been found to be strongly associated with low PA levels

(Schuch et al. 2017), likewise in a sample of breast cancer patients (Brunet et al. 2014), and might have also had a considerable impact on breast cancer patients' PA behavior in the current study. Since a low prevalence of some co-morbidities as well as potentially confounding effects in case of multiple co-morbidities did not allow to determine the unique contribution of each condition, their distinct role for cancer patients' PA behavior needs to be further explored in future research. Surprisingly, breast cancer patients with metastatic disease were significantly more likely to be meeting PA guidelines post-diagnosis than those having localized tumors. Previous research in contrast found negative associations between higher disease stages and PA (Gjerset et al. 2011; Knowlton et al. 2020), which might potentially be attributable to generally lower physical functioning and poorer health among cancer patients with advanced disease. However, one study indicated that despite lower average physical fitness levels, some patients with advanced breast cancer exceeded the fitness capacity of people with no disease (Yee et al. 2014). This finding points to a wide range of physical conditions among metastatic breast cancer patients and suggests that these individuals might also be interested in and capable of performing PA. To date, studies on PA among people with advanced disease are scarce, but first evidence suggests that exercise programs for people with metastatic breast cancer are safe and feasible (Heywood et al. 2017). This has led to efforts for more detailed investigations regarding PA among metastatic breast cancer patients in the scope of the multinational EU Horizon 2020 funded project 'PREFERABLE', in which I have been working as a study coordinator in the study center Heidelberg. First results regarding attitudes, barriers, facilitators, and preferences for PA among people with advanced breast cancer are expected to be published by the end of 2021.

Looking at determinants of sufficient post-diagnosis PA among prostate cancer patients revealed that for this patient group, treatment-related variables seemed to play a more important role than sociodemographic characteristics, which is in accordance with previous research (Forbes et al. 2014). In this respect, prostate cancer patients having been treated with hormone therapy had a significantly lower likelihood of being sufficiently active, potentially due to unfavorable changes in body composition, lower physical functioning, and increased fatigue levels caused by androgen deprivation therapy, which constitutes a standard systemic treatment for prostate cancer (Cornford et al. 2017; Haseen et al. 2010; Liede et al. 2016). Chemotherapy treatment, which also exerted a negative impact on post-diagnosis PA, is usually applied at a more advanced stage of prostate cancer (Cornford et al. 2017) and might therefore reflect a poorer physical condition and overall health. Surprisingly, the results yielded that prostate cancer patients currently receiving any kind of cancer treatment were more likely to be meeting PA guidelines post-diagnosis than those who had already completed or were yet to receive therapy. The positive association appears counterintuitive, given that prostate cancer treatment and its side-effects are oftentimes considered as barriers for PA (Yannitsos et al. 2020). The result is nevertheless encouraging, as RCTs have demonstrated several beneficial effects of exercise at therapy onset (Cormie et al. 2015; Taaffe et al. 2017) and a systematic review confirmed the safety of appropriately prescribed exercise during prostate cancer treatment (Gardner et al. 2014). However, the result has to be interpreted with caution since a low number of patients in this subgroup (n = 73, 21.5%) could have led to an overestimation of the effect, which is further reflected by a large confidence interval of the effect and therefore requires further clarification in follow-up research.

Summing up, the differing associations of sociodemographic and medical characteristics and sufficient post-diagnosis PA between the three cancer types demonstrate that the discussed predictors cannot be regarded as independent determinants but should always be appraised in consideration of other prevailing clinical and demographical characteristics of each cancer type. A classification tree analysis building upon the logistic regression results allowed the testing of such combinations of sociodemographic and medical characteristics, thereby enabling the identification of distinct patient subgroups that were most or least likely to be meeting PA guidelines after the diagnosis. Looking at sufficient post-diagnosis PA, the analyses revealed that the group of previously sufficiently active individuals with a longer time since diagnosis and higher educational levels was most likely to maintain high PA levels and therefore had the largest proportion of individuals meeting PA guidelines. Despite insufficient pre-diagnosis PA, the group of breast cancer patients having no co-morbidities had the highest likelihood of increasing their activity to sufficient PA levels after the diagnosis. Comparable results were obtained in a previous study among breast cancer patients with the group of women with no or low co-morbidities, a university degree, and above average pre-diagnosis PA levels being most likely to be sufficiently active post-diagnosis (Boyle et al. 2016). In contrast, the current analyses yielded a high tendency for negative PA change patterns for the group of previously insufficiently active prostate cancer patients in terms of remaining insufficiently active and for previously active patients who had been diagnosed more recently and were treated with chemotherapy in terms of becoming insufficiently active. These results imply that the time shortly after the diagnosis and during treatment might constitute a crucial window to introduce PA interventions, consistent with the above-mentioned theory of the teachable moment. Considering that appropriately tailored exercise shortly after the diagnosis and during cancer treatment is regarded as safe (Campbell et al. 2019; Jones and Alfano 2013; Schmitz et al. 2010b) and highly beneficial (Bradshaw et al. 2014), efforts should be made to promote PA during this particular time.

4.2.2. Structural barriers for physical activity

Although most people with cancer acknowledge the benefits and have positive attitudes towards PA (Haussmann et al., submitted; Roth et al. 2020; Smith et al. 2017), many of them nevertheless fail to maintain or increase their activity levels after the diagnosis. It is thus conceivable that cancer patients experience certain barriers preventing them from being sufficiently active. While the relevance of physical and disease-related barriers for PA after a cancer diagnosis has been extensively demonstrated in the literature, research on structural barrier is still scarce. The current study addressed this gap and revealed a highly perceived impediment for PA by structural barriers with more than 50% of individuals agreeing that a lack of therapeutic programs reimbursed by health care insurances as well as a missing contact person specialized in exercise oncology counseling and treatment kept them from performing PA. In accordance with a previous study, in which 52% of participants indicated to be unaware of available PA programs (Fernandez et al. 2015), almost half of the participants in the current study further considered a lack of PA offers designed for people with cancer as a barrier for PA. In contrast, with only 30% and 16%, respectively, much fewer individuals reported a lack of overall PA offers or a lack of parks, walking, running and cycling paths, or public pools in the neighborhood. The prevalence of barriers describing a lack of PA offers and support that is specifically tailored to the situation after a cancer diagnosis emphasize the desire for more support and possibilities for PA in a disease-adjusted setting. This assumption is reaffirmed by previous studies looking at facilitators and preferences for PA among cancer patients, where majority of individuals expressed the wish for their individual abilities and disease states to be taken into account (Avancini et al. 2020b; Blaney et al. 2010).

A precise targeting of strategies aiming to reduce the impediment by structural barriers requires a detailed understanding of which individuals feel most challenged by these obstacles. This is why patient characteristics associated with a stronger perception of impediment by structural barriers were investigated. The analyses revealed that individuals with a higher BMI and lower educational levels appeared to be more susceptible to the perception of different structural barriers, which refines findings of a previous study that yielded significant associations between obesity as well as lower educational levels and a higher overall barrier score in a sample of 662 cancer patients (Romero et al. 2018). Among these individuals, the perception of structural barriers could presumably lower the intention to initiate PA and therefore partially explain why cancer patients with a higher BMI and lower educational levels generally seem to be less inclined towards PA (Forbes et al. 2014; Schmidt et al. 2017; Steindorf et al. 2020). Consistent with Romero et al. (2018), a younger age was also significantly associated with higher impediment by structural barriers, although younger individuals have been shown to be generally more active after the diagnosis (Eng et al. 2018; Kampshoff et al. 2016; Lynch et al. 2016). A possible explanation for the rather counterintuitive finding could be that younger cancer patients are faced with higher work pressure or family duties (Adamsen et al. 2017), which might prevent them from searching for possibilities to maintain their PA after the diagnosis. With regard to medical determinants, a significant association of co-morbidities and stronger PA impediment by structural barriers emerged, implying that health issues and physical restrictions might not only directly limit the physical ability to perform PA (Blaney et al. 2013; Fisher et al. 2016), but could also lead to insecurities regarding safety of exercising. Therefore, patients with co-morbidities might need specific guidance and support on how and where to safely perform PA.

As expected, individuals who experienced stronger impediment by structural barriers were considerably more likely to be insufficiently active after the diagnosis. This result supports previous findings describing a 15% decrease in the likelihood of meeting PA guidelines five months post-diagnosis among colorectal cancer patients who were faced with structural barriers (Lynch et al. 2010). However, while Lynch et al. (2010) mostly referred to the physical environment and calculated an overall barrier score, the current analyses enabled the evaluation of thematically different structural barriers, which revealed a lack of information material to most strongly affect post-diagnosis PA behavior. The issue of lacking information regarding PA has been demonstrated in previous studies explaining that missing as well as vague or inconsistent information caused fear and concern about PA and inferring that cancer patients were consequently longing for safe and effective exercise guidelines (Browall et al. 2018; Lavallée et al. 2019; Nielsen et al. 2020; Sander et al. 2012). Providing information material constitutes a time-efficient hence convenient strategy to prevent patients' insecurity about PA. As previous qualitative research has revealed credible information about benefits of PA and possibilities to exercise as facilitators for PA engagement (Avancini et al. 2020b) and an RCT actually pointed to its effectiveness in increasing activity levels (Vallance et al. 2007), it appears necessary to establish and enhance the access to evidence-based educational material for cancer patients. Future research should explore which presentation modalities and distribution channels are best accepted by cancer patients in this respect. Looking at the remaining barriers illustrated that rather than the local environment, lacking disease-adjusted PA offers prevented cancer patients from being sufficiently active, which has already been elaborated in previous literature (Elshahat et al. 2021). Furthermore, the results showed that also missing expert contact persons as well as limited financial reimbursement for PA programs were associated with insufficient post-diagnosis PA. These results hold important practical implications, suggesting that it might not be sufficient to provide appropriate exercise programs for people with cancer. Instead, an informative communication as well as medical and financial support appear to be crucial for a successful uptake of exercise programs after a cancer diagnosis.

Considering that pre-diagnosis PA behavior has been revealed as the strongest determinant of PA after the diagnosis (Boyle et al. 2016; Steindorf et al. 2020), the impact of structural barriers on insufficient post-diagnosis PA was further explored in subsamples divided by whether or not participants were meeting PA guidelines pre-diagnosis. Interestingly, the perception of structural barriers did not significantly influence the change patterns of patients who were already insufficiently active pre-diagnosis. One possible explanation could lie in the statistical phenomenon of a floor effect, meaning that individuals who did not perform PA previously were not faced with structural barriers simply due to their inactivity. However, it is also conceivable that other factors such as social-cognitive constructs like intentions or behavioral control may have a greater impact on whether less exercise experienced cancer patients initiate PA after the diagnosis. The hypothesis implies that these individuals could benefit from fundamental support aiming at increasing their awareness and intention for PA. As the current analyses were of exploratory nature, such factors were however not yet considered and thus require further investigation in follow-up analyses. In contrast, a significant impact of structural barriers was found for the change patterns of cancer patients, who were complying with PA guidelines pre-diagnosis. Possibly, these patients might have had difficulties to maintain their previous activity due to newly experienced physical complaints or time restrictions caused by cancer treatment, but lack the knowledge on potential alternatives to continue exercising in their given circumstances. This could also explain why pre- to post-diagnosis declines in PA were shown to be stronger among individuals with higher pre-diagnosis PA levels when compared to less active individuals (Fassier et al. 2016; Huy et al. 2012). Particularly previously active cancer patients may therefore profit from targeted information and PA programs that are compatible with their situation after the diagnosis.

4.2.3. Physical activity counseling by physicians

The previous section on structural barriers has pointed out the detrimental effect of lacking information for cancer patients' post-diagnosis PA. One potential strategy to address this barrier could be a comprehensive exercise counseling, which, according to prior research, is desired by 70-80% of cancer patients during the time of cancer diagnosis and treatment (Murnane et al. 2012; Vallance et al. 2013). In this regard, physicians were rated as patients' favored information source (Elshahat et al. 2021), but shown to only scarcely provide the desired counseling (Demark-Wahnefried et al. 2000; Fisher et al. 2015; Kenzik et al. 2016). The counseling situation has, however, mostly been assessed in a rather unspecific manner. The present study used the 5A framework (Estabrooks and Glasgow 2006) as a means to gain a more comprehensive understanding of patients' perception of physicians' exercise counseling and its effect on post-diagnosis PA behavior, also in consideration of potentially underlying mechanisms.

To begin with, the analysis of the frequencies of single 5A steps yielded that almost a fifth of patients had not received any PA counseling or was even advised against PA. Although lower than previously reported (Kenzik et al. 2016), this number is still causing concern considering that some patients might miss out on the chance to improve their health and well-being due to lacking or fallacious information. However, consistent with findings of a large observational study among more than 900 cancer patients (Höh et al. 2018), the 5A counseling steps 'assess' and 'advise' seemed to be quite commonly implemented as indicated by 45% and 68% endorsement, respectively. This result appears encouraging as Schmitz et al. (2019) have recently defined the assessment of current PA behavior as a crucial step for successful exercise counseling. The authors explained that asking about PA can create the impression of physicians perceiving PA, just like other vital signs, as important for the patients' functioning and recovery. More profound counseling steps were in contrast only rarely reported in the current sample, which is in accordance with previous studies among cancer patients (Craike et al. 2011) and HCP (Hardcastle et al. 2018; Ligibel et al. 2019) and could be due to physicians' perception of certain barriers. Reviewing the body of literature regarding physicians' barriers to exercise counseling yielded that physicians often claim a lack of time, no qualification or training on exercise prescriptions, lack of resources, and limited knowledge about where to refer patients for PA as barriers to provide a comprehensive exercise counseling (Dennett et al. 2020; Hardcastle et al. 2018; Haussmann et al. 2018a; Nadler et al. 2017; Spellman et al. 2014). In this regard, a recent analyses of the Momentum study among 917 HCP found the barrier 'not enough time per patient' to be most impeding for PA promotion, followed by 'lack of structured and reimbursed therapeutic programs' and 'lack of expert contact persons' (Haussmann et al. 2018b). Given that the perception of barriers to counsel on PA was actually associated with less PA promotion (Haussmann et al. 2018b; Williams et al. 2015), it appears crucial to tackle this issue, e.g., by providing physicians with concise information about PA in the oncology setting as well as concrete points of contact where patients can be referred to. However, according to Nadler et al. (2019), it might not be sufficient to only provide information, but essential to ensure that physicians have the required tools to transfer their gained knowledge into practice. In this context, specific knowledge translation strategies that are designed to identify and consequently help to overcome individual barriers for exercise counseling could effectively support the knowledge translation process (Nadler et al. 2019).

To get a better insight into the mechanisms by which physicians' exercise counseling influences cancer patients' post-diagnosis PA behavior, a moderated mediation model was analyzed. The results revealed different mediation pathways for the effect of counseling depending on the individuals' pre-diagnosis PA levels, which implies that physicians' PA promotion could be particularly effective when tailored to the patients' exercise experience. Individuals with less PA experience, for whom exercise counseling was directly linked to higher PA levels, might already benefit from a standard counseling targeting their awareness and motivation for PA. In contrast, for previously highly active individuals the effect of PA counseling on post-diagnosis PA was mediated by satisfaction with counseling. Since satisfaction levels were correlated with a more comprehensive PA counseling, previously physically active cancer patients might require more profound advice on how and where to continue exercising in the presence of disease-related health issues. Since none of the previous studies investigating the impact of physicians' exercise counseling took patients' satisfaction with counseling into account, its mediating role could explain why merely a short recommendation to exercise was not found to affect PA behavior in previous studies (Park et al. 2015; Vallance et al. 2007), whereas regular counseling led to the maintenance of increased PA levels (Pinto et al. 2013). Hence, the current findings once more underline the importance of refraining from unspecific PA recommendations and instead moving towards more comprehensive counseling, which should ideally be based on the assessment of prior activity behavior to ensure suitable PA advice and referral.

Despite the promising results, it remains debatable whether it is in the physicians' scope to cover all counseling steps. According to Adams et al. (2018), the screening, advising, and designing of PA could be overburdening for physicians, who, in their opinion, should rather take an intermediary role to support the transition to suitable PA programs. This view was partially shared by physicians themselves, who in more than 50% of the cases did not consider PA counseling as their responsibility (Spellman et al. 2014). However, given that the interaction with physicians is valued as highly credible and motivating by cancer patients (Cantwell et al. 2020; Monteiro-Guerra et al. 2020), the goal should be to engage physicians in PA counseling in an efficient and feasible manner. Accordingly, previous studies have examined factors that enhance the provision of exercise counseling and detected education sessions, patient handouts, and the collaboration with exercise specialists as the most frequently rated facilitators (Nadler et al. 2017). The latter seems to be of particular importance as the expertise from exercise professionals has been shown to be not only highly appreciated by physicians but also by cancer patients (Avancini et al. 2020b; McGowan et al. 2013a; Wong et al. 2018). Thus, establishing broader, multidisciplinary exercise networks constitutes a key point for the successful implementation of PA counseling into clinical routine as a means to eventually improve cancer patients PA behavior.

4.3. Strengths and limitations

The present dissertation involved a detailed investigation of cancer patients' pre- to post-diagnosis PA change patterns as well a comprehensive evaluation of certain factors determining PA behavior after the diagnosis. The research was novel and gainful in many aspects; however, some limitations need to be considered. Both strengths and limitations are going to be outlined with regard to the study sample, data assessment, and the statistical analyses of the four objectives.

The current study was part of the large-scale Momentum Project and comprised a large sample of breast, prostate, and colorectal cancer patients. These cancer types are not only among those with the highest prevalence in Germany (Robert Koch-Institut and Gesellschaft der epidemiologischen Krebsregister in Deutschland e.V. 2019), but also for which the beneficial effects of exercise have been well documented (Patel et al. 2019). It therefore appears highly relevant to gain a better understanding of PA behavior particularly among these patient groups. With a total of 1,299 participants, the study sample was quite large and by far exceeded that of most previous studies in this field (cf. Table 1). Although the number of participants slightly differed between the cancer types, the large number of individuals from each cancer type still provided a sufficient basis for subgroup analyses, including profound comparisons between the different cancer types. This further constitutes a major advantage of the current study as, to my knowledge, only one previous study has compared post-diagnosis PA behavior and determinants between different cancer types (Forbes et al. 2014). However, it has to be noted that despite the large study population, the response rate for the paper-and-pencil questionnaire was rather low and the sample might be subject to a selection bias in the sense that preferentially cancer patients with a higher propensity for PA might have participated. To reduce this potential risk, the description of the study did not reveal its focus on PA behavior, but instead claimed to investigate self-management strategies for cancer patients in general. It is nevertheless conceivable that patients who are interested in self-management strategies are also more inclined to engage in PA, especially considering that PA constitutes the most common self-management strategy among cancer patients (Shneerson et al. 2015; Sieverding et al. 2020).

To acquire data in a reliable and comprehensive manner, validated assessment tools as well as novel items were used. However, the data collection as retrospective self-report could have led to certain biases, particularly with regard to the assessment of PA behavior. On the one hand, some participants could have answered PA items in a socially desirable fashion. Social desirability is defined as 'the tendency for people to present a favorable image of themselves on questionnaires' (van de Mortel 2008, pg.40), implying that individuals indicated higher PA levels than actually performed. On the other hand, a memory bias, i.e., incorrect or incomplete answers due to a temporal delay of data assessment, cannot be excluded. Previous studies have indeed detected biases in PA reports in the sense that cancer patients generally tend to overestimate their PA in self-reports when compared to objective measurements (Boyle et al. 2015). However, the currently used GSLTPAQ has shown substantial agreement (70.8%) with the accelerometer coding system for the classification of PA guidelines (Amireault et al. 2015) and its widespread use in the literature allows a reliable appraisal of the current results in the context of prior studies. Besides the recall of PA behavior, the memory bias could have further affected the description of physicians' exercise counseling. In this regard, a previous study found that 41% of participants in an RCT incorrectly recalled the exercise recommendation given during the consultation (Jones et al. 2004). It is however conceivable that the detailed descriptions of single counseling steps of the 5A framework as provided in the current study could have served as prompts for patients to better reconstruct the situation. Despite the 5A framework allowing a much more detailed look at the counseling situation, which is a clear advantage compared to previous studies, there are no guidelines on how to use the framework in an analytical manner. Originally, all 5A steps are deemed important in encouraging individuals for behavior change. However, since heterogeneous combinations of counseling steps in the present sample showed that the 5A framework cannot necessarily be regarded as a linear or stepwise approach, a weighted sum score was considered to best reflect the comprehensiveness of physicians' PA counseling. The establishment of guidelines on how to apply the 5A framework would nevertheless be useful to facilitate and standardize its use in future research.

With regard to data analyses, it should be stressed that throughout the whole study, advanced statistical approaches were used to enable profound insights into the research objectives. First and foremost, multivariate statistical methods such as multiple linear and logistic regression analyses ensured that all analyses were adjusted for potentially confounding factors. This appears highly necessary for a correct interpretation of the results but has oftentimes been neglected in previous studies, e.g., regarding sociodemographic and medical determinants of PA, where only bivariate associations were tested (e.g., Coletta et al. 2019; Forbes et al. 2014; Ramirez-Parada et al. 2019). In addition, complementary statistical approaches such as classification tree analyses or conditional process analyses were conducted to examine the interaction of different PA determinants as well as underlying mechanisms of proposed associations in a precise way. It has to be noted that all statistical analyses were carried out as complete case analyses, which led to slightly differing samples across the objectives and might thus limit the external validity of results. Further, it should be noted that albeit the adjustment of all analyses for patients' sociodemographic and medical characteristics, other potential covariates that might be relevant for PA behavior, e.g., psychological variables like attitudes or intentions towards PA, have not yet been considered. Beyond merely controlling for these factors, it would be interesting to actively explore their role for post-diagnosis PA, also regarding the interplay with patients' perception of physicians' exercise counseling or structural barriers.

Finally, the cross-sectional nature of the study yet facilitated a comprehensive assessment of a wide range of PA-related variables in a large sample of cancer patients, but does not allow to draw any causal inferences and therefore limits the validity of results. Possible strategies to avoid this as well as the preceding limitations will be discussed in the following section.

4.4. Future research directions

The present study addressed shortcomings of previous research in terms of content and methodology and produced inspiring results. Considering the above-mentioned limitations, it may set the basis for a validation and extension of the current findings in future research. Some potential research questions for follow-up studies have already been raised in the previous sections. The following future research directions will provide further concrete suggestions for methodological approaches regarding data collection, research design, and study population.

Firstly, considering that in the current study all data was assessed using retrospective self-report, it seems important to validate the results by using more objective measurements. With regard to PA levels, objective measurements include, for example, heart rate monitoring, direct observations, accelerometers, or pedometers. Weighing the precision of tools against the user-friendliness and patients' acceptance, accelerometers have been defined as the most suitable PA measure in studies among cancer patients. Accelerometers are small devices that are usually worn on the waist, wrist, or ankle to measure the magnitude of the body's acceleration in one (uniaxial), two (biaxial), or three (triaxial) planes. The derived activity counts enable researchers to examine the whole movement spectrum, i.e., from sedentary behavior to VPA, and to define the PA type, frequency, duration, and intensity (Boyle et al. 2015; Broderick et al. 2014). However, wearable devices entail the risk of a mere-exposure effect, i.e., an increase of PA levels merely due to the awareness of being monitored, especially during the first days (Clemes and Parker 2009; Michie et al. 2009). Sealing the devices or starting the actual measurement after a short adaption period appear as useful countermeasures to ensure the validity of the assessment (Clemes and Parker 2009). Since also the recall of the physicians' PA counseling could be subject to a memory bias, it makes sense to moreover capture the counseling situation in an objective manner, which could, for instance, be realized via videotapes (Milder et al. 2008). For an objective validation regarding patients' perception of structural barriers, it seems meaningful to test whether the perceived barriers actually correspond to the given external conditions. A similar analysis has previously been carried out by Fisher et al. (2016), who analyzed whether the perception of 'age' and 'co-morbidities' as PA barriers was actually stronger among older patients and those with more comorbid health conditions and indeed found significant associations. Applying this approach to the perception of structural barriers could, for instance, entail a search of available exercise programs near the patients' home or the verification of (missing) cost coverage for exercise programs by health care insurances.

As a second step, to avoid limitations caused by cross-sectional data assessment, the current findings should be further validated in future research using longitudinal study designs. Concerning the association between patient characteristics and post-diagnosis PA, longitudinal data could enable a verification of the proposed relations by investigating whether changes over time, e.g., in treatment schemes or medical conditions, go along with changes in PA behavior. Likewise, analyzing the impact of physicians' exercise counseling as well as structural barriers in longitudinal research would clarify to what extent these factors lead to changes in patients' activity behavior over the course of the disease. These questions will partially be answered by the results of the longitudinal sub-study of the Momentum Project that entailed four different measurement timepoints in a twelve-week timeframe. Beyond longitudinal observational studies, the insights from the current study should further be translated into intervention studies using randomized controlled study designs. With regard to physicians' PA promotion, a more comprehensive counseling as defined by the 5A framework was found to improve patients' PA behavior, thereby highlighting the role of tailoring the promotion to the individual's exercise experience. Firstly, it seems necessary to validate the effectiveness of the approach for cancer patients' PA by testing the 5A counseling against usual care. If proven efficient, further interesting research questions based on the implications of the current study could be addressed, such as to what extent the single components of the 5A framework contribute to the effect or which strategies to support physicians would facilitate a widespread implementation of exercise counseling in clinical routine. Given that handouts for patients were previously shown to facilitate PA counseling for physicians (Nadler et al. 2017) and given that current analyses revealed a lack of information material to actually prevent cancer patients from performing PA, educational material for patients appear as a promising means to enhance physicians' PA counseling as well as to address patients' desire for more information. Thus, the effectiveness of informational material, such as brochures or videos, could be analyzed on its own or even simultaneously as part of physicians' counseling. Notably, the analyses of the current study repeatedly highlighted the interplay of patient characteristics, especially PA experience, in their effect on post-diagnosis PA. Therefore, it would be worthwhile to explore which components or modalities of PA promotion strategies, such as 5A counseling or educational material, are more or less effective for different patient subgroups.

At last, the current study covered a wide range of patient groups by involving participants of three major cancer types receiving different kinds of cancer treatments and therefore serves as a solid basis for the attempt to extend the results to other patient groups. It is conceivable that the suggested tailoring of PA promotion strategies towards patient characteristics might be particularly crucial for cancer types or disease stages that typically imply poorer physical functioning and overall health of those concerned. Although the current study included patients with metastatic disease, it might not have covered the full spectrum of patients in this regard. The remaining knowledge gap is currently partially being addressed in the EU Horizon 2020 funded project 'PREFERABLE'. Besides a large RCT, the project comprises a mixed-methods cross-sectional study exploring cognitions such as attitudes or barriers regarding PA among metastatic breast cancer patients, for which I will soon start analyzing the data. Results of this as well as further future studies among different cancer groups will eventually help to get a step closer towards a full understanding of PA behavior and its determinants among cancer patients across the disease spectrum.

4.5. Conclusion

The present dissertation provided valuable new insights into pre- to post-diagnosis change patterns of PA among people with cancer and contributed to a more comprehensive understanding regarding determinants of patients' post-diagnosis PA. Thereby, strong methodological approaches were used to evaluate the impact of individuals' sociodemographic and medical characteristics, structural barriers as well as physicians' exercise counseling. With the analyses being based on a sample of 1,299 breast, prostate, and colorectal cancer patients, the work did not only extend previous research with regard to its research questions but also in terms of the size and variety of the study sample.

The first objective of the current dissertation comprised the description of pre- to post-diagnosis PA change patterns as well as the identification of differences between the three studied cancer types in this regard. The results showed that although PA levels slightly decreased after the diagnosis, an encouragingly high number of over 50% reported to still be sufficiently active post-diagnosis. The analyses further revealed that change patterns of PA indeed differed between cancer types with more favorable behavior changes among breast compared to prostate and colorectal cancer patients. Notably, these differences were reflected in an assimilation of substantial pre-diagnosis differences after the diagnosis. The use of objective PA measurement in future research could help to validate PA change patterns and thus help to appraise the interesting findings.

With regard to determinants of post-diagnosis PA behavior, a considerably strong influence of pre-diagnosis PA was confirmed for all cancer types. This is why it seems crucial to not only encourage the promotion of PA in the post-diagnosis setting, but already in the general population. Other PA determinants were found to differ between cancer types, e.g., with educational levels, BMI, and co-morbidities predicting activity levels among breast cancer patients and treatment-related variables playing a role for PA among prostate cancer patients. These results may point to further important anchor points for more targeted PA interventions after the cancer diagnosis. Moreover, complementary statistical approaches that enabled the classification of subgroups with the highest likelihood of (in)sufficient post-diagnosis PA identified previously inactive prostate cancer patients as well as recently diagnosed patients currently receiving cancer treatment to be at particular high risk of remaining or becoming insufficiently active. Since low PA levels are associated with several secondary health issues, the results emphasize the need for tailored PA intervention strategies specifically addressing the respective patient groups.

Beyond the contribution of patient characteristics, the role of certain external determinants for (in)sufficient post-diagnosis PA, i.e., structural barriers and physicians' exercise counseling, was evaluated. Structural barrier analyses yielded that particularly barriers describing lacking disease-adjusted PA offers and support, such as a lack of tailored exercise programs, expert contact persons, or financial support, were regarded as impeding. However, the perception of structural barriers differed with regard to cancer patients' sociodemographic and medical characteristics in the way that individuals with a younger age, no current work activity, lower educational levels, a higher BMI, co-morbidities, and indications of a less comprehensive PA counseling by physicians reported higher PA impediment. Evidently, individuals who perceived higher impediments by structural barriers were more likely to be insufficiently active post-diagnosis. The association was especially prominent for barriers regarding lacking cancer-specific PA support with the strongest impact of the barrier 'lack of information material'. This implies that not only the implementation of tailored exercise programs but also improvements in patient education as well as medical guidance and financial support appear necessary to enhance PA behavior. Interestingly, structural barriers seemed to predominantly affect cancer patients with high pre-diagnosis PA levels but not those who were previously insufficiently active. Therefore, previously active individuals, although usually more likely to remain active after the diagnosis, might need particular support in overcoming structural barriers to maintain their PA levels.

Lastly, the impact of physicians' exercise counseling, as defined by the 5A framework, on cancer patients' PA was investigated. It was explored whether the association was mediated through satisfaction with counseling and whether the effect differed by the individuals' previous PA behavior. Majority of participants reported having been provided with a simple PA recommendation by their physician, whereas more profound counseling steps like setting goals or making referrals still seem to be only rarely undertaken. Results of this dissertation, however, indicated that a more comprehensive exercise counseling could actually influence cancer patients PA behavior. Remarkably, the contribution may occur via differing pathways based on patients' previous PA behavior: While for patients with low pre-diagnosis PA levels, a more comprehensive counseling was found to be directly associated with higher PA levels after the diagnosis, a mediation of the association by satisfaction was observed for previously highly active individuals. This finding stresses the importance of not only a comprehensive but also tailored promotion that is adjusted to the patients' exercise experiences. The 5A framework could be a convenient approach to implement this demand into clinical practice. However, as profound counseling steps do not yet seem to be well implemented into the counseling routine, support for physicians, e.g., by providing educational material or establishing interdisciplinary exercise networks, appears highly necessary.

Altogether, the current dissertation has demonstrated how breast, prostate, and colorectal cancer patients change their PA from pre- to post-diagnosis and to what extent certain factors determine whether or not these individuals are sufficiently active after the diagnosis. The novel results may serve as a basis for future research studies and inform the development of intervention strategies aiming to increase PA behavior after a cancer diagnosis. As the findings of the current dissertation point out that PA determinants cannot be regarded as independent factors but seem to interact with each other in their effect on post-diagnosis PA behavior, the goal should be to specifically tailor PA promotion strategies to the individual's characteristics, with particular attention to previous PA experience. Stepping away from a 'one-size-fits-all' approach towards a more precise adjustment and individualization of PA interventions could enhance the support for cancer patients in increasing their PA after the diagnosis and consequently make relevant contributions to improved physical and psychological well-being of many individuals with cancer.

5. Summary

Although the benefits of physical activity (PA) for the physical and psychological health of people with cancer are widely acknowledged, studies have shown that cancer patients tend to decrease their PA after the diagnosis, resulting in a majority of individuals who are insufficiently active. In order to increase the number of physically active cancer patients, it appears important to obtain a comprehensive understanding of how a cancer diagnosis affects the PA behavior of those concerned. This comprises profound insights into how patients from different cancer types change their activity levels from pre- to post-diagnosis as well as which factors determine whether or not they perform sufficient activity after the diagnosis. Previous research has endeavored to answer these research questions, but left some uncertainties. First, looking at change patterns of PA, the heterogeneity concerning different PA intensities as well as different cancer types has not been sufficiently investigated. Second, with regard to determinants of post-diagnosis PA, several sociodemographic and medical factors have been shown to be associated with PA after the diagnosis, yet the results appear to be inconsistent across studies. This could potentially be due to a large heterogeneity in study samples, but direct comparisons between cancer types are lacking. Moreover, although previous research has examined certain external determinants in terms of barriers and facilitators for patients' post-diagnosis PA, the role of structural barriers and physicians' exercise counseling have not been evaluated in detail so that their impact as well as potentially underlying mechanisms remain obscure.

This dissertation aimed to address these objectives by comprehensively investigating pre-to post-diagnosis change patterns and determinants of post-diagnosis PA in a large German-wide cross-sectional study of 1,299 cancer patients, including 631 breast, 344 prostate, and 324 colorectal cancer patients. Despite an overall decrease in PA levels, an encouragingly high number of more than 50% of study participants reported being sufficiently active after the diagnosis with different patient characteristics determining the likelihood of sufficient PA for each cancer type. Previously

insufficiently active prostate cancer patients and recently diagnosed individuals undergoing treatment constituted the subgroups with the highest risk of remaining or becoming insufficiently active. Looking at external factors that might exacerbate or facilitate cancer patients' PA, results revealed that structural barriers were generally perceived as impeding for PA, but that the perception differed with regard to individuals' sociodemographic and medical characteristics such as their age, educational level, BMI, or co-morbidities. As expected, the perception of structural barriers seemed to actually contribute to insufficient activity levels after the diagnosis with particularly strong associations for barriers concerning disease-adjusted PA offers and support. Subsequent analyses further pointed out that the impact was considerably high among exercise experienced individuals. One possible way to reduce PA impediment by structural barriers could be a comprehensive PA counseling by physicians such as that proposed by the 5A framework. Yet, in practice, only basic recommendations seemed to be largely implemented, whereas more profound counseling steps were still rarely undertaken. A more comprehensive exercise counseling might, however, actually positively impact cancer patients' post-diagnosis PA behavior. Interestingly, the analyses revealed that the contribution may thereby happen via different pathways depending on patients' previous PA levels: For individuals with low pre-diagnosis PA, a direct association of physicians' PA counseling and post-diagnosis PA emerged, whereas for previously highly active individuals, the effect was mediated by satisfaction with counseling.

The valuable new insights into cancer patients' change in PA behavior and the enlightening results regarding post-diagnosis PA determinants appear worth being validated in future research using longitudinal or randomized controlled study designs and objective assessments. The current findings enabled the identification of certain risk groups for insufficient activity after the cancer diagnosis and further revealed how PA determinants might affect patients' PA behavior. Therefore, the results serve as an important foundation for the development and implementation of tailored strategies to promote and improve PA for individuals with cancer and might consequently contribute to enhanced physical and psychological well-being for many cancer patients.

6. Zusammenfassung

Obwohl die Vorteile körperlicher Aktivität für die physische und psychische Gesundheit von Personen mit einer Krebserkrankung bekannt sind, haben Studien gezeigt, dass die meisten Krebsbetroffenen ihre körperliche Aktivität nach der Diagnose verringern und nur unzureichend körperlich aktiv sind. Um die körperliche Aktivität nach der Krebsdiagnose zu steigern, erscheint es wichtig, ein umfassendes Verständnis darüber zu erlangen, wie sich die Diagnose auf das Aktivitätsverhalten der Betroffenen auswirkt. Hierbei ist von besonderem Interesse, Veränderungsmuster von vor zu nach der Diagnose im Detail zu analysieren sowie beeinflussende Faktoren für das Aktivitätsverhalten nach der Diagnose herauszustellen. Frühere wissenschaftliche Studien sind diesen Forschungsfragen bereits nachgegangen, es sind jedoch einige Unklarheiten geblieben. So wurde zwar die Veränderung der körperlichen Aktivität von vor zu nach der Krebsdiagnose beleuchtet, mögliche Unterschiede in Bezug auf verschiedene Aktivitätsintensitäten sowie zwischen verschiedenen Krebsarten blieben bislang jedoch weitgehend unbeachtet. Darüber hinaus konnten verschiedene soziodemografische und medizinische Faktoren identifiziert werden, die mit körperlicher Aktivität nach der Diagnose in Zusammenhang stehen, die Ergebnisse unterschieden sich aber zwischen den einzelnen Studien. Diese Diskrepanz könnte möglicherweise auf unterschiedliche Stichproben zurückzuführen sein, direkte Vergleiche zwischen Patient:innen verschiedener Krebsarten fehlen jedoch bislang. Auch bezüglich äußerer Einflussfaktoren von körperlicher Aktivität im Sinne von Barrieren und erleichternden Faktoren bestehen noch Unklarheiten, da zum Beispiel die Rolle struktureller Gegebenheiten als Barrieren oder die ärztliche Bewegungsberatung als potenzielle Unterstützung bislang nicht untersucht wurden, sodass deren Einfluss sowie möglicherweise zugrunde liegende Mechanismen ungewiss sind.

Die vorliegende Dissertation zielte darauf ab, diese Forschungslücken zu schließen, indem in einer großen, deutschlandweiten Querschnittsstudie mit 631 Brust-, 344 Prostata- und 324

Darmkrebspatient:innen Veränderungsmuster von körperlicher Aktivität sowie Determinanten des Aktivitätsverhaltens nach der Krebsdiagnose detailliert untersucht wurden. Trotz einer allgemeinen Verringerung der körperlichen Aktivität gab eine erfreulich hohe Anzahl von mehr als 50% der Teilnehmenden ausreichend hohe Aktivitätslevel nach der Diagnose an. Dabei schienen für jede Krebsart unterschiedliche Patient:innencharakteristika mit dem Aktivitätsverhalten zusammenzuhängen. Vor der Diagnose inaktive Prostatakrebspatienten sowie Patient:innen, deren Diagnose erst kürzlich zurücklag und die sich aktuell in Therapie befanden, stellten die Gruppen mit dem höchsten Risiko für unzureichende körperliche Aktivität dar. Bei der Betrachtung äußerer Einflussfaktoren zeigten die Ergebnisse zunächst, dass strukturelle Barrieren im Allgemeinen als hinderlich für die Ausübung körperlicher Aktivität wahrgenommen wurden. Das Ausmaß der Beeinträchtigung unterschied sich dabei jedoch in Abhängigkeit soziodemografischer und medizinischer Patient:innenmerkmale wie zum Beispiel dem Alter, Bildungsniveau, BMI oder Komorbiditäten. Wie zu erwarten, hing die Wahrnehmung struktureller Barrieren darüber hinaus mit unzulänglichen Aktivitätslevels nach der Diagnose zusammen. Dabei konnte ein besonders starker Zusammenhang für Barrieren beobachtet werden, die einen Mangel an speziellen Aktivitätsangeboten und -unterstützung für Krebsbetroffene beschrieben. Zudem schienen sich interessanterweise vor allem zuvor aktive Personen besonders stark von strukturellen Barrieren beeinträchtigt zu fühlen. Eine mögliche Strategie zur Verringerung dieser Beeinträchtigung könnte eine ausführliche Beratung zu körperlicher Aktivität durch Ärzt:innen sein, wie sie im Rahmen des 5A-Modells beschrieben wird. In der Praxis scheinen jedoch weitestgehend nur unspezifische Aktivitätsempfehlungen gegeben zu werden, wohingegen tiefgründigere Beratungsschritte eher selten vorgenommen werden. Wie die Ergebnisse dieser Arbeit zeigen, könnte sich eine ausführliche Beratung aber positiv auf das Aktivitätsverhalten von Krebsbetroffenen nach der Diagnose auswirken. Interessanterweise ergaben die Analysen in diesem Zusammenhang, dass der Effekt dabei je nach bisherigem Aktivitätslevel der Patient:innen über unterschiedliche Wirkweisen erfolgen könnte: Bei Personen, die vor der Diagnose gar nicht oder nur wenig körperlich aktiv waren, zeigte sich ein direkter Zusammenhang zwischen der ärztlichen Beratung und dem Aktivitätsverhalten der Patient:innen nach der Diagnose. Bei zuvor sehr aktiven Personen wirkte der Effekt hingegen über die Zufriedenheit mit der Beratung.

Diese aufschlussreichen Ergebnisse über die Veränderung des Aktivitätsverhaltens von Krebsbetroffenen sowie Determinanten von körperlicher Aktivität nach einer Krebsdiagnose sollten in der zukünftigen Forschung anhand von Längsschnittstudien oder randomisierten kontrollierten Studien und objektiven Messmethoden validiert werden. Die Ergebnisse der Dissertation haben herausgestellt, welche Patientengruppen einem erhöhten Risiko für unzulängliche Aktivität nach der Krebsdiagnose unterliegen und zeigen, inwiefern verschiedene Faktoren das Aktivitätsverhalten von Krebsbetroffenen beeinflussen könnten. Diese Erkenntnisse können als wichtige Grundlage für die Entwicklung und Implementierung maßgeschneiderter Strategien zur Förderung und Verbesserung der körperlichen Aktivität von Personen mit einer Krebserkrankung dienen und somit letztendlich zu einer Verbesserung des physischen und psychischen Wohlbefindens zahlreicher Krebspatient:innen beitragen.

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8. Publications

The present dissertation was conducted as part of the Momentum Project Heidelberg. As a student research assistant, my contribution to the project consisted of support in the patient recruitment, data collection, and data curation. Continuing my work in the Momentum Project as a doctoral candidate, I finalized the data curation and wrote three first author manuscripts, the first of them in shared first authorship with my supervisor Prof. Dr. Karen Steindorf. For the publications, I elaborated the specific research objectives in more detail in discussion with my supervisor. Accordingly, the data were analyzed and all written manuscripts composed by myself, in regular exchange with my supervisor Prof. Dr. Karen Steindorf. The other project members contributed to these publications to different extents. Prof. Dr. Monika Sieverding, Prof. Dr. Karen Steindorf, and PD Dr. Joachim Wiskemann as the principal investigators were responsible for the design, initiation, management, and coordination of the research project. Dr. Nadine Ungar, as project manager, Dr. Laura Schmidt, Dr. Alexander Haussmann, and Dr. Angeliki Tsiouris contributed to the study conception, management, and design. The latter two were also responsible for material preparation and data assessment. All project members reviewed the written manuscripts before publication.

Publications related to this dissertation

1. Steindorf, K.*, Depenbusch, J.*, Haussmann, A., Tsiouris, A., Schmidt, L., Hermann, S., Sieverding, M., Wiskemann, J.†, and Ungar, N.† (2020). **Change patterns and determinants of physical activity differ between breast, prostate, and colorectal cancer patients.** Support Care Cancer, *28*(7), 3207-3218, doi: 10.1007/s00520-019-05097-1. ** Shared first authorship. † Shared last authorship.*

Publication 1 is related to the results of sections 3.2 (PA levels and changes from pre- to post-diagnosis) and 3.3.1 (Sociodemographic and medical determinants of post-diagnosis PA). The corresponding discussion of pre- to post-diagnosis PA change patterns (section 4.1) as well as of sociodemographic and medical determinants of post-diagnosis PA (section 4.2.1) is also depicted in this publication. The publication contains a shared first authorship between my supervisor Prof. Dr. Karen Steindorf and myself, which reflects her great support for me carrying out the statistical analyses as well as our joint effort in interpreting and discussing the results and her comprehensive feedback for my initial version of the written manuscript.

2. Depenbusch, J., Haussmann, A., Tsiouris, A., Schmidt, L., Wiskemann, J., Ungar, N., Sieverding, M., and Steindorf, K. (2020). **The association between physicians' exercise counseling and physical activity in patients with cancer: Which roles do patients' satisfaction and previous physical activity levels play?** Psychooncology, *29*(11), 1856-1863, doi: 10.1002/pon.5506.

Publication 2 is related to the results of section 3.3.3 (PA counseling by physicians) and the corresponding discussion of the role of physicians' PA counseling for cancer patients' post-diagnosis PA (section 4.2.3).

3. Depenbusch, J., Wiskemann J., Haussmann, A., Tsiouris, A., Schmidt, L., Ungar, N., Sieverding, M.*, and Steindorf, K.* (2021). **Impact and determinants of structural barriers on physical activity in people with cancer.** Int J Behav Med, accepted for publication, will be published under doi: 10.1007/s12529-021-10014-0. **Shared last authorship.*

Publication 3 is related to the results of section 3.3.2 (Structural barriers for PA). The corresponding discussion of the impact of structural barriers on cancer patients' post-diagnosis PA (section 4.2.2) is also depicted in this publication.

Other publications

The following two manuscripts also had their origin in the Momentum cross-sectional study among cancer patients. I thus contributed to both publications by curating the data and further by discussing and/or carrying out the data analyses as well as reviewing and editing the written manuscript.

Haussmann, A., Ungar, N., Tsiouris, A., Depenbusch, J., Sieverding, M., Wiskemann, J., and Steindorf, K. (2021). **Physical activity counseling to cancer patients: How are patients addressed and who benefits most?** Patient Educ Couns, online first, doi: 10.1016/j.pec.2021.04.019.

Wiskemann, J.*, Tsiouris, A.*, Depenbusch, J., Haussmann, A., Sieverding, M., Ungar, N., and Steindorf, K. **Perceived impact of treatment-related side effects on physical activity in cancer patients.** In preparation. ** Shared first authorship.*

Oral presentations

Depenbusch J., Haussmann, A., Tsiouris, A., Schmidt, L., Ungar, N., Wiskemann, J., Sieverding, M., Stuiver M., May, A., and Steindorf, K. **Cancer patients' view on physical activity- Recent results and future directions.** NCT Online Retreat 2021, online, March 2021.

Depenbusch, J., Wiskemann J., Haussmann, A., Tsiouris, A., Schmidt, L., Ungar, N., Sieverding, M., and Steindorf, K. **Perception of structural barriers to physical activity among people with cancer.** 16. Jahrestagung der Deutschen Gesellschaft für Epidemiologie, online, September 2021.

Poster presentations

Depenbusch, J., Haussmann, A., Tsiouris, A., Schmidt, L., Hermann, S., Sieverding, M., Wiskemann, J., Ungar, N., and Steindorf, K. **A comparison of physical activity change patterns and determinants between breast, prostate, and colorectal cancer patients.** 34. Deutscher Krebskongress, Berlin, February 2020.

Depenbusch, J., Haussmann, A., Tsiouris, A., Schmidt, L., Wiskemann, J., Ungar, N., Sieverding, M., and Steindorf, K. **How physicians' exercise counseling is related to physical activity in patients with cancer.** Conference on Cancer Prevention, online, September 2020.

Depenbusch, J., Haussmann, A., Tsiouris, A., Schmidt, L., Sieverding, M., Ungar, N., Wiskemann, J., and Steindorf, K. **Can physicians' exercise counseling help to increase physical activity levels among patients with cancer?** Quality of Cancer Care Kongress, online, March 2021. *Awarded with one of three poster prizes.*

Depenbusch, J., Wiskemann, J., Haussmann, A., Tsiouris, A., Schmidt, L., Ungar, N., Sieverding, M., and Steindorf, K. **Structural barriers to physical activity in people with cancer: an investigation of determinants and impacts.** Annual Meeting of the Multinational Association of Supportive Care in Cancer, online, June 2021.

9. Curriculum vitae

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Education

11/2018 – 10/2021	Doctoral candidate Division of Physical Activity, Prevention and Cancer; German Cancer Research Center (DKFZ) and National Center for Tumor Diseases (NCT), Heidelberg
10/2016 – 08/2018	Study of Psychology, Master of Science Psychological Institute, Heidelberg University
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10. Acknowledgements

I would like to express my gratitude to some people in my professional and private life, without whose great support this dissertation would have not been possible.

First of all, I would like to thank my supervisor Prof. Dr. Karen Steindorf not only for giving me the most valuable input and feedback for my work, but also for always having a sympathetic ear and supporting me in the best way possible throughout my whole time as a doctoral candidate. As this dissertation is based on the Momentum Project Heidelberg, I would further like to extend my thanks to the other project members, Prof. Dr. Monika Sieverding, PD Dr. Joachim Wiskemann, Dr. Nadine Ungar, Dr. Laura Schmidt, Dr. Alexander Haussmann, and Dr. Angeliki Tsiouris, for their great management of the project. I appreciate them for allowing me the opportunity to be part of this meaningful project and providing their constructive feedback on my work in this regard. Also, I would like to thank my colleagues in the Division of Physical Activity, Prevention and Cancer at the DKFZ for always being available as contact persons and ensuring a great work atmosphere.

Finally, I am truly grateful for my amazing family and friends, who have always stood by my side, cheered me on, and supported me in every step of the way.

11. Eidesstattliche Versicherung

1. Bei der eingereichten Dissertation zu dem Thema

Change patterns and determinants of physical activity in people with cancer

handelt es sich um meine eigenständig erbrachte Leistung.

2. Ich habe nur die angegebenen Quellen und Hilfsmittel benutzt und mich keiner unzulässigen Hilfe Dritter bedient. Insbesondere habe ich wörtlich oder sinngemäß aus anderen Werken übernommene Inhalte als solche kenntlich gemacht.

3. Die Arbeit oder Teile davon habe ich bislang nicht an einer Hochschule des In- oder Auslands als Bestandteil einer Prüfungs- oder Qualifikationsleistung vorgelegt.

4. Die Richtigkeit der vorstehenden Erklärungen bestätige ich.

5. Die Bedeutung der eidesstattlichen Versicherung und die strafrechtlichen Folgen einer unrichtigen oder unvollständigen eidesstattlichen Versicherung sind mir bekannt. Ich versichere an Eides statt, dass ich nach bestem Wissen die reine Wahrheit erklärt und nichts verschwiegen habe.

Heidelberg, 21.09.2021 J. Depenbusch

Ort und Datum Unterschrift