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Effects of Digital Physical Activity Interventions for Breast Cancer Patients and Survivors: A Systematic Review and Meta-Analysis

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Objectives: The benefits of physical activity (PA) for breast cancer (BC) patients and survivors are well documented. With the widespread use of the internet and mobile phones, along with the recent coronavirus disease 2019 pandemic, there has been a growing interest in digital health interventions. This study conducted a systematic review and meta-analysis to evaluate the effects of digital PA interventions for BC patients and survivors in improving PA and quality of life (QoL). **Methods:** We searched eight databases, including PubMed, CINAHL, Embase, Scopus, Web of Science, Cochrane Central Register of Controlled Trials in the Cochrane Library, RISS, and DBpia. Studies were included if they provided digital PA interventions, assessed PA and QoL among BC patients and survivors, and were published from inception to December 31, 2022. **Results:** In total, 18 studies were identified. The meta-analysis showed significant improvement in the total PA duration (five studies; standardized mean difference [SMD] = 0.71; 95% confidence interval [CI], 0.25–1.18; I^2 = 86.64%), functional capacity (three studies; SMD = 0.38; 95% CI, 0.10–0.66; I^2 = 14.36%), and QoL (nine studies; SMD = 0.45; 95% CI, 0.22–0.69; I^2 = 65.55%). **Conclusions:** Digital PA interventions for BC patients and survivors may significantly improve PA, functional capacity, and QoL. Future research should focus on the long-term effects of digital PA interventions, using objective outcome measures.

Keywords: Breast Neoplasms, Digital Technology, Exercise, Meta-Analysis, Systematic Review

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I. Introduction

The benefits of physical exercise for breast cancer (BC) patients and survivors are widely recognized. A recent meta-analysis revealed that physical activity (PA) can reduce both BC mortality and overall mortality rates. Notably, women with BC who engage in high levels of recreational activities have a lower risk of all-cause mortality and BC-related death than those who participate in lower levels of activity [1]. Consistent participation in PA can help to maintain and enhance cardiopulmonary function, muscle strength, and cancer-related fatigue. It can also improve quality of life (QoL) and other aspects of psychological health in cancer survivors [2,3].

Since the advent of telemedicine in the 2000s, the widespread use of the internet and smartphones has spurred the rapid expansion of mobile health [4]. The recent coronavirus disease 2019 pandemic has further heightened the demand for digital health technologies.

Digital health interventions (DHIs) are defined as the use of technologies, including text messaging, emails, mobile applications, videoconferencing, social media, websites, and online portals, for the purpose of promoting health promotion or treatment adherence [5]. The impact of DHIs has been widely investigated due to their immense potential in areas such as efficacy, cost-effectiveness, safety, and scalability [6]. DHIs have been implemented to boost medication adherence, foster smoking cessation, and encourage PA [7,8]. They also aim to improve health outcomes for long-term conditions and offer remote access to treatment for individuals grappling with mental health and somatic issues [9,10].

Although studies have explored the effects of DHIs, the findings regarding their effect on increasing PA are often inconsistent. Roberts et al. [5] found that DHIs targeting PA and diet significantly increased moderate and vigorous PA per week and reduced body mass index (BMI) among cancer survivors, irrespective of the type of cancer. More recently, Singleton et al. [11] carried out a systematic review and meta-analysis on health interventions using electronic technologies for BC patients. However, only three studies focusing on PA-related patient-reported outcomes were included in the review. It has been reported that these individuals are at risk of maintaining sedentary behaviors following a BC diagnosis and often do not adhere to the appropriate PA level recommended by expert-developed health behavior guidelines [12]. Despite this, research findings suggest that PA is beneficial for BC patients undergoing active treatments and for survivors who have completed treatments [2,3]. Given the importance of improving PA to maximize treatment effects and various aspects of positive health outcomes, it is crucial to gain a clear understanding of the impact of digital PA interventions. Therefore, this study conducted a systematic review and meta-analysis to evaluate the effects of digital PA interventions provided for BC patients and survivors on improving PA and QoL.

II. Methods

This systematic review and meta-analysis adhered to the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) 2020 guidelines [13].

1. Eligibility Criteria

Studies were considered eligible for inclusion if they satisfied the following criteria: (1) the subjects were patients or survivors over the age of 18 who were either undergoing or had completed active treatments such as surgery, chemotherapy, and/or radiotherapy following a BC diagnosis; (2) the study compared digital PA interventions in BC patients or survivors with a contemporaneous control group (which could include conventional or no intervention). Digital PA interventions were defined as those utilizing the internet, mobile applications, text messaging, email, videoconferencing (e.g., Skype), social media, websites, or online patient portals to encourage PA; (3) the study was a randomized controlled trial (RCT) or employed a quasi-experimental design, and was published in English or Korean in a peer-reviewed journal; (4) the study's outcomes of interest were PA-related outcomes (e.g., PA, physical function, and QoL). However, pilot and feasibility studies, conference proceedings, and studies that included patients with other types of cancer were not included.

2. Information Sources and Searches

Two independent authors conducted the search, employing identical methodologies. They searched eight electronic databases, including PubMed, CINAHL, Embase, Scopus, Web of Science, Cochrane Library, Korean RISS, and DBpia, from their inception until December 31, 2022. The search was completed by February 1, 2023. The primary search terms were "breast neoplasms," "internet," "smartphone," "mobile applications," "text messaging," "telemedicine," "electronic mail," "physical activity," "exercise," and "quality of life," along with their respective synonyms. These terms were combined to formulate a search strategy. The sample search strategy for PubMed, used in this review, is presented in Supplement A.

3. Literature Selection Process

In the initial screening, two authors (HK and MM) independently reviewed the titles and abstracts to assess the eligibility of the studies. The full texts were also independently evaluated by these two authors. They engaged in discussions and sought consensus regarding the inclusion and exclusion of studies at each stage.

4. Data Extraction

Using a structured protocol, both authors extracted data from the selected studies (Supplement B). This data included study characteristics such as the author, year, and study design, as well as the study population, components and duration of the intervention, and outcomes related to PA.

5. Risk of Bias

The two authors independently evaluated the risk of bias (RoB) in the included studies using the Cochrane collaboration's RoB tools. These tools included the revised Cochrane risk-of-bias tool for randomized trials (RoB2) for RCTs and the RoB assessment tool for non-randomized studies (RoBANS) for quasi-experimental studies [14]. Each study's RoB was assessed as either low, raising some concerns, or high in the following domains: the randomization process, deviation from intended interventions, missing outcome data, measurement of the outcome, and selection of the reported result. Any disagreements between the authors were resolved through discussion until a consensus was reached.

6. Statistical Analysis

The meta-analyses for PA levels, as measured by the International Physical Activity Questionnaires (IPAQ) [15] and a 7-day physical activity recall (PAR) [16], as well as functional capacity as assessed by the 6-minute walk test (6MWT), were conducted using Stata version 17.0 (Stata Corporation, College Station, TX, USA). QoL was evaluated using the EORTC QLQ-C30 [17], EORTC QLQ-BR23 [18], FACT-B [19], FACT-ES [20], and WHO QoL-BREF [21]. The standardized mean difference (SMD, Hedges' g) over time and the corresponding 95% confidence interval (CI) were calculated using a random-effect model for both PA duration and QoL. This approach was chosen due to the use of different scales to measure the same outcome across separate studies, and the varying characteristics of the studies. For the pooled functional capacity results, a fixed-effect model was selected to provide an accurate estimate, given the limited number of studies. Statistical heterogeneity was assessed using the I^2 statistic and chi-square test, and the *p*-value was also evaluated. A forest plot was used for visual inspection. Additionally, a subgroup analysis was conducted specifically for PA duration.

III. Results

1. Search Results

As depicted in Figure 1, the initial search of eight databases yielded 1,618 records. Once 341 duplicates were eliminated, 1,277 titles remained for review, leaving 605 records for abstract review. Following the exclusion of 497 records post-abstract review, 108 full-text articles were obtained. Out of these, 90 records were excluded as they failed to meet the inclusion and exclusion criteria, leaving 18 studies for consideration. Three studies (A3[a,b], A7[a,b], A15[a,b]) were published in two or more journals with different variables, and we only included journal articles published with PA- or QoL-associated outcomes.

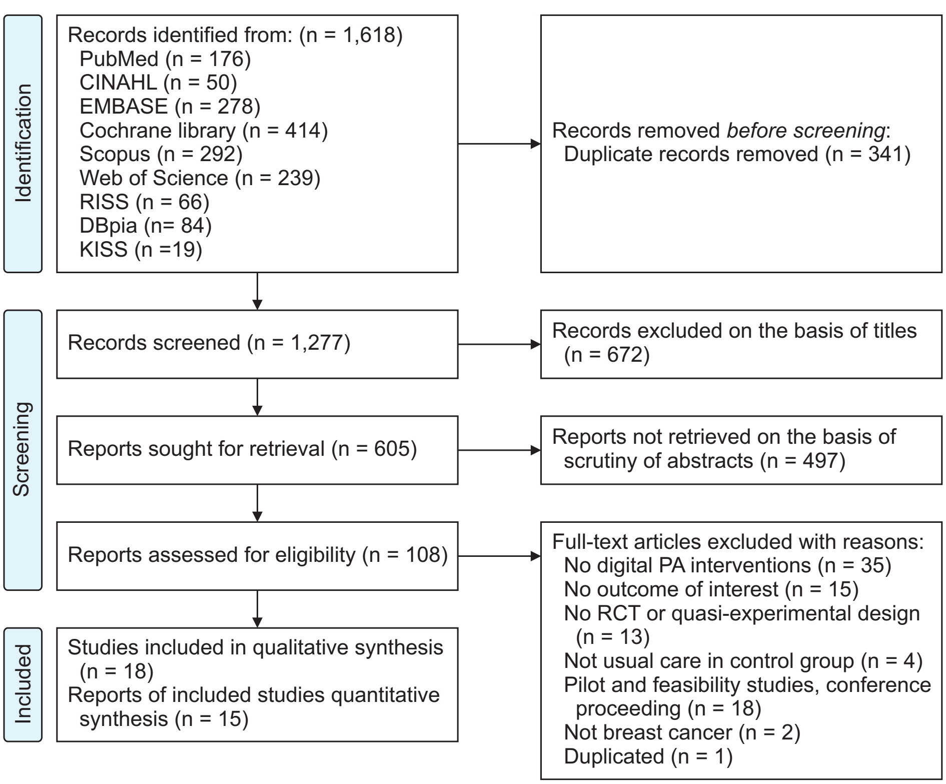

Figure 1. Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) diagram. PA: physical activity, RCT: randomized controlled trial.

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2. Characteristics of the Included Studies

Among the 18 selected studies, 16 were RCTs and two were quasi-experimental studies (Table 1). All studies were conducted after 2010. Specifically, 10 studies took place between approximately 2013 and 2019, while the remaining eight studies were conducted from 2020 to 2022. In terms of geographical distribution, three studies were conducted in the United States, three in South Korea, and two each in Australia, Spain, and Turkey, with the remaining studies taking place in Canada, China, Germany, Japan, and Taiwan. The total number of participants across all studies was 1,703. The duration of the interventions ranged from 3 weeks to 12 months. However, the majority of the studies (72%, n = 13) had an intervention period of 12 weeks.

Approximately 50–100 participants were involved in 12 of the studies, while four studies had more than 100 participants, and two studies had fewer than 50 participants. The average age of the participants ranged from 41.5 to 62 years. In terms of BC stages, 12 studies included participants in stages 0–III or those without metastasis, two studies included participants with metastasis (A4, A16), and four studies did not consider the cancer stage as a criterion for inclusion (A1, A9, A14, A17). Studies that included only participants with metastasis aimed to improve QoL (A4, A16) or reduce the side effects of chemotherapy (A4) by promoting PA, rather than increasing the duration of PA or functional capacity. All participants were women, but only 50% (n = 9) of the studies specified female sex as an inclusion criterion. Additionally, some studies included criteria such as limited moderate-to-vigorous physical activity (MVPA) (A2, A7[b], A8, A10, A16, A18) or a BMI of ≥23 kg/m^2 (A10, A12, A15).

3. Quantitative Analysis of PA Outcomes

1) PA duration

Five studies (A1, A9, A10, A14, A17) reported pre- and post-treatment PA duration using IPAQ and the PAR data, which could be combined for meta-analysis; these studies included 41% of participants in the systematic review. Follow-up data were excluded from the analysis due to the significant variation in follow-up periods across the studies. The total PA time from each study was aggregated using a random effects model with Hedges' g. The meta-analysis results comparing the intervention and control groups are illustrated in Figure 2A. The overall effect size was 0.71 (95% [CI], 0.25–1.18), indicating a significant improvement in PA duration with substantial heterogeneity (I^2 = 86.64%).

The results for the subgroup analysis according to whether there was feedback or monitoring for participants' performance (monitoring vs. no-monitoring) are presented in Figure 2B. The monitoring group showed a significant improvement in PA duration (SMD = 0.88; 95% CI, 0.45–1.32; I^2 = 72.12%), whereas the effects of the interventions without monitoring were not statistically significant.

2) Physical function

Three (A3[b], A5, A18) of 18 studies (6% of participants) evaluated functional capacity using the 6MWT. These three studies were pooled in a fixed-effect meta-analysis. A significant improvement was observed in the intervention group compared with the control group (SMD = 0.38; 95% CI, 0.10–0.66; I^2 = 14.36%) (Figure 2C).

3) Quality of life

Nine studies (A3[a], A4, A7[b], A8, A11, A13, A14, A16, A17) were included in the meta-analysis of QoL. Using data from 57.4% of the total participants, there was a significant pooled improvement in QoL (SMD = 0.45, 95% CI, 0.22–0.69; I^2 = 65.55%) (Figure 2D).

4. Qualitative Analysis of PA and QoL Outcomes

1) PA-related outcomes

The outcome measures related to PA in digital PA interventions included the duration of PA in daily life and the level of functional capacity. Seven studies (39%) utilized instruments or questionnaires to measure self-reported PA duration. These included the PA recall (A1), the IPAQ (A9, A10, A14, A17), global PA questionnaires (A18), or the weekly duration of MVPA (A2). Only two studies (A8, A15[a,b]) employed wearable devices, such as an actigraph, to objectively measure the duration of PA. Most studies reported that the intervention groups significantly increased their PA duration compared to the control groups. However, two studies (A14, A15[a,b]) did not observe any significant differences between the groups.

In addition to PA duration, functional capacity was evaluated by measuring the 6MWT, 2MWT, and muscle strength of the abdomen, upper, or lower limbs, or grip strength (A3[a,b], A5, A6, A18). Significant between-group effects were noted in some or all variables. Four studies (A5, A8, A10, A12) evaluated anthropometrics, including BMI and waist and hip circumferences, and the intervention effects were inconsistent between studies.

2) QoL outcomes

QoL was measured in 14 studies, of which 11 observed significant intervention effects (A2–A4, A6, A9, A11, A13–17).

Table 1. Characteristics of the included studies

Study ID*	First author (yr)	Study design	Country	Number of participants (stage of cancer)	Intervention	Interven-tion period	Retention	Outcome measurements for PA and QoL	Findings on PA, functional capacity, and QoL
A1	Hatchett (2013)	RCT	USA	85 (NI)	SCT-based email intervention	12 wk	87.1% (74/85)	PA: PAR-Q	Significant for PA
A2	Lee (2014)	RCT	South Korea	59 (0–III)	Web-based self-management exercise and diet intervention	12 wk	96.7% (57/59)	PA: frequency of exercise ≥150 min/wk QoL: EORTC QLQ-C30	Significant for PA and QoL
A3[a] A3[b]	Galiano-Castillo (2016) Galiano-Castillo (2017)	RCT	Spain	81 (I–IIIA)	Internet-based exercise program: e-CUIDATE system	8 wk	88.9% (72/81)	PA: 6MWT QoL: EORTC QLQ-C30	Significant for QoL and functional capacity
A4	Kim (2018)	RCT	South Korea	76 (IV, metastatic)	Mobile game for self-management and reducing the side effects of chemotherapy	3 wk	94.7% (72/76)	QoL: WHO QoL-BREF	Significant for QoL
A5	Ariza-Garcia (2019)	RCT	Spain	68 (I–IIIa)	A web-based exercise program: e-CuidateChemo	8 wk	67.7% (46/68)	PA: 6MWT, muscle strength, anthropometric measurement	Significant for functional capacity
A6	Dong (2019)	RCT	China	60 (I–III)	Combined exercise intervention based on the internet and social media software (CEIBISMS)	12 wk	83.3% (50/60)	PA: muscle strength, cardiorespiratory capacity QoL: SF-36	Significant for functional capacity and QoL
A7[a] A7[b]	Lynch (2019) Vallance (2020)	RCT	Australia	83 (I–III)	ACTIVATE Trial using a wrist-worn activity tracker	12 wk	94.0% (78/83)	PA: MVPA QoL: FACT-B	Significant for PA and non-significant for QoL
A8	McNeil (2019)	RCT	Canada	45 (I–IIIc)	PA training application of the wearable activity tracker	12 wk	95.6% (43/45)	PA: Total, MV, and light-intensity PA time QoL: FACT-B, SF-12	Significant for PA and non-significant for QoL
A9	Nemli (2019)	Quasi-experimental	Turkey	62 (NI)	Exercise training and follow-up by phone calls at home	12 wk	100% (62/62)	PA: IPAQ QoL: QLQBR-23	Significant for QoL and PA
A10	Park (2019)	Quasi-experimental	South Korea	71 (0–IIIa)	Smartphone Application Peer Support (SAPS)	12 wk	67.9% (38/56)	PA: IPAQ	Significant for PA

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Table 1. Continued

Study ID*	First author (yr)	Study design	Country	Number of participants (stage of cancer)	Intervention	Interven-tion period	Retention	Outcome measurements for PA and QoL	Findings on PA, functional capacity, and QoL
A11	Hou (2020)	RCT	Taiwan	112 (0–III)	Breast cancer self-management support (BCSMS) using the mHealth application	6 mo	89.3% (100/112)	QoL: EORTC QLQ-C30, QLQ-BR23	Significant for QoL
A12	Santa-Maria (2020)	RCT	USA	96 (0–III)	POWER-remote: telephone-based behavioral coaching and use of a web-based self-monitoring and learning platform	12 mo	91.7% (88/96)	PA: anthropomorphic measurements	Significant for weight loss and improvement in body weight
A13	Cinar (2021)	RCT	Turkey	64 (non-metastatic)	Mobile web-based patient education and web-based management application	12 wk	96.9% (62/64)	QoL: FACT-ES Quality of Life Scale	Significant for QoL
A14	Holtdirk (2021)	RCT	Germany	363 (NI)	Optimune: web-based CBT techniques to improve health behaviors	12 wk	84.3% (306/363)	PA: IPAQ QoL: WHOQOL-BREF	Non-significant for PA, significant for QoL
A15[a] A15[b]	Reeves (2021) Terranova (2022)	RCT	Australia	159 (I–III)	Remotely delivered weight loss intervention	12 mo	81.8% (130/159)	PA: Actigraph, MVPA QoL: PROMIS Global Health Scale	Non-significant for PA and significant for QoL (physical health domain only)
A16	Sheean (2021)	RCT	USA	35 (metastatic)	Supervised exercise, telephone-based coaching, text messages: everyday counts	12 wk	97.1% (34/35)	PA: Handgrip strength QoL: FACT-B	Significant for QoL
A17	Changizi (2022)	RCT	Iran	134 (NI)	Educational clip, text message, video, and online group support using WhatsApp	12 wk	91.8% (123/134)	PA: IPAQ QoL: EORTC QLQ-BR2	Significant for PA and QoL
A18	Ochi (2022)	RCT	Japan	50 (I, IIa)	Habit-B program: home-based smartphone-supported high-intensity interval training (HIIT)	12 wk	88.0% (44/50)	PA: Global PA Questionnaire 6MWT QoL: EQ-5D	Non-significant for PA and QoL

CBT: cognitive behavioral therapy, FACT-B: Functional Assessment of Cancer Therapy-Breast, IPAQ: International Physical Activity Questionnaire, MVPA: moderate-to-vigorous physical activity, PA: physical activity, NI: not indicated, QoL: quality of life, RCT: randomized controlled trial, SCT: social cognitive theory.

*Articles published with the same intervention, and refer to Supplement B for more information.

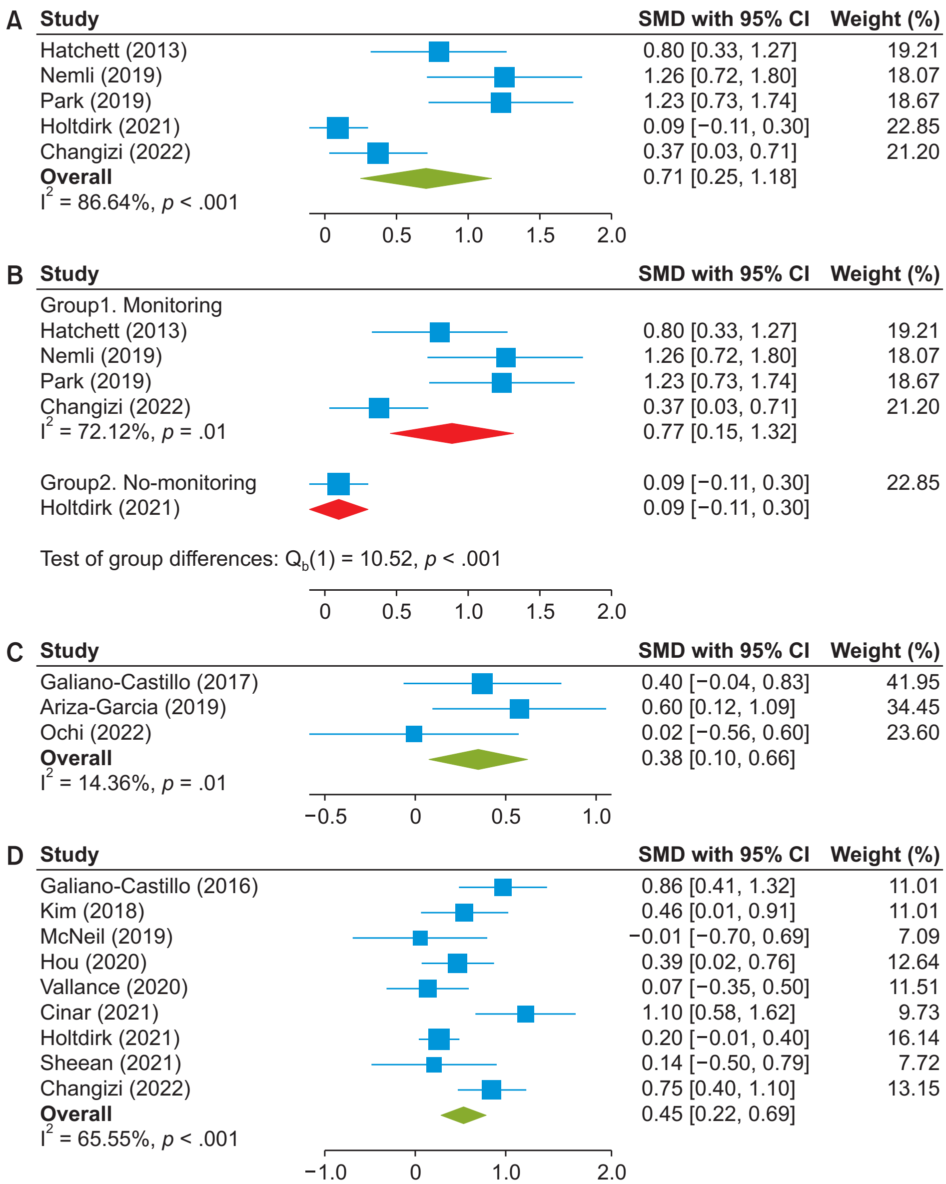

Figure 2. Forest plots of the effects of digital physical activity (PA) interventions: (A) PA duration, (B) subgroup analysis for PA duration, (c) functional capacity, and (D) quality of life.

Of these studies, 64.3% (n = 9/14) used cancer- or BC-specific measurements, including the EORTC QLQ-C30 [17] (A2, A3[a], A11, A17), EORTC QLQ-BR23 [18] (A9, A11), FACT-B [19] (A7[b], A8, A16), and FACT-ES [20] (A13). The other studies used global QoL or health-related QoL measures, including WHO QoL-BREF [21] (A4, A14), SF-12 [22] (A8), SF-36 [22] (A6), PROMIS Global Health Scale [23] (A15[a]), and EQ-5D (A18). One study (A8) used both BC-specific and global QoL measurements.

5. Components of Digital PA Interventions

As shown in Table 2, a substantial majority of the studies (83.3%) employed multi-component interventions. These primarily included (1) training or encouraging PA, (2) monitoring participants' performance either by the research team or through self-monitoring, and (3) offering feedback or peer support. The application of digital technologies varied in the delivery of these interventions.

- Mobile applications: Half of the studies (A4, A6, A8, A10–A13, A17, A18) utilized mobile applications or games to deliver disease-related education (A4, A6, A11–A13), PA training (A13, A17, A18), monitor PA participation (A8), and provide peer support (A10). The intervention group demonstrated a significant increase in PA in all studies, with the exception of the study by Ochi et al. (A18).
- Websites or internet modules: Three studies (A2, A3[a,b], A5) employed websites to offer individualized exercise programs and monitor PA participation (A12). Additionally, one study (A14) utilized Internet modules to provide information on health behaviors, including PA.

Table 2. Intervention components of the included studies

Study ID*	First author (yr)	Intervention component	Theory applied for intervention development
A1	Hatchett (2013)	Email messages to enhance PA + e-counselor (physiologist) advice	Social cognitive theory
A2	Lee (2014)	Web-based self-management (WSEDI): tailored education + action planning + automatic feedback - No intervention-related interactions - SMS encouraging to use WSEDI - Self-adjusted exercise type, intensity, duration, and frequency	Transtheoretical model of behavior change
A3[a] A3[b]	Galiano-Castillo (2016) Galiano-Castillo (2017)	e-CUIDATE system: Public interface (homepage) + private interface (tailored exercise program) + telephone calls - Exercise program and remote feedback by staff - Video conferences three times/week - Telephone calls	-
A4	Kim (2018)	ILOVEBREAST: Mobile game during chemotherapy: education on side effects, encouragement of mood, and activities, self-assessment using a personal avatar	-
A5	Ariza-Garcia (2019)	e-CuidateChemo system: web-based exercise + communication system + weekly contacts - Tailored resistance exercises - Communication with the research team through internal service	-
A6	Dong (2019)	Face-to-face televedio PA training and cardiorespiratory training + BC knowledge education using a social media application - Muscle training: face-to-face televideo instruction on PA rehabilitation three times per week - Cardiorespiratory capacity training: face-to-face televideo instruction, complete target numbers of steps using a phone step-recording application - Social media apps: postoperative BC rehabilitation knowledge	-

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Table 2. Continued

Study ID*	First author (yr)	Intervention component	Theory applied for intervention development
A7[a] A7[b]	Lynch (2019) Vallance (2020)	ACTIVATE trial: face-to-face feedback and goal setting + activity tracker + telephone counseling - Face-to-face behavioral feedback and goal setting - Wrist-worn activity tracker - Five telephone-delivered behavioral counseling sessions	-
A8	McNeil (2019)	Activity tracker + individualized PA using mobile application + phone calls or emails for follow-up discussion - Wrist-worn activity tracker for recording HR/PA intensity and PA duration - Participants upload their data to the Polar Flow application and study physiologists track their progress - A diary: questions on goal setting, feasibility of prescribed PA, strategies, and barriers - Follow-up discussion by phone calls or emails with study physiologists	-
A9	Nemli (2019)	Exercise training + telephone follow-up - Exercise training provided to increase moderate-intensity PA - Telephone follow-up at home once a week for 12 weeks	-
A10	Park (2019)	Smartphone application peer support: face-to-face education + peer support and self-monitoring using a smartphone application - Face-to-face: PA, diet group education for 2 weeks - Peer support using smartphone app: small group sharing health behavior and barriers, watching videos about peer's health behavior interviews - Self-monitoring of diet and exercise using smartphone apps	Social cognitive theory
A11	Hou (2020)	Breast cancer self-management support (BCSMS) mHealth application: knowledge about BC + exercise and rehabilitation after surgery + diet and nutrition, emotional support, experience sharing, expert consulting - Participants used the BCSMS app at any time as needed. - No prompts or reminders from the study team.	-
A12	Santa-Maria (2020)	Power-remote intervention: telephone-based behavioral weight loss coaching + web-based self-monitoring and learning platform - Dietary intake recording, exercise, and weight on a web-based platform - Tracking health behaviors using the website - Smartphone app: access to educational materials - 21 phone calls over the 1-year study period	-

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Table 2. Continued

Study ID*	First author (yr)	Intervention component	Theory applied for intervention development
A13	Cinar (2021)	Mobile web education + mobile application exercise + text messages - Mobile web-based patient education - Relaxation exercise on mobile application - Reminder messages	-
A14	Holtdirk (2021)	Optimune: 16 internet modules with topics consisting of (1) psychological well-being, (2) dietary coaching, (3) PA and exercise, and (4) sleep management	-
A15[a] A15[b]	Reeves (2021) Terranova (2022)	Telephone calls + text messages - Telephone and optional text messages aiming at weight loss by reducing energy intake, limiting alcohol, incremental increases in moderate-to-vigorous aerobic activity and resistance exercise - Self-monitoring using workbook, scale, measuring tape, pedometer, calorie-counter book, diary - Telephone calls and text messages	Social cognitive theory
A16	Sheean (2021)	Everyday counts: supervised exercise + telephone-based coaching + text messages - Four supervised aerobic/resistance exercise sessions (individualized) - Weekly individual telephone sessions: previous week's achievements and challenges, review of adherence to nutrition and PA guidelines, setting goals - Intervention support: Fitbit activity tracker, exercise bands, cooking utensils, and text messages	Social cognitive theory
A17	Changizi (2022)	Educational clip + WhatsApp + text messages - Pamphlet: muscle relaxation and guided image visualization - Video and text messages: goal-setting skills - WhatsApp for teaching physical exercises, reviewing patient care experiences - Daily messages to reinforce and support	-
A18	Ochi (2022)	Habit-B program: smartphone application + emails + smartphone-supported high-intensity interval training (HIIT) - Exercise counseling and guidance - Home-based exercise support using ICT (emails and exercise app) - Wearable device to monitor PA	Social cognitive theory

*Articles published with the same intervention, and refer to Supplement B for more information.

- Emails: Two studies (A1, A18) used email messages as a means to encourage PA.
- Telephone or text messages: Telephone calls or text messages were used in studies A7, A9, and A13 to provide counseling or follow-up on PA participation, and in studies A15 and A16 for PA training.
- Wearable devices: Five studies (A7[a,b], A8, A15[a,b], A16, A18) incorporated wearable devices, such as activity trackers or pedometers, into their interventions to monitor participants' PA levels.

All studies except for three studies (A4, A11, A14) implemented interventions using a combination of two or more technologies.

6. Retention and Sustainability and Theories for Intervention Development

The overall retention rates were high, ranging from 67.7% to 100%. No serious intervention-related adverse events were reported. Four studies (A3[a,b], A8, A14, A15[a,b]) measured the sustained between-group effects of digital PA interventions at 24 weeks (A8), 6 months (A3[a,b], A14), and 18 months (A15[a,b]). The intervention effects were maintained in three studies (A3[a,b], A14, A15[a,b]); however, in one study (A8), the intervention effects declined and became non-significant between the groups. Attrition was minimal at follow-up in three studies (A3[a,b], A8, A15[a,b]); however, one study (A14) reported that the attrition rates increased from 15.7% to 25.7% at the 6-month follow-up.

Six studies applied theories associated with health behavior promotion, including the social cognitive theory (A1, A10, A15[a,b], A16, A18) and the transtheoretical model [24] (A2). Three (A1, A2, A10) studies explicitly described theoretical underpinnings and how the theory was used to develop the interventions and measured the main constructs such as self-efficacy (A1, A2, A10), stage of change (A2), or motivation (A10). Two studies (A1, A2) significantly increased the self-efficacy for exercise, and Lee et al. (A2) reported a significant increase in the stage of change in the intervention groups. The other studies (A15[a,b], A16, A18) provided a brief explanation about the major concepts of theories; their interventions were grounded and did not measure the theoretical construct.

7. RoB Assessment

Among 16 RCTs, 2 (A7[a,b], A17) had concerns in the randomization domain since they did not clearly describe the randomization process and allocation concealment (Figure 3). Owing to the nature of the studies, no studies blinded the participants and only some blinded the assessors. This fact increased the risk of bias in the measurement of the outcome domain since 44% of studies (A8, A9, A12–A17) used self-report outcome measures, for which the assessment of the outcome could be potentially skewed based on the participants' knowledge of their group assignment status.

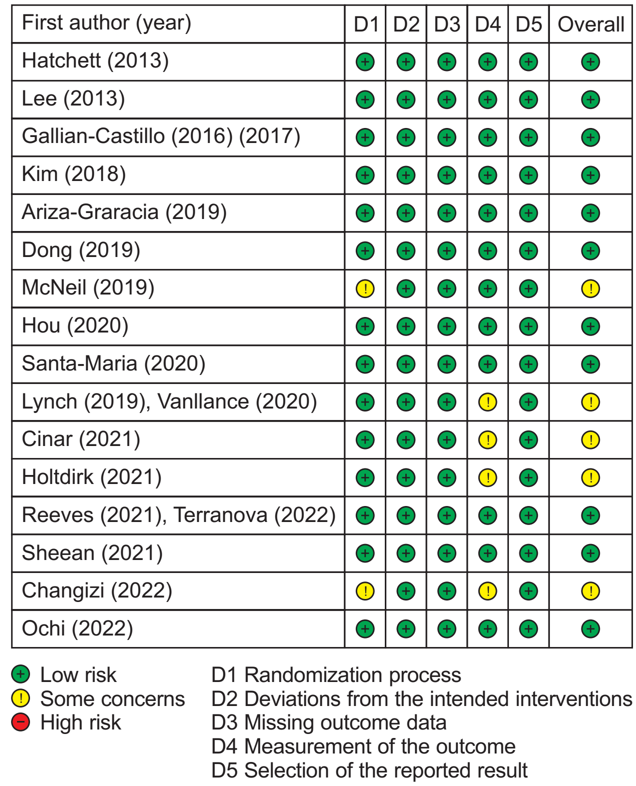

Figure 3. Risk of bias graph for included randomized controlled trials.

8. Publication Bias

The results of the Egger regression test to assess the publication bias for studies with functional capacity ($p = 0.28$) and QoL ($p = 0.93$) showed no evidence of publication bias. However, publication bias for the studies with total PA times was observed ($p < 0.001$) and corrected using the trim-and-fill method [25].

IV. Discussion

The findings of this study showed that digital PA interventions significantly improved the PA and functional capacity of BC patients and survivors. The meta-analysis of pooled data from fivve studies (A1, A9, A10, A14, A17) showed that digital PA interventions significantly increased PA duration with a medium effect size (SMD = 0.71; 95% CI, 0.25–1.18)

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and high heterogeneity (I^2 = 86.64%). The qualitative analysis of the other included studies also showed significant intervention effects, demonstrating that digital PA interventions are promising interventions that actually improve exercise participation among patients with BC. The result regarding PA duration agrees with a previous study conducted by Roberts et al. [5] who reported that DHIs for cancer survivors significantly increased MVPA, with considerable heterogeneity (effect size = 41.5, I^2 = 81.3%).

Among the five studies included in the meta-analysis of PA duration, only the study by Holtdirk et al. (A14) observed no significant between-group effects. This study's intervention components differed from the other three studies that did demonstrate significant between-group effects. The intervention in this study did not involve any interaction or feedback with providers during the study period. In contrast, the other three studies included regular interactions with the research team via text messages (A17), phone calls (A8), or self-monitoring (A9) as key elements of their interventions. However, another study (A15[a,b]), not included in the meta-analysis, involved consistent interaction with participants through phone calls and optional texts. Despite a relatively long intervention period (12 months), this study reported non-significant findings for PA-related outcomes. Therefore, additional research is required to determine which component would effectively contribute to improving PA in this population.

Various combinations of digital technologies, including mobile applications, telephone, text messages, and websites, have been used to deliver digital interventions. Furthermore, these digital technologies were applied to different roles, such as PA training or encouragement (A1, A2, A3[a,b], A5, A13, A15[a,b], A16, A17, A18), disease- or treatment-related education (A4, A6, A11–A13), monitoring PA performance (A7[a,b], A8, A12, A15[a,b], A16, A18), and/or feedback or peer support (A7, A9, A10, A13). The specific subtypes or dosage of interventions did not seem to significantly impact the improvement of PA duration. For instance, the use of a single mode such as email messages (A1), as well as the combined use of multiple technologies like mobile applications, telephone calls, and/or text messages (A8, A12, A13), led to a significant increase in PA, despite the relatively small sample size. However, determining the most effective combination of digital technologies to enhance PA in this population proved challenging. Further research is required to compare the effects of PA interventions that utilize different technologies.

A meta-analysis of the 6MWT with three studies (A3[b], A5, A18) showed that digital PA interventions effectively increased functional capacity with a medium effect size (SMD = 0.38; 95% CI, 0.10–0.66; I^2 = 14.36%). This finding is supported by previous studies reporting that exercise training improved exercise capacity and endothelial function [26]. Functional capacity is linked to the ability to carry out activities primarily under aerobic conditions, which involves the integration of the cardiovascular, pulmonary, and skeletal muscle systems [27,28]. Consequently, the improvement in PA observed after participating in interventions could lead to an increase in functional capacity.

A meta-analysis of QoL using pooled data from nine studies showed a significant intervention effect (SMD = 0.45; 95% CI, 0.22–0.69; I^2 = 65.55%). This finding suggests that digital interventions promoting PA effectively improved the QoL of BC survivors and patients. Conversely, a prior meta-analysis conducted by Roberts et al. [5] did not identify a significant improvement in cancer-specific QoL following the implementation of DHIs for cancer survivors. However, a direct comparison is not feasible since the study by Roberts et al. [5] only incorporated five studies in their review, which included both RCTs and pre-post designs, and did not limit the types of cancer.

The overall retention rate of the included studies was high; however, there was insufficient evidence regarding sustainability. Only four studies (A3[a,b], A8, A14, A15[a,b]) examined sustained effects post-intervention, with three of these studies reporting that the intervention effects were maintained. Kabore et al. [29] identified several barriers to the sustained effects of DHIs, including user integration with the technology, lack of staff and expertise, and barriers related to age, language, myths, and misconceptions. Given the rapid advancement of digital health technology and the high prevalence of BC, there is an urgent need to examine the long-term effects of digital PA interventions for this demographic.

This study had some limitations. First, the majority of participants in the chosen studies were in their 40s or 50s. Given the rising prevalence of BC in older age groups, the findings of this study may not be broadly applicable to older individuals with BC. Second, the RoB assessment results suggest that evaluating the effects of interventions could be challenging, primarily due to the reliance on patient-reported outcome measurements for PA. Given the nature of the studies, where blinding participants was not feasible, the subjectivity of these measurements could impede an accurate estimation of PA changes, thereby complicating the interpretation of the impact of digital PA interventions. Lastly, the meta-analysis of the pooled effect of PA duration demonstrated a high degree of heterogeneity stemming from variations in the intervention, the intervention group, or the data analysis method [30]. A high level of heterogeneity is problematic as it can render the efficacy of interventions unpredictable when applied to new participants [30]. Conducting RCTs to investigate the effects of interventions with similar delivery modes and employing objective measures could aid in comparing and identifying the most effective PA-promoting intervention. Despite these limitations, this study holds significance as it offers the most recent evidence and current understanding of the effects of digital PA interventions, by selecting relatively high-quality studies for BC patients and survivors.

In conclusion, this systematic review and meta-analysis demonstrated that digital PA interventions for BC patients and survivors effectively increased daily PA duration, functional capacity, QoL compared to usual care. A variety of digital technologies were employed to deliver PA training, disease-related education, and feedback or reminders from a third party or for self-monitoring, all of which effectively increased PA. Moreover, the high overall retention and compliance rates suggest that this population may encounter minimal barriers when participating in digital PA interventions. Further research is needed to explore the long-term effects of digital PA interventions and to conduct studies with older BC patients and survivors.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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Supplementary Materials

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