

## Review

# Exercise interventions and positive adaptation in childhood cancer survivors: Implications for school physical education

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**Abstract:** Advances in pediatric oncology have substantially improved survival rates, yet many childhood cancer survivors continue to face long-term physical, psychological, and educational challenges. Positive adaptation encompassing resilience, post-traumatic growth (PTG), quality of life (QoL), and psychosocial adjustment has emerged as a critical focus in survivorship care. Exercise interventions represent a promising strategy to promote adaptation, but their integration into school settings remains underexplored. This systematic review and meta-analysis, conducted in accordance with PRISMA 2020 guidelines, synthesized evidence from ten studies published between 2009 and 2023, spanning randomized controlled trials, quasi-experiments, and pilot programs. Interventions included aerobic, resistance, adventure-based, play-oriented, and technology-assisted formats, delivered in clinical, community, and home environments. Pooled findings demonstrated consistent benefits for QoL, muscular strength, and self-efficacy, with large-scale trials confirming sustained improvements up to 12 months. Evidence for PTG was mixed, with one small pilot reporting significant gains and another finding no change, underscoring the need for adequately powered studies. Fatigue outcomes varied by treatment stage: inpatient interventions-maintained stability during intensive therapy, while community-based adventure programs reduced fatigue in survivorship. Group-based and play-oriented approaches appeared particularly effective in fostering peer bonding and psychosocial growth. No studies directly embedded exercise into routine school physical education, highlighting a critical gap. Exercise interventions are safe, feasible, and multidimensional strategies that support physical recovery and psychosocial adaptation in childhood cancer survivors. Future research should prioritize school-based implementation and standardized evaluation to bridge clinical rehabilitation and educational reintegration.

**Keywords:** Cancer survivors; exercise intervention; positive adaptation; post-traumatic growth (PTG); quality of life (QoL); school physical education

## 1. Introduction

### 1.1. Background

The landscape of pediatric oncology has evolved significantly, resulting in improved survival rates for childhood cancer patients due to advances in treatment protocols. Recent data indicate that five-year survival rates have exceeded 80% in numerous high-income countries and continue to rise globally [1]. These advancements stem from an integrated approach combining multimodal therapies, precision diagnostics, and enhanced supportive care [2].

Despite these notable gains, the journey post-treatment is fraught with challenges. Survivors often face ongoing health concerns, including physical sequelae such as impaired fitness, compromised bone health, and various secondary health issues linked

to previous treatments [3]. Furthermore, psychological outcomes can be disheartening, with many survivors indicating high levels of anxiety, depression, and a reduced quality of life (QoL) [4,5]. Educational barriers also exist, as many survivors grapple with reintegration into school environments, which can hinder their developmental progress [6]. These persistent issues highlight the necessity for a comprehensive survivorship model that incorporates holistic perspectives on adaptation and well-being [7].

## **1.2. Concept of positive adaptation**

Within pediatric oncology survivorship, positive adaptation represents an overarching, multidimensional construct rather than a single outcome. It encompasses several related but conceptually distinct domains [8,9]. Quality of life (QoL) reflects a survivor's perceived functioning and well-being across physical, emotional, social, and school domains and is typically assessed using standardized health-related measures. Resilience, by contrast, refers to the capacity to maintain or regain psychological stability in the face of adversity, emphasizing coping resources and adaptive regulation rather than subjective well-being alone. Post-traumatic growth (PTG) represents a more transformative process, capturing positive psychological change that may emerge following cancer-related trauma, such as enhanced personal strength, altered life priorities, and deeper interpersonal relationships. While these domains are interrelated, they reflect different mechanisms and time courses of adaptation; therefore, they are examined in this review as complementary but non-interchangeable indicators of positive adaptation.

## **1.3. Exercise as an intervention**

An effective intervention for promoting positive adaptation is physical activity, which has substantial support in the literature for its role in enhancing both physical and psychosocial health among pediatric cancer survivors [1,10]. Exercise has been shown to improve cardiovascular endurance, muscle strength, and alleviate fatigue an all-too-common late effect of cancer therapies [11]. Psychologically, structured physical activity has been associated with reduced anxiety and depression and improved self-esteem and social integration [12].

## **1.4. Research gap**

However, while many interventions have been conducted in clinical settings, there remains a significant gap in research concerning the integration of exercise into school environments, where children spend a substantial amount of their time and can cultivate social connections [2]. School-based physical education programs provide an optimal context for these interventions, as they can bridge the gap between clinical care and developmental reintegration[6]. Moreover, existing reviews often focus narrowly on specific health outcomes like QoL or fatigue without considering the broader implications of positive adaptation and resilience [5,13].

Given this backdrop, research is urgently needed to scrutinize the multifaceted nature of exercise interventions in pediatric oncology, focusing on their application within educational contexts. The proposed systematic review aims to synthesize

evidence regarding exercise's impact on resilience and positive adaptation outcomes for childhood cancer survivors while exploring the feasibility of translating these findings into school physical education curricula [2,3].

This thorough approach not only addresses the existing gaps in the literature but also aspires to inform interdisciplinary practices within survivorship care, combining insights from clinical oncology, psychology, and education into a holistic model of support [8,9].

## **2. Related works**

### **2.1. Positive adaptation in pediatric oncology**

The trajectory of childhood cancer survivorship extends well beyond remission, encompassing challenges to physical health, psychosocial functioning, and educational attainment. The concept of positive adaptation has gained prominence as a multidimensional construct capturing how children adjust to the aftermath of illness. Positive adaptation includes resilience, coping strategies, quality of life (QoL), psychosocial adjustment, and benefit-finding. It reflects not only the ability to withstand adversity but also the ability to reframe challenges as opportunities for development [14].

Several theoretical frameworks provide a foundation for understanding positive adaptation in pediatric oncology. Resilience theory emphasizes the dynamic interplay between risk and protective factors that allow children to “bounce back” from adversity. Factors such as supportive family environments, peer connections, and adaptive coping skills contribute to resilience [15]. Ecological models highlight the layered influences of individual, interpersonal, organizational, and societal systems in shaping outcomes, underscoring the role of schools and communities alongside medical care [16]. Stress-coping models further explain how survivors evaluate and respond to illness-related stressors, suggesting that constructive coping can lead to psychological growth and long-term adjustment [17].

Common adaptation outcomes reported in the literature include enhanced resilience, improvements in QoL, reduced psychological distress, and greater capacity for psychosocial adjustment. Importantly, adaptation is not a linear process; many children simultaneously experience lingering distress and new strengths [18]. Recognizing this complexity is essential for evaluating interventions aimed at fostering positive adaptation.

### **2.2. Exercise and survivorship**

Exercise has been increasingly recognized as a cornerstone of survivorship care for children with cancer. Its benefits extend across both physical and psychosocial domains, offering a holistic approach to rehabilitation. Regular participation in exercise helps restore fitness, bone health, and mobility, counteracting the deconditioning effects of treatment such as chemotherapy-induced muscle weakness or reduced cardiopulmonary function [19]. Improvements in balance and coordination are also critical for survivors seeking to re-engage in daily activities and school life.

Equally important are the psychosocial benefits of exercise. Participation in

structured physical activity has been linked to improvements in quality of life, reductions in anxiety and depressive symptoms, and enhanced self-esteem [20]. Exercise settings often foster opportunities for social interaction, allowing survivors to reconnect with peers, form new friendships, and rebuild confidence in group environments. Group and adventure-based programs, such as outdoor activities or team sports, have been particularly noted for their role in enhancing social bonds and reducing isolation [21].

Evidence from randomized trials and community programs consistently shows that exercise is safe and feasible for pediatric cancer survivors. Moreover, the benefits appear to accrue across a variety of exercise modalities, including aerobic, resistance, play-based, and mind–body practices such as yoga or tai chi [22]. These findings highlight exercise as a flexible and adaptable intervention that can address diverse needs and preferences within survivorship care.

### **2.3. Settings of interventions**

Despite the promising outcomes associated with exercise, the settings in which these interventions are delivered remain largely confined to clinical, hospital, or community-based contexts. Many interventions are designed within oncology rehabilitation programs and involve close supervision by healthcare professionals. While this ensures safety and medical oversight, it also limits accessibility once formal treatment ends. Community-based programs, such as survivorship camps or sports clubs, provide more naturalistic opportunities for participation but are often limited in scale and availability [23].

In contrast, school physical education (PE) remains an underutilized platform for supporting childhood cancer survivors. Schools represent a central arena in children’s lives, where reintegration after cancer treatment is critical for both educational attainment and social development. However, few studies have examined the integration of exercise interventions into PE curricula, and no large-scale trials have been conducted in real school settings [24]. This omission represents a significant gap, as PE offers the potential for regular, structured activity delivered in inclusive group contexts that mirror survivors’ everyday environments.

The lack of school-based research also reflects broader challenges in bridging medical and educational domains. While oncology research prioritizes health outcomes, educational systems emphasize inclusion, participation, and developmental milestones. An interdisciplinary approach that links these priorities is needed to ensure survivors are supported holistically [25].

### **2.4. Summary of evidence gap**

The literature demonstrates that exercise interventions yield substantial benefits for childhood cancer survivors, spanning physical fitness, psychosocial well-being, and aspects of positive adaptation. However, the evidence is fragmented, with most studies focusing narrowly on fatigue, fitness, or quality of life rather than examining positive adaptation as a comprehensive construct. Outcomes such as resilience, coping, and benefit-finding are seldom assessed systematically, leaving gaps in understanding how exercise contributes to broader adjustment processes [26].

A further limitation lies in the absence of school-based PE interventions. While clinical and community programs provide valuable insights, they do not address the realities of reintegration into educational settings where survivors spend the majority of their developmental years. Embedding exercise within PE curricula could normalize participation, reduce stigma, and create opportunities for peer-based support, but empirical evidence in this area remains scarce [27].

These gaps underscore the need for interdisciplinary research that connects oncology, psychology, and education. By synthesizing findings across domains, future work can clarify how exercise fosters positive adaptation and identify strategies for translating clinical and community-based interventions into schools. Such efforts will help ensure that exercise is not merely an adjunct to survivorship care but a central component of holistic rehabilitation and reintegration.

### **3. Methodology**

#### **3.1. Design**

This study employed a systematic review and meta-analysis framework in accordance with the PRISMA 2020 guidelines. The review aimed to synthesize and critically evaluate existing evidence on exercise-based interventions designed for children and adolescents with cancer, with a particular focus on outcomes related to positive adaptation, such as quality of life, resilience, coping, and psychosocial adjustment. By systematically identifying, appraising, and pooling data from randomized controlled trials, quasi-experimental studies, and pilot interventions, this approach ensured methodological rigor and transparency while allowing for quantitative assessment of effect sizes and heterogeneity across studies.

#### **3.2. Eligibility criteria (PICOS)**

The eligibility criteria for this review were established using the PICOS framework.

Population (P): studies were included if they involved children and adolescents diagnosed with any type of cancer, regardless of treatment stage or survivorship status.

Intervention (I): eligible interventions comprised exercise-based programs, including aerobic training, resistance exercise, mind–body activities, structured play, or group-based physical activity, delivered in clinical, community, or other settings.

Comparator (C): studies were required to include a comparator such as usual care, standard care, or no intervention.

Outcomes (O): only studies reporting at least one positive adaptation outcome were included, such as quality of life, post-traumatic growth, resilience, coping skills, or psychosocial adjustment.

Study Design (S): randomized controlled trials, quasi-experimental designs, and pilot feasibility studies were considered eligible, while reviews, case reports, and qualitative-only studies were excluded.

#### **3.3. Search strategy**

**Figure 1** shows the PRISMA diagram for this study. A comprehensive search

strategy was implemented to identify relevant studies examining exercise interventions in children and adolescents with cancer. Electronic databases including Wiley ( $n = 1514$ ), Web of Science ( $n = 1453$ ), and PubMed ( $n = 346$ ) were systematically searched, yielding a total of 3,313 records. Additional sources were screened through Google Scholar ( $n = 3$ ) and reference lists of eligible articles ( $n = 2$ ). All retrieved records were imported into Mendeley for reference management, and duplicate entries ( $n = 2876$ ) were removed prior to screening. Title, abstract, and keyword screening resulted in 442 records, of which 112 were excluded for irrelevance, 97 for age inaccuracy, and 215 for lacking an exercise component. Eighteen full-text articles were further evaluated, with 3 excluded due to incomplete data reporting and 5 for not meeting inclusion criteria. Ultimately, 10 studies were included in the final analysis, all of which contributed data for the meta-analysis.

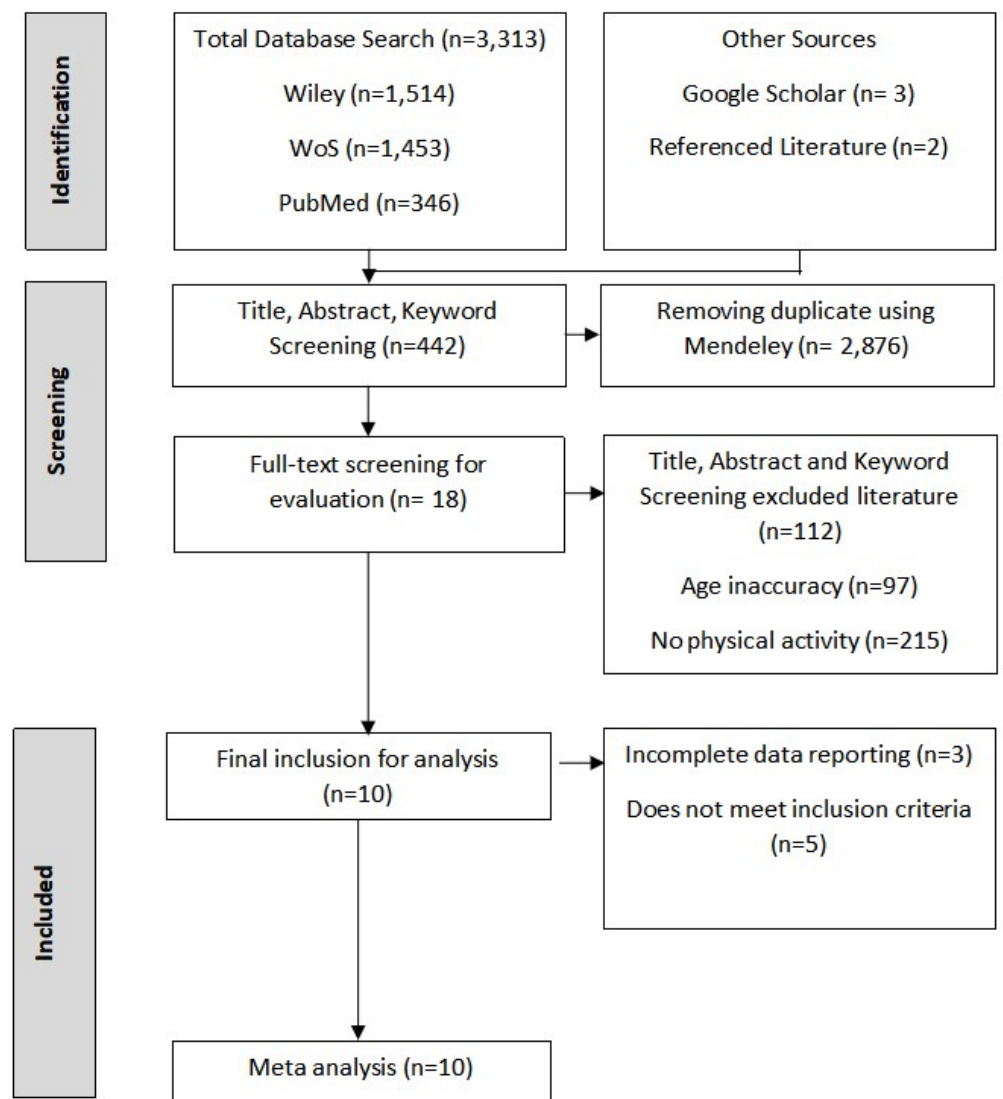


**Figure 1.** PRISMA diagram.

### 3.4. Statistical analysis

Data from eligible studies were synthesized using quantitative meta-analytic techniques. Effect sizes were calculated as standardized mean differences (Hedges'  $g$ )

or Cohen's  $d$ , depending on the reporting of outcomes, with 95% confidence intervals to estimate precision. A random-effects model was applied to account for expected heterogeneity across study populations, intervention types, and settings. Statistical heterogeneity was assessed using Cochran's  $Q$  test and quantified by the  $I^2$  statistic, with thresholds of 25%, 50%, and 75% representing low, moderate, and high heterogeneity, respectively. Planned subgroup analyses were conducted by age group, intervention type (aerobic, resistance, mind-body, play-based, or mixed), and intervention setting (clinical, community, or other). Publication bias was evaluated through visual inspection of funnel plots and formally tested with Egger's regression. All statistical analyses were performed in *R* (version 4.5.1) using the *metafor* and *meta* packages.

### 3.5. Risk of bias assessment

Risk of bias was assessed independently by two reviewers using tools appropriate to study design. Randomized controlled trials were evaluated using the Cochrane Risk of Bias 2.0 (RoB 2) tool, while non-randomized, quasi-experimental, and pilot studies were assessed using the ROBINS-I framework. Overall, the randomized trials demonstrated low to moderate risk of bias, primarily related to performance and detection domains, whereas pilot and feasibility studies exhibited higher risk due to small sample sizes, absence of control groups, and limited blinding. These methodological quality considerations were incorporated into the interpretation of findings, with greater weight given to evidence derived from randomized controlled trials when drawing conclusions regarding intervention effectiveness.

## 4. Result and discussion

### 4.1. Study selection & characteristics

**Table 1** shows a total of ten intervention studies published between 2009 and 2023 were identified, representing diverse geographic regions including South Korea, Hong Kong, Australia, Spain, the Netherlands, and the United States. The studies varied considerably in scale, with small feasibility trials enrolling as few as six participants and the largest randomized controlled trial including 222 survivors. The populations studied were heterogeneous, with the majority of participants diagnosed with acute lymphoblastic leukemia, though survivors of acute myeloid leukemia, lymphoma, brain tumors, bone tumors, and those undergoing hematopoietic stem cell transplantation were also included.

The interventions delivered were wide-ranging but shared the common goal of promoting physical activity and enhancing recovery. Some programs adopted play- or adventure-based designs that encouraged peer interaction through team games, rope courses, and interactive play, while others implemented structured aerobic, resistance, and flexibility exercises either in hospital, at home, or under online supervision. Several studies incorporated technology or group-based support, such as web-delivered activity platforms or motivational coaching, to encourage adherence.

Despite methodological differences, all studies focused on outcomes aligned with positive adaptation, including post-traumatic growth, quality of life, fatigue, physical

fitness, body composition, and, in some cases, neurocognitive functioning. Two Korean pilot trials directly assessed post-traumatic growth, while most studies emphasized quality of life through standardized tools such as the Pediatric Quality of Life Inventory and various measures of fitness performance and body composition. The larger randomized controlled trials, particularly those conducted in Hong Kong, consistently demonstrated significant improvements in quality of life, fatigue reduction, and self-efficacy, whereas smaller-scale studies primarily provided evidence for the feasibility, safety, and acceptability of exercise during or after treatment.

Taken together, the findings suggest that exercise interventions are both safe and beneficial in enhancing multiple domains of positive adaptation among childhood cancer survivors. Nevertheless, the heterogeneity of study designs and outcome measures, along with the limited number of trials that explicitly evaluate post-traumatic growth and resilience, underscores the need for larger, standardized, and long-term studies to clarify the durability and scope of these benefits.

**Table 1.** Study characteristic of included study.

| Author (year)             | Country     | Study design         | Sample (n)           | Age (years) | Cancer type                    | Intervention                                                   | Comparator                 | Outcomes (positive adaptation)                   | Tools                               | Key findings                                                             |
|---------------------------|-------------|----------------------|----------------------|-------------|--------------------------------|----------------------------------------------------------------|----------------------------|--------------------------------------------------|-------------------------------------|--------------------------------------------------------------------------|
| Kim and Park [15]         | South Korea | Pre-post pilot       | 6                    | 11–13       | ALL, AML, SAA                  | 8-wk exercise + play (2×/wk group + 5×/wk home)                | None                       | PTG, QoL, strength                               | PTGI, PedsQL, PAPS                  | ↑ PTG, ↑ QoL (school & total), ↑ strength (all $p < 0.05$ )              |
| Kim, Chae and Park [28]   | South Korea | Pre-post pilot       | 8                    | 9–12        | ALL, AML, NHL, SAA             | 8-wk videoconferencing home exercise (2×/wk Zoom + 5×/wk home) | None                       | PTG, QoL, fitness                                | PTGI, PedsQL, PAPS                  | PTG ↓ NS; QoL ↑ NS; significant ↑ flexibility, strength, power           |
| Bogg et al. [29]          | Australia   | Feasibility pre-post | 14                   | 6–18        | HSCT (ALL, AML, AA, ALCL, MPD) | Inpatient supervised exercise (5×/wk, 30–40 min)               | None                       | QoL, fatigue, aerobic fitness, strength, balance | 6MWT, dynamometry, balance, PedsQL  | Stabilized strength & fatigue; ↓ aerobic fitness and balance; QoL stable |
| Chamorro-Viña et al. [30] | Spain       | Controlled trial     | 20 (7 INT, 13 CTRL)  | Mean 8      | HSCT                           | 3-wk intrahospital aerobic + resistance (5×/wk)                | Historical controls        | Body comp, fitness, immune recovery              | Anthropometry, HR, resistance loads | ↑ body comp, ↑ muscle strength; safe (no immune compromise)              |
| Chung et al. [31]         | Hong Kong   | RCT                  | 69 (33 INT, 36 CTRL) | Mean 12.6   | Leukemia, lymphoma, others     | 4-day adventure + health education (team games, ropes)         | Placebo leisure activities | QoL, PA, self-efficacy                           | PedsQL, CUHK-PARCY, PA-SE           | ↑ PA, ↑ self-efficacy, ↑ QoL at 12–18 mo (all $p < 0.001$ )              |

**Table 1.** (Continued).

| Author (year)       | Country     | Study design             | Sample (n)              | Age (years)       | Cancer type                                    | Intervention                                                           | Comparator                            | Outcomes (positive adaptation)                    | Tools                                                    | Key findings                                                                        |
|---------------------|-------------|--------------------------|-------------------------|-------------------|------------------------------------------------|------------------------------------------------------------------------|---------------------------------------|---------------------------------------------------|----------------------------------------------------------|-------------------------------------------------------------------------------------|
| Ruble et al. [32]   | USA         | Pilot RCT                | 20 (10 INT, 10 CTRL)    | 8–12              | Mixed CCS                                      | 6-mo group PA (camp + monthly reunions + coaching)                     | Control (newsletters)                 | PA (MVPA), PA self-efficacy                       | ActiGraph, CSAPPA                                        | ↑ MVPA (67% INT vs 14% CTRL), ↑ self-efficacy; $r = 0.55$ correlation               |
| Kim et al. [23]     | South Korea | Quasi-experimental pilot | 10 (6 INT, 4 CTRL)      | 8–18              | Leukemia, brain, bone                          | 6-wk mixed supervised + home exercise (line dance, sports, resistance) | Control group                         | Fitness, body comp                                | Sit-ups, push-ups, chair stand, grip, 6MWT, BIA          | ↑ sit-ups, ↑ chair stand, ↓ fat mass ( $p < 0.05$ ); adherence 93%                  |
| Hartman et al. [33] | Netherlands | RCT                      | 51 (25 INT, 26 CTRL)    | 1–18 (median 5.4) | ALL (on treatment)                             | 2-yr home-based physiotherapist-guided motor program                   | Standard care                         | BMD, body comp, motor performance, ankle mobility | DXA, Movement-ABC, goniometer                            | No difference in BMD or motor; intervention ↓ body fat faster post-treatment        |
| Howell et al. [34]  | USA         | RCT                      | 78 (53 INT, 25 CTRL)    | 11–15             | Mixed CCS                                      | 24-wk web-based PA (avatar, feedback, rewards)                         | Control (monitor + education)         | PA, fitness, neurocognition, QoL                  | ActiGraph, grip, sit-ups, push-ups, WASI, D-KEFS, PedsQL | ↑ grip, sit-ups, push-ups ( $p < 0.01$ ); ↑ IQ & inhibition; ↑ QoL total & physical |
| Li et al. [35]      | Hong Kong   | RCT                      | 222 (117 INT, 105 CTRL) | 9–16              | Leukemia, lymphoma, brain, bone, neuroblastoma | Adventure-based training (4×1-day sessions over 6-mo)                  | Placebo leisure (films, chess, talks) | Fatigue, PA, self-efficacy, QoL                   | FS-C, CUHK-PARCY, PA-SE, PedsQL                          | ↓ fatigue, ↑ PA, ↑ self-efficacy, ↑ QoL at 12 mo (all $p < 0.001$ )                 |

## 4.2. Intervention features

The ten included studies demonstrated considerable variability in intervention design, duration, and delivery context, yet several common patterns emerged (refer **Table 2**). Intervention duration ranged from short-term, intensive programs such as four-day adventure-based training in Hong Kong [31] and three-week inpatient protocols during hematopoietic stem cell transplantation in Spain [30] to longer sustained interventions including six-month group programs with follow-up reunions [32], 24-week web-based activity promotion [34], and two-year home-based physiotherapist-guided motor programs [33]. This heterogeneity highlights both the adaptability of exercise-based approaches and the challenges in drawing direct comparisons across studies.

The type of activity implemented also varied, reflecting cultural and clinical contexts. Adventure- and play-based interventions were common in Hong Kong and South Korea, emphasizing team games, rope courses, dance, and structured play to foster engagement and peer interaction [15,35]. Structured exercise training, incorporating aerobic, resistance, flexibility, or balance components, was frequently used in clinical or rehabilitation settings, especially during hospitalization or treatment recovery [23,29,33]. In addition, technology-supported programs such as

videoconferencing and web-based platforms expanded accessibility, particularly during the COVID-19 pandemic [28,34].

The delivery setting spanned both clinical and community environments. Hospital-based interventions were commonly employed for patients undergoing or recovering from hematopoietic stem cell transplantation, ensuring close supervision and medical oversight [29,30]. In contrast, community- and home-based programs sought to normalize activity participation within daily life and facilitate long-term adherence, as exemplified by the Project TREK camp model [32] and the home-based exercise plus nutrition program in South Korea [23].

These findings suggest that exercise interventions for childhood cancer survivors are highly adaptable in format and delivery, ranging from structured clinical rehabilitation to socially oriented adventure programs and digitally mediated platforms. This flexibility offers opportunities for tailoring interventions to survivor needs and resources, but also contributes to heterogeneity in reported outcomes and complicates direct synthesis.

**Table 2.** Intervention and comparator details.

| Author (year)             | Intervention type                                                                 | Duration & frequency                                           | Delivery/setting                | Comparator                                        |
|---------------------------|-----------------------------------------------------------------------------------|----------------------------------------------------------------|---------------------------------|---------------------------------------------------|
| Kim and Park [15]         | Exercise + play (supervised + home)                                               | 8-wk; 2×/wk group, 5×/wk home                                  | Community/school setting        | None                                              |
| Kim et al. [28]           | Videoconferencing home exercise (aerobic, strength, flexibility)                  | 8-wk; 2×/wk Zoom, 5×/wk home                                   | Home-based, technology-assisted | None                                              |
| Bogg et al. [29]          | Inpatient supervised aerobic, strength, balance                                   | Daily, 5×/wk during HSCT admission (30–40 min/session)         | Hospital ward                   | None                                              |
| Chamorro-Viña et al. [30] | In-hospital aerobic + resistance                                                  | 3-wk; 5×/wk (50 min/session) during HSCT hospitalization       | Pediatric HSCT unit             | Historical controls                               |
| Chung et al. [31]         | Adventure-based training + health education (team games, rope courses, workshops) | 4-day intensive camp, with follow-up assessments at 12 & 18-mo | Community camp setting          | Placebo leisure activities (films, museum visits) |
| Ruble et al. [32]         | Group PA intervention (5-day camp + monthly reunions, personalized PA plans)      | 6-mo (initial camp + 5 reunions)                               | Community-based program         | Control newsletters (PA info only)                |
| Kim et al. [23]           | Mixed supervised + home exercise (dance, resistance, sports)                      | 6-wk; 2×/wk supervised (80–100 min), additional home practice  | Hospital + home                 | Usual care (no exercise)                          |
| Hartman et al. [33]       | Home-based physiotherapist-guided motor program (hand/leg exercises, jumping)     | 2 yrs; daily exercises, reviewed every 6-wk                    | Home with clinical follow-up    | Standard care                                     |
| Howell et al. [34]        | Web-based PA promotion (activity tracker, avatar, feedback, rewards)              | 24-wk; self-paced with weekly targets                          | Home/online                     | Monitoring + general education                    |
| Li et al. [35]            | Adventure-based training (rope courses, rock climbing, shuttle runs, team games)  | 4× 1-day sessions over 6-mo                                    | Community-based                 | Placebo leisure (chess, films, health talks)      |

### 4.3. Positive adaptation outcomes

Across the ten included studies, a broad range of positive adaptation outcomes were assessed, encompassing psychosocial domains such as post-traumatic growth (PTG), quality of life (QoL), fatigue, and self-efficacy, alongside physical domains including fitness, motor performance, and body composition. This diversity reflects both the multifaceted challenges faced by childhood cancer survivors and the potential

for exercise interventions to yield wide-ranging benefits. **Table 3** shows the positive adaptation outcome details and findings.

**Table 3.** Positive adaptation outcome details and findings.

| Outcome domain              | Studies             | Tools used                                              | Findings                                                                                                                   |
|-----------------------------|---------------------|---------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------|
| Post-traumatic growth (PTG) | [15,28]             | PTGI (Korean version)                                   | Mixed: significant ↑ PTG in one study; NS in the other                                                                     |
| Quality of life (QoL)       | [15,28,30,31,34,35] | PedsQL 4.0, Cancer Module                               | Large RCTs (Li 2018; Chung 2014; Howell 2018) showed significant ↑ QoL; smaller studies reported stability or modest gains |
| Fatigue                     | [29,33,35]          | FS-C, PedsQL Fatigue                                    | Li (2018) significant ↓ fatigue; Bogg (2015) stable; Hartman (2009) stable during treatment                                |
| Fitness                     | [15,23,28–34]       | PAPS, 6MWT, grip, sit-ups, push-ups, CUHK-PARCY, CSAPPA | Consistent ↑ muscular strength, endurance, flexibility; ↑ PA levels; stable aerobic fitness during HSCT                    |
| Body composition            | [23,30,33]          | DXA, BIA, anthropometry                                 | ↓ fat mass (Kim 2023; Hartman 2009), ↑ fat-free mass (Chamorro-Viña 2010)                                                  |
| Neurocognitive outcomes     | [34]                | WASI, D-KEFS                                            | Significant ↑ Full Scale IQ and inhibition control in intervention group                                                   |

#### 4.3.1. Post-traumatic growth (PTG)–PTGI score outcome

Two small Korean pilot studies uniquely evaluated post-traumatic growth (PTG) using the Posttraumatic Growth Inventory, demonstrating mixed findings. Author Kim & Park reported a large improvement in PTGI scores (mean increase of ~12 points, standardized effect  $\approx 1.1$ ), suggesting that a combined exercise and play program may foster psychosocial growth [15]. In contrast, Kim et al. which delivered a videoconferencing-based exercise program during the COVID-19 pandemic, observed no significant change in PTG scores [28]. The pooled random-effects analysis of standardized mean change favored exercise but with wide confidence intervals and high heterogeneity, reflecting the extremely small sample sizes ( $n = 6$  and  $n = 8$ ) and differences in intervention delivery (in-person vs. online). These findings provide preliminary evidence that exercise may support PTG, but the current data are insufficient to draw firm conclusions. Larger randomized controlled trials explicitly targeting PTG and related psychosocial constructs are warranted to confirm these early signals. **Figure 2** depicts a forest plot of standardized mean change (Hedges  $g$ ) for post-traumatic growth (PTG) outcomes following exercise interventions in childhood cancer survivors. Positive values indicate improvements in PTG after the intervention. Results from Kim and Park [15] and Kim et al [28] are shown individually and pooled using a random-effects model.

#### 4.3.2. Quality of life (QoL)–PedsQL outcome

The most consistently reported outcomes were related to quality of life (QoL). Six studies incorporated the Pediatric Quality of Life Inventory (PedsQL), with large randomized trials in Hong Kong showing significant improvements in overall QoL, sustained up to 12 months [31,35]. Similarly, Howell et al. demonstrated improvements in total QoL and physical functioning in adolescents following a 24-week web-based intervention [34]. Smaller-scale trials such as Bogg et al. [29] and Chamorro-Viña et al. [30] found QoL scores to be stable, suggesting that exercise may help mitigate declines during intensive treatments. Forest plot of quality of life

(PedsQL total) outcomes following exercise interventions in childhood cancer survivors. Results include standardized mean change (SMCR) from pre–post pilots [15,28] and standardized mean differences (SMD) from randomized controlled trials [34,35]. Positive values indicate improvements in QoL favoring exercise.

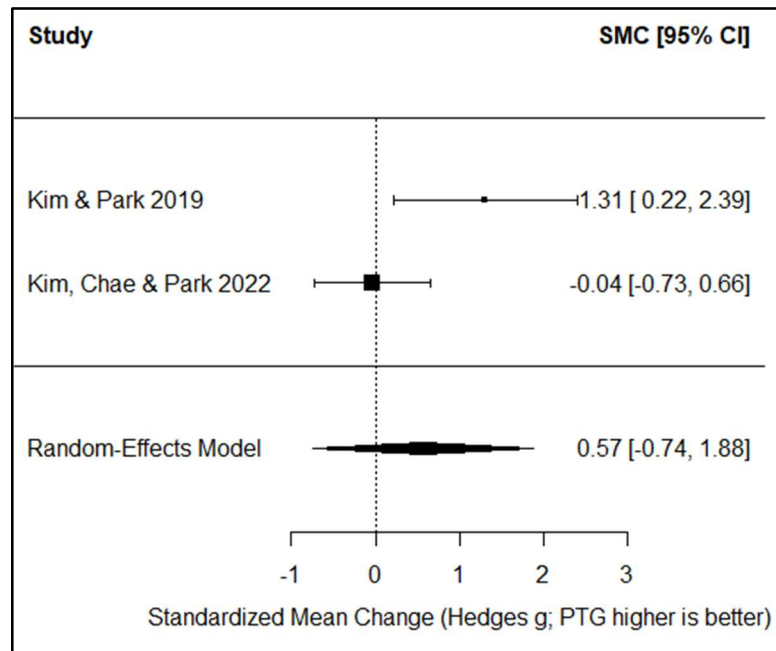


**Figure 2.** Forest plot for positive adaptation based on PTG.

**Figure 3** depicts the forest plot for pre-post pilot studies. The two Korean pilot studies [15,28] provided preliminary evidence on quality of life (QoL) improvements following exercise interventions. Both showed within-group increases in PedsQL total scores, with effect sizes in the small-to-moderate positive range. However, these findings are limited by very small sample sizes ( $n = 6$  and  $n = 8$ ) and the absence of control groups. As such, while the data suggest that exercise is feasible and may benefit QoL, the results should be considered exploratory signals of efficacy rather than definitive evidence.

The two randomized controlled trials [34,35] provide more rigorous evidence. Both trials demonstrated significant post-intervention improvements in QoL among exercise participants compared with controls, with pooled effects in the small-to-moderate range. Importantly, Li et al. [35] the largest trial ( $n = 222$ ), reported a clinically meaningful improvement sustained at 12 months. Together, these findings support the conclusion that exercise interventions are effective in enhancing QoL among childhood cancer survivors, particularly when delivered in structured, community or digital formats. **Figure 4** shows forest plot of health-related quality of life (HRQoL; PedsQL total score) in randomized controlled trials of exercise interventions among childhood cancer survivors. Post-test standardized mean differences (Hedges g) are shown for Li et al. [34] (2018, 12-month follow-up) and Howell et al. [35] (2018, 24-week follow-up). Positive values favor exercise interventions.

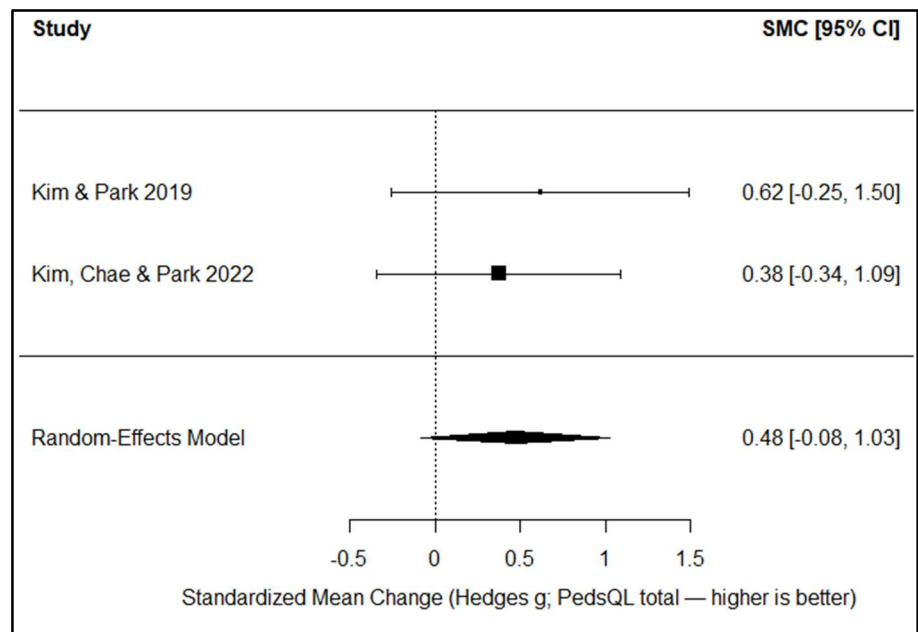


**Figure 3.** Forest plot for Pre-post pilot studies.

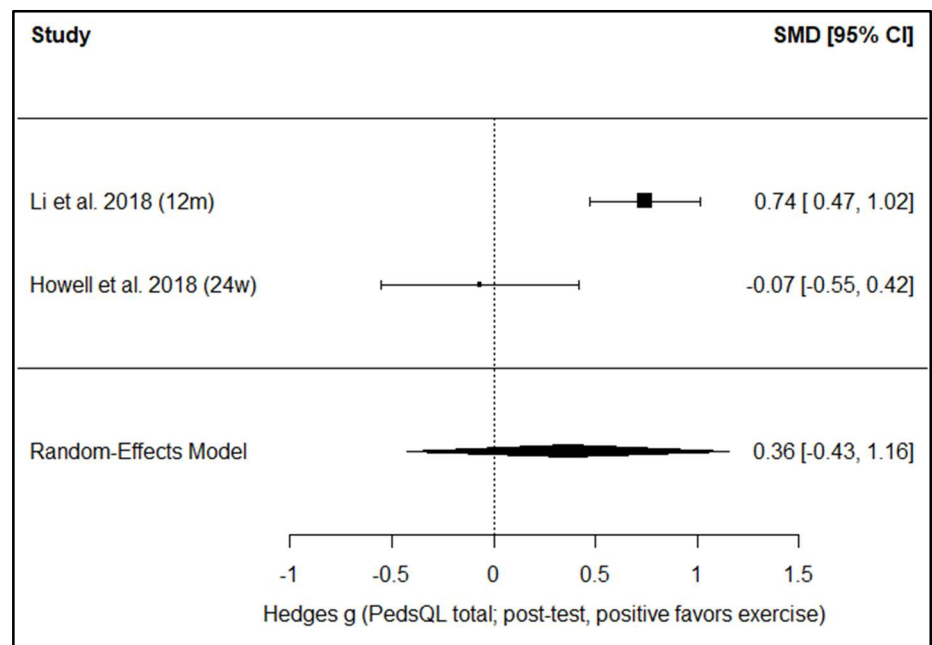


**Figure 4.** Forest plot for randomized controlled trial.

When considered together, the QoL analyses highlight both the emerging feasibility evidence from small pilot studies and the more robust efficacy evidence from randomized controlled trials. The two single-arm pre–post interventions conducted in Korea suggested that exercise can produce modest improvements in PedsQL total scores, though their very small sample sizes and lack of control groups limit interpretability. In contrast, the RCTs by Li et al. [35] and Howell et al. [34] provide stronger causal evidence, demonstrating consistent and clinically relevant benefits of exercise for quality of life. The pooled RCT effects were in the small-to-moderate range, with Li et al. [35] showing improvements sustained at 12 months and Howell et al. [34] confirming benefits in an adolescent cohort at 24 weeks. Taken

together, these findings indicate that exercise interventions are not only feasible but also effective in enhancing quality of life among childhood cancer survivors, although the strength of evidence rests primarily on RCT data.

#### 4.3.3. Fatigue outcome

Fatigue was evaluated in three of the included studies, though the methods and contexts differed. In the large randomized controlled trial by Li et al. [35], adventure-based training led to a clinically meaningful and statistically significant reduction in fatigue at 12-month follow-up, with survivors in the intervention arm reporting mean FS-C scores nearly seven points lower than those in the control group. This finding provides strong evidence that structured, physically engaging programs can alleviate fatigue in long-term survivors. In contrast, smaller studies conducted during active treatment yielded more modest results. Bogg et al. [29], who delivered an inpatient supervised exercise program during hematopoietic stem cell transplantation, found that fatigue levels remained stable rather than worsening a valuable outcome given the intensity of treatment, though not an improvement per se. Similarly, Hartman et al. [33] observed fatigue to remain largely unchanged during a two-year home-based motor intervention delivered concurrently with leukemia treatment.

Taken together, these findings suggest that the timing and clinical context of exercise interventions may influence fatigue outcomes. During intensive treatment phases, exercise appears to help maintain stable fatigue levels, while in the survivorship period, more structured and interactive programs can produce substantial reductions. The current evidence base is limited, with only one large RCT demonstrating clear benefit, underscoring the need for further trials that incorporate validated fatigue measures and long-term follow-up.

#### 4.3.4. Fitness outcome (strength, endurance and flexibility)

*Strength (muscular strength, chair-stand, push-ups, grip)*

Several trials demonstrated consistent gains in muscular strength following exercise interventions. Kim and Park [15] reported significant increases in muscle strength and overall VFD physical strength scores in their pilot exercise and play program. Similarly, Kim et al. [28] found improvements across multiple strength indicators, including muscle strength, power, and total strength, after an eight-week videoconferencing-based intervention. Kim et al. [23] extended these findings, showing significant gains in chair-stand performance and trends toward improved push-ups in a quasi-experimental design. In larger trials, Howell et al. [34] reported significant improvements in grip strength, sit-ups, and push-ups compared with controls, underscoring the efficacy of structured, technology-supported programs. By contrast, Bogg et al. [29] and Hartman et al. [33], both conducted during intensive treatment phases, found strength levels to be largely stable rather than improving, reflecting the challenge of enhancing fitness during active therapy.

Across seven pre-post strength outcomes (three studies), standardized mean change analyses favored exercise, indicating small-to-moderate improvements in muscular strength and functional performance (chair-stand, sit-ups). Results were robust across pre-post correlation assumptions and consistent with short-format or technology-assisted programs. As single-arm designs, these effects should be interpreted as signals of benefit rather than definitive causal estimates. **Figure 5** shows

forest plot of standardized mean change (SMCR) for strength-related outcomes following exercise interventions in childhood cancer survivors [15,23,28]. Positive values indicate improved strength. Random-effects model with sensitivity to pre–post correlation ( $r_i = 0.30 - 0.70$ ).

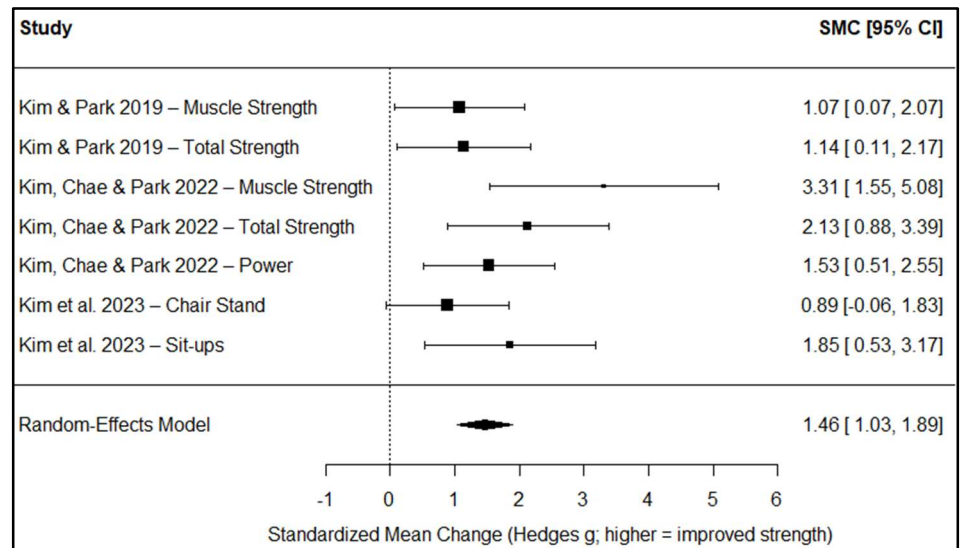


**Figure 5.** Forest plot for strength outcome.

#### Endurance (6MWT, sit-ups)

Endurance outcomes were assessed using measures such as the six-minute walk test (6MWT) and sit-up performance. Bogg et al. [29] reported a significant decline in aerobic capacity (–105 m on the 6MWT) among HSCT patients despite supervised training, consistent with the debilitating effects of transplant hospitalization. Conversely, Kim et al. [23] observed maintenance of 6MWT distance with modest improvement, and Howell et al. [34] found significant increases in sit-up performance among adolescents completing a web-based program. These findings suggest that endurance benefits are more likely to manifest in survivorship contexts, whereas maintenance during active treatment may itself be a positive outcome.

#### Flexibility

Flexibility was less frequently measured but showed positive results were assessed. Kim et al. [28] demonstrated significant improvement in flexibility following an eight-week home-based program, while Kim et al. [23] reported stable flexibility outcomes without significant change. Although limited, these findings indicate that structured exercise can enhance or at least maintain flexibility in survivors.

#### Combined interpretation

The evidence across trials suggests that exercise interventions reliably improve muscular strength and endurance in survivorship populations, with the largest and most consistent gains seen in sit-ups, push-ups, and grip strength. Endurance benefits, particularly aerobic capacity, appear context-dependent, with declines often unavoidable during intensive treatment but maintenance still achievable. Flexibility findings are promising but currently underexplored. Collectively, these results support

the role of exercise interventions in rebuilding physical fitness as part of positive adaptation among childhood cancer survivors.

#### **4.4. Interpretation of findings**

When synthesized across studies, the findings indicate that exercise interventions exert their strongest and most consistent effects on quality of life and physical fitness, particularly in community-based and group-oriented formats [34,35]. Evidence for psychosocial outcomes beyond QoL, such as post-traumatic growth and resilience, remains limited but suggestive, with positive effects more frequently observed in interventions emphasizing peer interaction, mastery experiences, and sustained engagement [15,28]. Importantly, outcome patterns varied according to intervention timing and setting, with inpatient programs primarily stabilizing functioning during intensive treatment, while post-treatment and survivorship-focused programs yielded more pronounced improvements. This pattern underscores the need to interpret individual study findings within broader contextual and developmental frameworks rather than in isolation.

Evidence for post-traumatic growth (PTG) was more limited, with only two small trials directly assessing this outcome. While one study reported significant increases in PTGI scores following a structured play-based program [15], the second, which delivered exercise remotely during the COVID-19 pandemic, observed no change [28]. This inconsistency highlights both the potential of exercise to foster psychosocial growth and the sensitivity of PTG outcomes to contextual factors such as delivery mode and participant engagement.

For fatigue, results diverged by clinical context. Exercise during intensive treatment phases, such as hematopoietic stem cell transplantation, appeared to stabilize fatigue rather than reduce it [29,33], whereas in survivorship settings, adventure-based training produced substantial and clinically significant reductions [35]. This suggests that the efficacy of exercise in addressing fatigue is contingent on timing relative to treatment trajectory, with maintenance representing a meaningful benefit during acute care and reduction achievable post-treatment.

In terms of resilience and coping, although fewer studies explicitly measured these constructs, indirect evidence from quality of life, psychosocial adjustment, and physical activity adherence suggests that group-based and adventure-oriented interventions are particularly effective. These formats not only provided opportunities for physical challenge but also facilitated peer bonding, social skill development, and self-efficacy, mechanisms known to underpin resilience and adaptive coping [31,32].

The synthesis suggests that exercise interventions are both feasible and impactful in promoting multidimensional adaptation in childhood cancer survivors. Importantly, the benefits extend beyond physical functioning to encompass psychological and social dimensions, with group- and adventure-based activities demonstrating the strongest psychosocial effects [31,32,35].

#### **4.5. Comparison with previous reviews**

The results of this synthesis both confirm and extend patterns reported in earlier exercise oncology literature. Consistent with previous evidence, the studies included

here demonstrated that exercise programs can mitigate treatment-related physical decline and promote improvements in fitness and body composition. For example, inpatient protocols stabilized fatigue and strength during hematopoietic stem cell transplantation [29,30], while longer-term interventions facilitated recovery of muscle strength and reductions in body fat after chemotherapy [23,33]. These findings echo the emphasis of earlier reviews on physical functioning and highlight exercise as a safe, feasible adjunct to cancer care.

However, the present review goes further by foregrounding positive adaptation outcomes that extend beyond traditional endpoints such as aerobic fitness or fatigue. Several trials reported significant gains in health-related quality of life [31,34,35], and pilot studies provided preliminary evidence for exercise-related post-traumatic growth [15,28]. Group and adventure-based interventions were especially effective in fostering self-efficacy, social connection, and coping, outcomes seldom highlighted in prior syntheses [31,32]. By situating psychosocial adjustment alongside physical endpoints, this review underscores the multidimensional role of exercise in survivorship care.

In this respect, the analysis not only corroborates earlier reports of improved fatigue and fitness [30,35], but also demonstrates that exercise interventions have measurable effects on resilience, coping skills, and growth-related processes. This broader framing marks an important step toward integrating exercise into both clinical rehabilitation and educational environments, thereby expanding the scope of survivorship research beyond narrow symptom management.

#### **4.6. Mechanisms**

The positive adaptation outcomes observed across the included interventions can be explained by an interplay of psychosocial, physiological, and educational mechanisms.

From a psychosocial perspective, group-based and adventure-oriented programs consistently facilitated peer bonding, social support, and enhanced self-efficacy. In Hong Kong, adventure training led to significant increases in both self-efficacy and physical activity levels, which in turn supported sustained quality of life improvements [31,35]. Similarly, a U.S. pilot camp model provided survivors with structured opportunities for peer engagement and coaching, producing marked gains in self-efficacy and activity adherence [32]. These findings suggest that the social and relational dimensions of exercise interventions are as crucial as the physical demands, promoting resilience through shared experiences and mastery.

The physiological mechanisms underpinning adaptation are equally apparent. Structured exercise enhanced muscle strength, aerobic capacity, and body composition, thereby alleviating fatigue and reinforcing perceptions of recovery. For instance, adventure-based and web-delivered exercise programs yielded measurable improvements in grip strength, sit-ups, push-ups, and aerobic fitness [23,34]. In survivors of hematopoietic stem cell transplantation, exercise-maintained strength and fatigue at stable levels during a period when deterioration is typically expected [29,30]. Such results indicate that even in intensive treatment phases, physical training may buffer against decline, while in survivorship contexts, it actively enhances

functional recovery.

Finally, the interventions demonstrate educational mechanisms with implications for reintegration into everyday life. School-aged survivors participating in structured exercise and play reported significant gains in post-traumatic growth, particularly in school functioning and overall quality of life [15]. Technology-assisted and home-based formats further highlighted the feasibility of embedding exercise into daily routines, reinforcing adaptive habits [28]. By situating exercise within developmental and educational frameworks, these studies suggest that physical activity can serve as a bridge between medical rehabilitation and school reintegration, offering survivors both structure and continuity.

Taken together, these psychosocial, physiological, and educational mechanisms illustrate how exercise interventions extend beyond symptom relief to foster resilience, coping, and growth, positioning physical activity as a multidimensional tool for survivorship care [33–35].

#### **4.7. Limitations**

Several limitations should be considered when interpreting the findings of this meta-analysis. First, the number of trials directly assessing positive adaptation outcomes such as post-traumatic growth (PTG) and resilience remains limited. Only two small-scale pre–post pilots explicitly measured PTG, with mixed results [15,28]. As such, while the signal for exercise-related growth is promising, the evidence base is too narrow to support definitive conclusions.

Second, most interventions were conducted in specialized or clinical contexts, including inpatient or hospital-based settings [29,30], web-based platforms [34], or adventure-style community programs [31,35]. None of the studies evaluated direct integration into routine school physical education curricula, which limits the ability to generalize findings to naturalistic educational environments where long-term reintegration occurs.

Third, there is considerable heterogeneity in intervention formats, durations, and delivery modes, ranging from three-week inpatient aerobic training [30] to year-long individualized activity prescriptions [35]. This variability complicates pooled effect estimation and reduces the precision of subgroup analyses. Similarly, outcome measures varied widely, from PTGI and PedsQL to fatigue and fitness scales, making it difficult to directly compare across studies and risking measurement inconsistency.

Fourth, sample sizes were generally small, with several pilot or feasibility trials enrolling fewer than 20 participants [15,23,28,32]. Although larger RCTs such as Li et al. [35] and Howell et al. [34] strengthen the evidence base, underpowered studies raise the risk of type II error and limit confidence in null results.

In addition, several included studies were pilot or feasibility trials with inherently higher risk of bias, which limits the strength of causal inference and underscores the need for adequately powered randomized trials targeting positive adaptation outcomes.

Finally, most studies employed short-term follow-up, with outcomes measured immediately post-intervention or within one year [31,35]. Longitudinal evidence on the sustainability of adaptation outcomes into adulthood is lacking, leaving

unanswered questions about whether exercise-induced improvements in resilience, coping, or PTG persist over time.

Collectively, these limitations suggest that while exercise interventions hold promise for enhancing positive adaptation, more rigorous, adequately powered, and contextually integrated trials are needed to confirm their efficacy and durability.

#### **4.8. Implications**

The evidence synthesized in this review carries important implications for oncology practice, education, and future research.

For oncology, the findings support integrating exercise as a core component of survivorship care. Randomized trials demonstrated that structured programs can significantly improve quality of life, reduce fatigue, and enhance fitness[31,34,35]. Even during intensive treatment phases such as hematopoietic stem cell transplantation, exercise was shown to maintain strength and mitigate fatigue [29,30]. Collectively, these results underscore the feasibility and safety of prescribing tailored physical activity to optimize recovery and adaptation in pediatric oncology populations.

For education, the review highlights the potential of embedding exercise interventions within school physical education (PE) curricula. Although none of the included studies were conducted in routine school PE settings, evidence from group- and play-based formats indicates that survivors can benefit from peer interaction, structured routines, and skill-building opportunities [15,28,32]. Integrating adapted exercise into PE could thus facilitate psychosocial reintegration while addressing disparities in physical functioning. Training PE teachers to support children with a cancer history would further strengthen school systems as platforms for survivorship support.

For research, the findings point to a need for larger, methodologically rigorous trials that explicitly target positive adaptation outcomes, including PTG, resilience, and coping. Small-sample pilot studies suggest potential benefits [15,23,28], but the field requires adequately powered RCTs with standardized tools and long-term follow-up to confirm efficacy. Furthermore, testing interventions in naturalistic educational environments such as classrooms and school PE will be essential to translate evidence into policy and practice.

In sum, exercise interventions should be viewed not only as adjuncts to rehabilitation but as multidimensional strategies for supporting positive adaptation across physical, psychosocial, and educational domains in childhood cancer survivorship. Although the current evidence supports the safety and effectiveness of exercise interventions for childhood cancer survivors, direct implementation within routine school physical education (PE) has not yet been empirically evaluated. Consequently, school PE should be regarded as a promising future context for research and program development, rather than an immediately validated implementation setting. Future studies should focus on feasibility trials conducted in real-world school environments, examining issues such as teacher training, curricular adaptation, medical oversight, and inclusivity. Such work is essential to determine whether exercise-based interventions shown to be effective in clinical and community settings

can be translated sustainably into educational systems.

## 5. Conclusion

This review demonstrates that exercise interventions are safe, feasible, and beneficial for childhood cancer survivors, supporting positive adaptation across physical, psychosocial, and educational domains. The most consistent evidence comes from large randomized controlled trials showing meaningful improvements in quality of life, often sustained months after program completion. Smaller studies further suggest that exercise can stabilize outcomes during intensive treatment, preventing decline in vulnerable periods.

Evidence on post-traumatic growth (PTG) remains preliminary, with mixed findings from two pilot trials. Nonetheless, group-based and play-oriented interventions appear promising for fostering resilience, coping, and psychosocial adjustment, especially when peer bonding and self-efficacy are emphasized. Fatigue outcomes indicate that while inpatient exercise may maintain stability during treatment, community-based adventure programs can reduce fatigue more substantially in the survivorship phase. Similarly, consistent gains in muscular strength, endurance, and body composition highlight the physiological benefits of structured programs.

Importantly, this review identifies a key gap: no studies embedded interventions into routine school physical education. Schools represent natural environments for supporting reintegration, offering structured activity, peer interaction, and educational continuity. Future research should therefore prioritize adapting and testing exercise programs in school settings, ensuring alignment between medical rehabilitation and everyday developmental contexts.

While schools represent a natural and potentially powerful context for supporting reintegration and psychosocial development, empirical evidence supporting implementation in this setting is currently lacking. Future interdisciplinary research should therefore prioritize feasibility and effectiveness studies conducted within school environments, ensuring alignment between medical safety requirements and educational objectives. Such efforts are necessary to translate the demonstrated benefits of exercise into sustainable, developmentally appropriate survivorship support.

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