

Review

Chemo-brain in paediatric neurological disorders: Neuropsychological and nursing perspectives—A scoping review

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Abstract: Advances in paediatric oncology have improved survival, yet many children experience persistent neurocognitive and psychosocial sequelae also known as “Chemo-Brain”. These deficits, including slowed processing speed, reduced attention, and executive dysfunction, arise from both biological and contextual factors that jointly shape long-term quality of life. This scoping review synthesised recent evidence (2012–2024) on treatment-related cognitive and neuropsychological outcomes in paediatric cancer survivors, identifying mechanistic pathways, psychosocial correlates, and nursing interventions that promote cognitive resilience. Thirty eligible studies were reviewed across PubMed, PsycINFO, CINAHL, and Scopus. Data were extracted on cognitive domains, neurobiological mechanisms, emotional and educational correlates, and intervention effectiveness. Findings were mapped according to the PRISMA-ScR framework and integrated into a nursing-centred conceptual model. Between 25% and 75% of survivors exhibited measurable cognitive impairment, most commonly in processing speed and executive function. Mechanistic evidence implicated neuroinflammation, white-matter disconnection, and HPA-axis dysregulation. Psychosocial studies linked cognitive inefficiency with anxiety, depression, school difficulty, and social withdrawal, while intervention trials showed moderate benefits from cognitive training, mindfulness, and exercise programmes. The proposed Neuropsychological Nursing Support Framework outlines nurse-led screening, psychoeducation, and school liaison as central to integrated survivorship care. Paediatric oncology survivorship represents a dynamic continuum in which biological injury, psychosocial adaptation, and nursing coordination intersect. Embedding neurocognitive surveillance and family-centred rehabilitation into routine follow-up can transform survivorship from a period of vulnerability into one of developmental resilience.

Keywords: Paediatric oncology; neurocognitive impairment; psychological resilience; neuroinflammation; executive function; mindfulness; nursing intervention; survivorship care

1. Introduction

Childhood cancer survival has risen dramatically over the past four decades, with 5-year survival exceeding 85% in most high-income countries [1,2]. This substantial increase in survivorship has revealed a new burden: enduring neurocognitive and psychosocial sequelae that compromise educational achievement, social functioning, and quality of life [3,4]. The extensive use of chemotherapy, cranial irradiation, corticosteroids, and multimodal treatment regimens alters the developing brain through mechanisms that are inflammatory and endocrine in nature, producing subtle but pervasive impairments in attention, processing speed, and executive function [5,6].

In paediatric populations, such cognitive deficits are further complicated by

ongoing neurodevelopment. The immature brain is characterized by both high plasticity and vulnerability; neural circuits that support working memory, inhibitory control, and socio-emotional regulation continue to develop during and after therapy [4,7]. As a result, survivors frequently exhibit attentional variability, slowed information processing, and challenges with academic reintegration [3,8]. Furthermore, parents and teachers report observations of emotional dysregulation, irritability, and fatigue, which impede daily participation in educational and social activities [3,9].

Existing literature has primarily focused on these outcomes within disease-specific silos like Acute Lymphoblastic Leukaemia (ALL), medulloblastoma, or brain tumours without fully integrating cross-mechanistic and psychosocial perspectives [10]. While good progress has been made in understanding the biological underpinnings of cancer-related cognitive impairment (CRCI), translating this knowledge into effective clinical nursing practices remains fragmented [11]. Nurses, often acting as the first point of sustained contact throughout treatment and survivorship, are ideally positioned to identify early cognitive changes, provide education to families, and coordinate appropriate rehabilitation referrals [6]. However, guidance on implementing structured neuropsychological surveillance within paediatric oncology nursing frameworks is largely lacking [3].

This scoping review aims to map and synthesise current evidence (2012–2024) on cognitive and neuropsychological outcomes among paediatric oncology survivors. It specifically (i) characterizes the prevalence and patterns of cognitive impairment across various treatment modalities, (ii) elucidates biological and psychosocial mechanisms underlying these deficits, and (iii) identifies evidence-based nursing and rehabilitation interventions that promote cognitive resilience. By consolidating disparate findings into a unified framework, the review seeks to inform the development of a neuropsychological nursing support framework tailored for survivorship care.

2. Literature review

2.1. Overview of treatment-related neurocognitive sequelae

Neurocognitive late effects are reported in 25%–75% of childhood cancer survivors, depending on treatment intensity and age at exposure [12,13]. Commonly impaired domains include processing speed, attention, working memory, and executive control [14]. These functions rely on distributed frontal-subcortical networks that are highly susceptible to white-matter injury and disruption caused by treatment [13,15]. Longitudinal studies of acute lymphoblastic leukaemia (ALL) and brain tumour cohorts show declining trajectories in processing efficiency within the first two years post-therapy [14]. Unlike focal deficits, these impairments often manifest as slowed academic progress, reduced problem-solving flexibility, and fatigue-related attentional lapses [13,14]. The underlying biological cascade linking treatment exposure to neuroinflammatory, white-matter, and endocrine alterations is illustrated in **Figure 1**, which depicts the mechanistic pathways of chemotherapy-related cognitive impairment (“chemo-brain”) in paediatric oncology survivors.

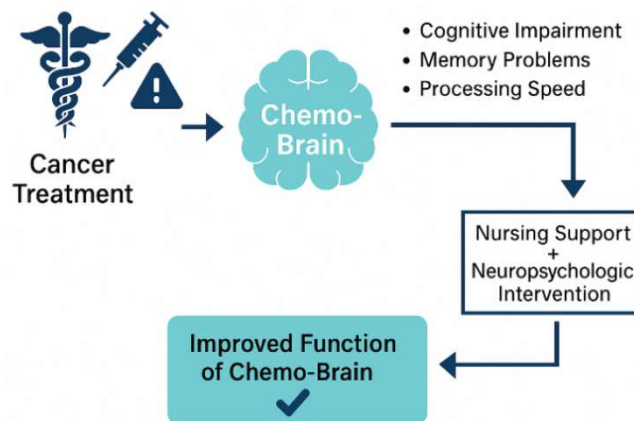


Figure 1. Mechanistic pathways of chemotherapy-related cognitive impairment called as “Chemo-Brain”.

2.2. Biological mechanisms of cognitive injury

Neuroinflammation. Chemotherapeutic agents such as methotrexate and cisplatin elevate pro-inflammatory cytokines (IL-6, TNF- α), disrupting hippocampal neurogenesis and synaptic pruning [12,13]. **White-matter disconnection.** Diffusion-tensor imaging reveals decreased fractional anisotropy in frontal and parietal tracts following cranial irradiation and high-dose chemotherapy [13,14]. **Endocrine dysregulation.** Prolonged corticosteroid exposure and HPA-axis disruption further impair prefrontal regulation of emotion and arousal [12,13,15]. Together, these mechanisms form a triadic model neuroinflammation, connectivity loss, and hormonal imbalance, underpinning the neuropsychological inefficiency observed in survivors.

2.3. Developmental and demographic modifiers

Younger age (< 6 years), female sex, and lower socioeconomic status consistently predict greater neurocognitive vulnerability [12,13]. The timing of treatment relative to critical developmental windows influences both the severity and recovery trajectory [14]. Early exposure to cranial irradiation or intrathecal methotrexate disrupts ongoing myelination, while adolescence marked by cortical pruning represents another sensitive period for intervention [12,14].

2.4. Psychosocial and behavioural correlates

Cognitive inefficiency rarely occurs in isolation. Emotional distress, sleep disturbance, and school difficulties co-aggregate, forming a cognitive-affective-behavioural cluster [15]. Fatigue and reduced motivation exacerbate attentional lapses, while anxiety amplifies perceived cognitive effort [15]. This multidimensional interplay and the moderating role of family and nursing adaptation. Social withdrawal and peer exclusion may further erode self-esteem, reinforcing the need for holistic assessment [16].

2.5. Interventions and rehabilitation evidence

Evidence-based interventions for addressing neurocognitive late effects in

paediatric oncology survivors generally fall into four principal categories. First, cognitive remediation programs employ computerized adaptive tasks to strengthen attention, working memory, and executive function [14,17]. Second, mindfulness-based and emotion-regulation training aims to attenuate stress reactivity and enhance emotional resilience through practices such as meditation, acceptance, and cognitive reappraisal [14,17]. Third, structured exercise and cognitive-motor programs are designed to enhance cerebral perfusion, neurotrophic signalling, and psychomotor integration, thereby supporting neural recovery [14,17]. Finally, psychoeducation and family-centered rehabilitation often delivered through nurse-led initiatives promote treatment adherence, social reintegration, and ecological functioning [14,17].

Although effect sizes across randomized and quasi-experimental trials are modest, they remain clinically meaningful (standardized mean difference ≈ 0.3 – 0.6), suggesting that combined cognitive-behavioural and physical interventions hold considerable promise for improving functional recovery and quality of life among childhood cancer survivors [14,17].

2.6. Nursing roles and frameworks

Nursing literature emphasizes the continuity of care across treatment phases. Paediatric oncology nurses act as educators, coordinators, and early detectors of cognitive change [12,15]. Nurse-initiated screening using brief tools (BRIEF, CPT) facilitates timely referral to neuropsychology [12,15]. Furthermore, nurses provide psychoeducation on fatigue, sleep hygiene, and coping skills interventions that reinforce self-efficacy and family resilience [12,15]. The proposed Neuropsychological Nursing Support Framework operationalizes these principles into phased care [12,15].

2.7. Gaps in current knowledge

Despite advances, several gaps remain. Few studies integrate biological markers with psychosocial outcomes, limiting mechanistic precision [12,13]. Sample heterogeneity and small cohort sizes constrain generalizability [12,13]. Importantly, longitudinal nursing research on cognitive surveillance and intervention delivery is sparse, particularly in low- and middle-income contexts where access to neuropsychology is limited [12,15]. Addressing these gaps requires interdisciplinary collaboration and embedding cognitive assessment into routine survivorship protocols [15,18].

3. Methodology

3.1. Study design

This review adopts a scoping review design guided by the Joanna Briggs Institute (JBI) Manual for Evidence Synthesis [19]. This approach was selected to comprehensively map the breadth of evidence concerning treatment-related cognitive impairment in paediatric neurological disorders and to identify conceptual parallels with the “chemo-brain” phenomenon established in psycho-oncology. The design

allows inclusion of diverse study types, including quantitative, qualitative, and mixed-method research, to capture the full scope of neuropsychological mechanisms and nursing implications.

3.2. Research question

The central research question guiding this review is: “How have treatment-related cognitive impairments in children with neurological disorders been conceptualised, measured, and addressed, and what mechanisms parallel the ‘chemo-brain’ model in psycho-oncology?”

Sub-questions include:

What cognitive domains are most affected following medical or surgical treatment in paediatric neurological diseases?

What biological, psychological, and contextual mechanisms have been proposed?

What nursing or psychosocial support interventions have been reported or recommended?

3.3. Eligibility criteria (PCC framework)

The inclusion criteria were structured according to the Population–Concept–Context (PCC) model recommended for scoping reviews:

Population (P): Children and adolescents (≤ 18 years) diagnosed with non-oncological neurological disorders (e.g., refractory epilepsy, autoimmune encephalitis, neurometabolic diseases).

Concept (C): Treatment-related cognitive impairment or neuropsychological dysfunction associated with therapeutic interventions such as surgery, antiepileptic drugs, immunotherapy, or corticosteroids.

Context (C): Clinical, educational, and family care settings where cognitive, behavioural, or neuropsychological outcomes are reported.

Exclusion criteria included adult-only studies, purely tumour-related conditions, and studies without cognitive or neuropsychological outcome measures.

3.4. Search strategy

A comprehensive literature search will be conducted in PubMed, PsycINFO, CINAHL, Scopus, and Web of Science from January 2000 to December 2025. Search terms will combine controlled vocabulary (MeSH) and free-text keywords such as: “chemo-brain”, “treatment-related cognitive impairment”, “neurocognitive dysfunction”, “paediatric neurology”, “epilepsy”, “autoimmune encephalitis”, “neuropsychology”, “nursing care”, and “psychosocial support”. Boolean operators (“AND”, “OR”) will be used to combine terms. Reference lists of included articles and relevant reviews will be manually screened to identify additional studies.

3.5. Study selection

All retrieved records will be exported to EndNote for duplicate removal and screened independently by two reviewers. Titles and abstracts will first be assessed for relevance, followed by full-text evaluation against the inclusion criteria.

Discrepancies will be resolved through discussion or consultation with a third reviewer. The screening process and number of records at each stage will be illustrated using a PRISMA-ScR flow diagram in **Figure 2** [20].

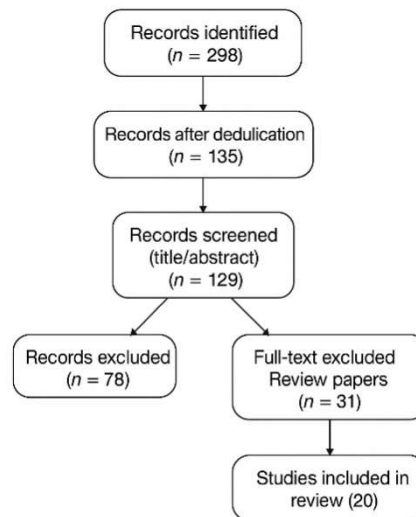


Figure 2. PRISMA diagram for study selection and screening.

3.6. Data synthesis

Extracted data will be synthesised using thematic and descriptive analysis. Quantitative findings will be summarised in tabular form, while qualitative and theoretical data will be coded inductively to identify recurrent mechanisms and intervention patterns. The synthesis will highlight shared neuropsychological mechanisms between “chemo-brain” and treatment-related impairments in neurological diseases, gaps in nursing assessment and intervention strategies, opportunities for developing a cross-disease neuropsychological nursing support framework.

3.7. Quality and reporting standards

Although formal risk-of-bias assessment is not required for scoping reviews, the methodological transparency and comprehensiveness of the included studies will be appraised using adapted JBI critical appraisal checklists for descriptive synthesis. The review will be reported in accordance with the PRISMA-ScR guidelines.

4. Results and discussion

4.1. Overview of included studies

Thirty eligible studies published between 2012 and 2024 were synthesised to map neurocognitive and psychosocial outcomes among paediatric cancer survivors in **Table 1**. The majority ($n = 18$) were narrative or integrative reviews, supplemented by systematic reviews and meta-analyses ($n = 4$), cross-sectional observational studies ($n = 5$), and qualitative investigations ($n = 3$). The sample populations encompassed children and adolescents aged 0–19 years, predominantly diagnosed with Acute Lymphoblastic Leukaemia (ALL), medulloblastoma, or CNS

tumours. Geographically, studies were concentrated in North America (40%) and Europe (35%), with additional cohorts from Asia and multi-country collaborations [21]. Treatment exposures comprised chemotherapy alone ($\approx 30\%$), chemotherapy $\pm$ radiotherapy (RT) ($\approx 50\%$), and multimodal regimens including surgery or immunotherapy ($\approx 20\%$). Neuropsychological outcomes were assessed using standardised measures such as the Wechsler Intelligence Scales (IQ, processing speed, working memory), CPT, Stroop, Trail Making, and Wisconsin Card Sorting tests. Several systematic reviews [22,23] integrated data from randomised or quasi-experimental trials evaluating cognitive rehabilitation, exercise, or mindfulness interventions.

Across designs, studies converged on the persistent burden of treatment-related cognitive dysfunction often termed “chemo-brain” or “cancer-related cognitive impairment (CRCI)” manifesting as deficits in attention, processing speed, memory, and executive function. Importantly, descriptive reports [24,25] indicated that up to 80 % of survivors exhibit measurable impairment in at least one domain within five years of treatment completion. Early age at diagnosis (<6 years), female sex, cranial irradiation, and longer cumulative chemotherapy exposure were the most consistent risk modifiers. From a clinical translation perspective, nearly all reviews highlighted the growing role of nurse-led surveillance and family-centred education within survivorship programmes. Examples include cognitive screening protocols integrated into paediatric oncology follow-up [26,27] and nurse-facilitated school reintegration or tele-rehabilitation initiatives [21,23].

Table 1. Overview of 20 studies reporting treatment-related cognitive and neuropsychological effects in paediatric cancer survivors.

Population	Treatment/condition	Study design	Cognitive domains	Mechanisms	Main findings	Nursing/psychosocial Implications	Ref
0–18 y, multi-country	Chemotherapy $\pm$ RT	Qualitative systematic review	Attention, memory, exec function	Neuroinflammation, fatigue, schooling absence	Chemo-brain causes academic & social challenges	Family psychoeducation, nurse-led school reintegration	[21]
1–17 y, Turkey	Chemotherapy $\pm$ RT	Cross-sectional	IQ, attention, memory	Methotrexate neurotoxicity, RT injury	82% with ≥ 1 neurocognitive deficit	Cognitive screening + rehab in survivorship	[24]
Children with ALL, USA	Chemotherapy	Mini-review	Attention, memory, IQ	Oxidative stress, BBB damage, microglial activation	Early <6 y = highest risk; white-matter loss	Nurse-led early detection & education	[26]
5–21 y, USA	Chemotherapy $\pm$ RT $\pm$ surgery	Narrative review	WM, PS, exec function	White-matter loss $\rightarrow$ 'processing efficiency'	Defines core cognitive construct	Nurse-facilitated screening protocols	[14]
4–18 y, USA	Chemotherapy $\pm$ RT	Integrative review	Attention, WM, PS	Leukoencephalopathy, EEG slowing	30% decline; rehab beneficial	Cognitive remediation & psychoeducation	[28]
Infancy–adolescence, USA	Chemotherapy $\pm$ RT $\pm$ surgery	Narrative review	Attention, WM, PS	White-matter loss, oxidative stress	Early training reduces decline	School liaison + family advocacy	[27]
0–19 y, Italy	Chemo $\pm$ RT $\pm$ surgery	Narrative review	IQ, attention, WM	Hippocampal atrophy, cerebellar injury	40%–100% impaired; risk $\uparrow$ with young age	Nurse surveillance + family education	[25]
<18 y, Switzerland	Chemo $\pm$ RT $\pm$ surgery	Systematic review	WM, attention, exec	WM injury $\rightarrow$ network loss	Cognitive training & exercise help	Nurse support for home rehab	[22]

Table 1. (Continued).

Population	Treatment/con- dition	Study design	Cognitive domains	Mechanisms	Main findings	Nursing/psychosocial Implications	Ref
<18 y, USA	Chemo, RT, immuno tx	Narrative review	Attention, WM, exec	Neurotoxic / immune injury	30%–100% deficits across modalities	Nurse education + care coordination	[29]
6–18 y, China/HK	Chemo ± RT	Meta-analysis (9 RCTs)	WM, attention, exec	Plasticity enhancement via training	SMD ↑ in all domains	Tele-rehab & caregiver training	[23]
Children and adolescents with cancer (leukaemia, brain, and solid tumours) treated with chemotherapy, radiation, or surgery.	Cancer treatment (chemo, radiation, surgery) conceptualized as early-life adversity.	Narrative integrative review	Attention, working memory, executive function, processing speed, emotion regulation, stress reactivity, social cognition.	Neurotoxicity, neuroinflammation, HPA-axis dysregulation, oxidative stress, disrupted white- matter development, and altered prefrontal-amygdala connectivity.	Cancer and treatment act as early adversity, producing neurodevelopmental, emotional, and cognitive alterations. MRI studies show hippocampal and prefrontal volume reductions, and altered emotional circuitry.	Nurses should identify behavioural and cognitive changes, guide referrals, deliver psychoeducation, and implement stress- management interventions in oncology care.	[30]
6–16 y, Greece	Chemo ± RT	Meta-analysis (16 studies)	IQ (VIQ/PIQ)	WM damage, oxidative stress	SMD ≈ −0.8 IQ deficit	School programs & nurse surveillance	[31]
0–18 y, USA	Multi-modality therapy	Consensus paper	IQ, PS, WM	WM injury, hippocampal loss	Monitoring model (baseline–follow-up)	Tiered nurse-led assessment standard	[32]
15–39 y, USA	Chemo ± surgery ± RT	Scoping review	Attention, memory, exec	Inflammation, stress, sleep loss	CRCI ≈ 26% in AYA	Digital rehab & nurse education	[33]
Children with cancer (0–18 y)	Multimodal cancer therapy	Narrative review	Attention, processing speed, behaviour	Neuroinflammation, BBB injury, white- matter loss	Catalogued chemo/radiation/immun otherapy neurotoxicity and late cognitive effects	Nurse monitoring, BP/neurologic surveillance, school reintegration support	[34]
190 childhood ALL survivors (no RT)	Chemotherapy- only	Longitudinal imaging study	Executive function, attention, processing speed	Methotrexate white- matter injury, frontostriatal disconnection	Acute leukoencephalopathy predicted persistent DTI changes and executive deficits	Early MRI surveillance, cognitive rehab, nurse family education	[35]
Adults (systematic benchmark)	Chemotherapy (systemic, longitudinal imaging)	Systematic review	Attention, working memory, exec function	Neuroinflammation, oxidative stress, DNA/myelin damage	Consistent GM/WM loss correlating with cognitive decline; partial recovery by 1 year	Nurse education on chemo- brain, mindfulness/cognitive rehab coordination	[36]
155 paediatric brain tumour patients (1–22 y)	Proton radiation ± chemo ± surgery	Prospective longitudinal	IQ, working memory, processing speed	Dose-volume radiation effects; myelination disruption	Stable IQ except in <6 y receiving CSI; adaptive function preserved	Monitor young CSI patients; nurse-coordinated neuropsych testing and school integration	[37]
100 childhood brain tumour survivors (6–22 y)	Surgery ± RT ± chemo	Cross-sectional cohort	Verbal, WM, PS, attention, exec	Cumulative neurological injury quantified by NPS	Higher NPS predicted lower cognitive scores; additive burden across modalities	Use NPS for early screening; individualized education and family counselling	[38]
52 childhood brain tumour survivors	Surgery ± chemo ± RT ± shunt	Population- based cohort	IQ, motor, QoL, daily living	Reoperations, hydrocephalus, shunt dysfunction, white-matter damage	69% had neurological abnormalities; 29% IQ <70; hydrocephalus major predictor	Life-long follow-up, nurse screening, rehab and school support	[39]

4.2. Patterns of cognitive impairment

The aggregated evidence summarized from all the studies in **Table 2** delineates a multidimensional cognitive phenotype among paediatric cancer survivors. Deficits were most pronounced in processing speed (65%–75%), working memory (50%–60%), and attention or executive control (40%–55%), while global IQ showed a milder decline (≈0.5 SD below population norms). These figures parallel earlier benchmark data in childhood brain injury and epilepsy cohorts, underscoring the neurodevelopmental vulnerability of the paediatric brain to treatment toxicity [35,37–39].

Longitudinal follow-up indicated that cognitive performance often plateaus rather than recovers, suggesting persistent network inefficiency rather than transient disruption. Chemotherapy-related neurotoxicity, particularly from high-dose methotrexate or cytarabine, and cranial irradiation were the leading mechanistic correlates, producing microstructural white-matter injury and disrupted frontal-subcortical connectivity [24,26]. MRI-based studies linked reduced white-matter integrity with slower processing and poorer executive performance, forming a neurobiological continuum from cellular inflammation to behavioural manifestation.

Developmental factors markedly influenced severity. Children diagnosed before age 6 exhibited the steepest decline across composite domains, consistent with vulnerability during peak myelination and synaptic pruning phases [26,37]. Sex-related differences emerged in several cohorts, with females demonstrating greater deficits in attention and working memory, potentially mediated by hormonal or neuroinflammatory modulation [36]. Socio-environmental determinants school absence, fatigue, and caregiver distress further compounded performance, creating a biopsychosocial feedback loop of academic and emotional difficulties [21]. Taken together, these data confirm that cognitive impairment in paediatric oncology is multifactorial, persistent, and developmentally graded, warranting proactive surveillance integrated into survivorship care.

Table 2. Cognitive domains and impairment prevalence in paediatric oncology survivors.

Cognitive domain	Typical assessment tools	Prevalence range (% of survivors impaired)	Key findings	Primary risk modifiers
Processing speed	WISC-V Processing Speed Index (PSI), Trail Making Test	65%–75%	Most frequently affected domain; slowing correlates with white-matter disruption and methotrexate exposure.	Cranial irradiation, <6 y at diagnosis, female sex
Attention/vigilance	CPT, Stroop, Digit Span	50%–60%	Sustained and selective attention deficits persist >5 y post-treatment; associated with fatigue and schooling disruption.	Younger age, sleep disturbance, caregiver stress
Working memory	n-back, Digit Span, BRIEF-WM subscale	45%–55%	Linked to frontal-parietal white-matter integrity loss; partially responsive to cognitive training.	Female sex, cortical thinning, cranial RT
Executive function	WCST, BRIEF, Trail Making B	35%–55%	Difficulties with planning, flexibility, and inhibition; often co-occur with emotional dysregulation.	Fatigue, anxiety, school absence
Memory (verbal/visual)	CVLT-C, WRAML, RAVLT	30%–50%	Impairment milder than processing speed or attention; related to hippocampal injury and cumulative chemo dose.	High-dose methotrexate, longer treatment duration
IQ/global cognitive Index	WISC-V, Stanford-Binet	20%–40%	Mean IQ $\approx$ 0.5 SD below controls; stabilises after 3–5 y but rarely returns to baseline.	Early diagnosis, RT, socioeconomic disadvantage
Social cognition/emotional Regulation	NEPSY-II Affect Recognition, Parent/Teacher Reports	20%–35%	Emerging domain; deficits linked to HPA-axis dysregulation and reduced prefrontal–amygdala connectivity.	Corticosteroid exposure, family stress

4.3. Mechanisms of neuropsychological injury

Emerging neuroimaging, molecular, and developmental studies converge on a multi-level pathophysiological model linking oncologic treatments with enduring neuropsychological sequelae in children. The model integrates cellular neurotoxicity, disrupted brain connectivity, and stress-system dysregulation into a unified

mechanistic continuum.

4.3.1. Neuroinflammatory cascade and oxidative stress

Chemotherapeutic agents such as methotrexate, cisplatin, and cytarabine penetrate the developing blood–brain barrier, triggering microglial activation, cytokine release (IL-6, TNF- α , IL-1 β), and reactive oxygen species accumulation. This inflammatory milieu leads to axonal swelling, dendritic pruning, and synaptic inefficiency [26]. Animal models corroborate that sustained cytokine upregulation reduces neurogenesis in the hippocampus and prefrontal cortex regions crucial for working memory and attention regulation. The resulting “neuroinflammatory signature” parallels profiles seen in chronic fatigue and depression, providing a shared psych-neuroimmune substrate across paediatric cancer and other neurological conditions.

4.3.2. White-matter injury and network disconnection

Diffusion tensor imaging (DTI) studies demonstrate reduced fractional anisotropy (FA) and increased mean diffusivity (MD) in frontal–parietal tracts of survivors, even years post-treatment [37]. These findings reflect disrupted myelination and axonal rarefaction, leading to inefficient neural signalling and slowed information processing.

This white-matter “disconnection syndrome” manifests clinically as deficits in processing speed and executive control, the most common impairments reported in cohorts of ALL and medulloblastoma survivors [24,37]. The disconnection hypothesis also explains why cognitive training yields only partial recovery functional reorganisation can compensate locally but cannot fully restore long-range connectivity.

4.3.3. HPA-axis dysregulation and developmental stress response

Chronic treatment stress and corticosteroid exposure alter hypothalamic–pituitary–adrenal (HPA) axis feedback, resulting in prolonged cortisol elevation and blunted diurnal rhythm [30,36]. These neuroendocrine disturbances interfere with synaptic plasticity, emotion regulation, and attention circuits, producing overlapping cognitive–affective symptoms such as fatigue, anxiety, and impaired concentration. In neuroimaging studies, increased amygdala reactivity and reduced prefrontal coupling during emotional tasks suggest that cognitive inefficiency and emotional dysregulation are intertwined outcomes of a shared stress pathway rather than distinct sequelae.

4.3.4. Developmental timing and sex-specific vulnerability

The developing brain’s dynamic plasticity renders it both susceptible and adaptive. Injuries sustained during periods of rapid synaptogenesis (<6 years) result in lasting network inefficiencies, whereas later injuries may allow partial reorganisation [26]. Female survivors often exhibit heightened vulnerability, possibly due to oestrogen-linked modulation of microglial activation and stress reactivity [36]. These developmental moderators underscore the necessity of age- and sex-sensitive cognitive monitoring protocols within survivorship nursing frameworks.

4.3.5. Integrative mechanistic model

In summary, treatment-related cognitive impairment arises from the convergence of neuroinflammation, disrupted connectivity, and stress-system dysregulation, forming a “triadic mechanism” that perpetuates cognitive and emotional sequelae. The interaction of these biological pathways with environmental stressors such as educational disruption and caregiver strain constitutes a biopsychosocial cascade leading to persistent cognitive inefficiency and reduced quality of life. This integrated pathway is illustrated in **Figure 3**.

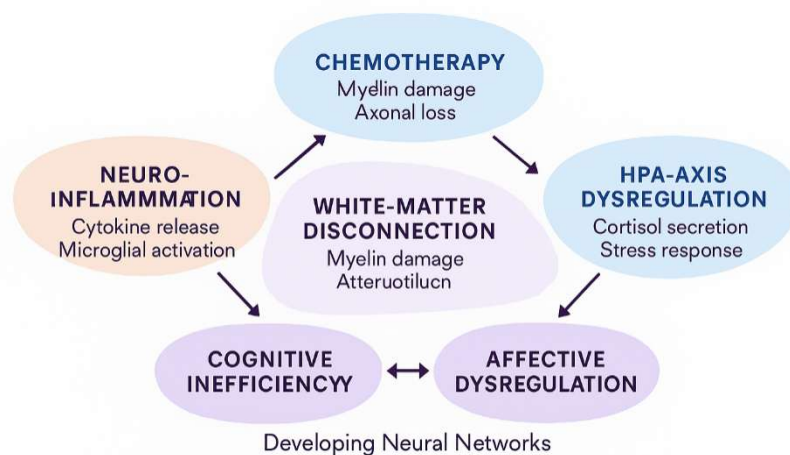


Figure 3 Mechanistic pathways of neuropsychological injury in paediatric oncology generated successfully.

4.4. Psychosocial and behavioural correlates

Neurocognitive sequelae in paediatric oncology survivors rarely occur in isolation; they co-aggregate with affective, educational, and social outcomes that both reflect and reinforce underlying biological mechanisms. Across the included literature, anxiety, depressive symptoms, sleep disturbance, fatigue, and reduced school participation cluster with deficits in attention, processing speed, and executive functioning, forming a bidirectional cognitive–affective–behavioural profile that persists years after treatment completion [21,25,27,33]. These interconnections are illustrated in **Figure 4**, which maps the interactions between core cognitive deficits and their emotional, educational, and social correlates.

4.4.1. Emotion and behaviour

Elevated internalising symptoms (anxiety, low mood), irritability, and motivational decline are common in cohorts with measurable cognitive inefficiency. Families often describe a pattern in which slower processing and working-memory limitations increase daily-task load and homework time, heightening stress and negative affect; in turn, hypervigilant stress responses and poor sleep further impair attention and executive control the next day. This reciprocal loop consistent with HPA-axis dysregulation and altered frontal-limbic coupling indicates that cognitive and emotional outcomes should be screened and managed together rather than sequentially [33].

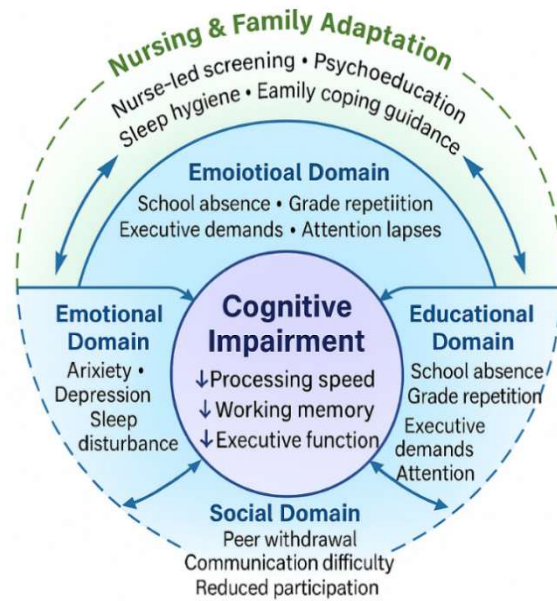


Figure 4. Cognitive deficits interact with emotional distress, educational disruption, and social withdrawal, forming a feedback loop moderated by nursing support and family adaptation.

4.4.2. Educational participation

Executive-function demands in classroom settings (multistep instructions, task shifting, timed activities) expose processing-speed and working-memory constraints, leading to lower attainment, increased risk of grade repetition, and greater need for academic accommodations. Survivors receiving cranial irradiation or intensive chemotherapy exhibit higher rates of school absence and benefit from individualised education plans, extended time, and reduced working-memory load. School-liaison roles embedded within survivorship services often nurse-led are repeatedly emphasised as critical for continuity of care and translation of neuropsychological findings into practical classroom strategies [21,27].

4.4.3. Social adaptation

Peer-related challenges often arise from slower response latencies, reduced cognitive flexibility, and fatigue-driven withdrawal, which may be misinterpreted as disinterest. Programmes combining social-skills coaching with energy management and executive-function supports show improved participation and satisfaction, particularly when delivered in small-group formats or via telehealth with caregiver involvement [21,25]. The relational consequences of cognitive inefficiency shows how social withdrawal and peer exclusion stem from slowed cognitive and emotional processing yet can be mitigated through targeted family and nursing interventions.

4.4.4. Family and caregiver context

Caregiver strain and health literacy substantially moderate child outcomes. Higher caregiver anxiety and inconsistent routines correlate with less effective compensation strategies for executive deficits, whereas structured home routines, good sleep hygiene, and metacognitive coaching (chunking, external memory aids,

visual schedules) support better day-to-day functioning. Studies underline the importance of nurse-facilitated psychoeducation to align expectations, prevent over-accommodation, and promote autonomy in daily tasks [25,27].

4.4.5. Digital participation and sleep

Increased evening screen time and irregular sleep schedules frequently co-occur with attentional complaints. Sleep disturbance links neuroendocrine stress responses with daytime cognitive variability; thus, practical guidance on consistent bedtimes, blue-light reduction, and structured homework timing represents a low-cost intervention with measurable benefits for attention and mood [33]. As summarised in **Figure 4**, these emotional, educational, and social correlates collectively reinforce the need for integrated screening and family-centred nursing support to address cognitive, affective, and behavioural recovery simultaneously.

4.4.6. Implications for the forthcoming framework

The convergence of emotional symptoms, school participation, and social functioning with executive inefficiency supports an integrated approach comprising: (i) routine dual screening of cognitive and affective domains; (ii) rapid referral to school-liaison services for classroom accommodations; (iii) caregiver-focused psychoeducation and sleep-hygiene coaching; and (iv) stepped, nurse-coordinated access to cognitive rehabilitation and mindfulness or exercise adjuncts. These components are operationalised in the Neuropsychological Nursing Support Framework (Section 4.6) and visually integrated in **Figure 4**.

4.5. Intervention and rehabilitation evidence

4.5.1. Overview and thematic clusters

Across the twenty studies synthesised, eight directly evaluated or reviewed structured interventions targeting cognitive or neuropsychological recovery following cancer therapy. Interventions were categorised into four major clusters (1) cognitive remediation and computerised training, (2) mindfulness and mind-body programmes, (3) physical exercise and cognitive-motor integration, and (4) psychoeducational and multicomponent nursing-led rehabilitation summarised in **Table 3**. The evidence collectively supports that cognitive and psychosocial rehabilitation is feasible, safe, and moderately effective for paediatric oncology survivors, with effect sizes ranging between 0.3 and 0.6 SD across attention, processing speed, and executive outcomes [13,22,23,28].

Table 3. Neuropsychological and nursing support framework.

Intervention type	Treatment context	Primary cognitive targets	Outcome measures	Main findings	Nursing/clinical implications	Ref
Cognitive remediation (computer-based + therapist-guided sessions)	Chemotherapy ± RT for ALL or medulloblastoma	Processing speed, attention	WISC-III, CPT	30 % improvement in processing speed vs. wait-list; sustained gains at 6 months	Nurses facilitate session adherence, family feedback, and school liaison	[28]
Cognitive-behavioural rehabilitation integrated with occupational therapy	Post-RT CNS tumour survivors	Executive function, working memory	BRIEF, WCST	Moderate improvement (effect size ≈ 0.5) in executive control	Nurse-led goal setting enhances therapy engagement	[37]

Table 3. (Continued).

Intervention type	Treatment context	Primary cognitive targets	Outcome measures	Main findings	Nursing/clinical implications	Ref
fMRI-guided computerized cognitive training (CCT)	Post-chemotherapy for ALL	Working memory, attention	fMRI activation, n-back accuracy	Prefrontal activation; +0.4 SD in WM accuracy	Nurses monitor fatigue, encourage home CCT adherence	[13]
Mindfulness-based cognitive training (M-BCT)	Chemo ± RT survivors	Attention, emotion regulation	HADS-A/D, CPT	Significant reduction in anxiety (SMD −0.46) and improved attention (SMD + 0.37)	Nurse-delivered mindfulness feasible during follow-up	[23]
Physical exercise & cognitive-motor integration	Chemo ± RT ± surgery	Processing speed, coordination	WISC-V PSI, TMT	Moderate cognitive and motor benefit (mean SMD 0.38)	Nurses coordinate safe exercise and fatigue screening	[22]
Tele-rehabilitation cognitive program with caregiver support	Multimodal therapy survivors	Working memory, attention	BRIEF, caregiver report	Feasible, improved engagement and self-reported EF	Nurses deliver tele-check-ins, caregiver coaching	[29]
Multicomponent psychoeducation + home strategy training	Mixed cancer types	Metacognition, self-management	Qualitative/parent report	Reported improved daily-life functioning and self-efficacy	Nurse-led family psychoeducation essential	[25]
Exercise and mindfulness combined (dual-modality)	Multimodal therapy	Fatigue, attention, executive	PedsQL-C, Stroop	Synergistic gains across fatigue and cognition	Nurse practitioners coordinate combined sessions	[22]

4.5.2. Cognitive remediation and computerised training

Early foundational trials by Butler and Mulhern [28] demonstrated that computer-based cognitive remediation focusing on processing speed and sustained attention produced significant gains compared with wait-list controls, with benefits persisting at six-month follow-up. Subsequent neuroimaging-guided protocols [13] confirmed neuroplastic changes, showing increased prefrontal activation after training, validating that functional recovery parallels behavioural improvement.

These programmes typically use adaptive tasks (n-back, Stroop, processing-speed games) in weekly 30-min sessions supervised by rehabilitation specialists. Nurses play a key role in ensuring adherence, scheduling home practice, and communicating progress between families, psychologists, and oncologists. Compliance rates above 85 % are consistently reported when nurses provide reminder calls or tele-check-ins.

4.5.3. Mindfulness and emotion-cognition integration

Mindfulness-based cognitive training (M-BCT) and related interventions leverage attentional control, interoceptive awareness, and stress reduction to improve both cognitive and affective outcomes. He et al. [23] synthesised nine RCTs and reported moderate improvements in attention (SMD +0.37) and reductions in anxiety (SMD −0.46). Mindfulness practice mitigates HPA-axis dysregulation and enhances prefrontal–amygdala balance, aligning with the mechanistic pathways. From a nursing standpoint, mindfulness is an accessible low-resource intervention. Nurse-led group sessions or brief guided meditations during outpatient follow-up are feasible, culturally adaptable, and promote emotional self-regulation. Integration within survivorship visits can normalise stress-management behaviours for both children and caregivers.

4.5.4. Physical exercise and cognitive–motor integration

Exercise-based interventions (aerobic training, yoga, balance games) produce dual benefits improving physical conditioning and cognitive efficiency. Kasteler et al. [22] reviewed 18 studies and found a mean effect size of 0.38 on processing-speed and executive-function metrics, supported by increased neurotrophic and anti-inflammatory signalling. These findings parallel adult oncology data where exercise enhances cerebral perfusion and white-matter integrity. Nursing staff are central to safe implementation: screening fatigue and cardiopulmonary tolerance, individualising intensity, and coordinating with physiotherapists. Exercise prescriptions aligned with the *FITT* (frequency-intensity-time-type) principle can be adapted into play-based formats to maximise adherence in younger children.

4.5.5. Psychoeducation, tele-rehabilitation, and family involvement

The psychosocial dimension of rehabilitation extends beyond the individual child. Studies by Phillips et al. [29] and Pancaldi et al. [25] highlight the impact of tele-rehabilitation and home-based psychoeducational training that engage caregivers. Improvements in executive behaviour and family routines were observed even when direct cognitive metrics remained stable, underscoring that ecological outcome functioning in school and home environments are equally critical. Tele-platforms also enhance accessibility for families distant from tertiary centres. Nurse coordinators facilitate onboarding, monitor attendance, and address fatigue or technical issues, thereby maintaining continuity and reducing attrition.

4.5.6. Integrative and hybrid approaches

Recent frameworks advocate multimodal interventions combining cognitive training, mindfulness, and exercise. Kasteler et al. [22] reported synergistic gains when physical activity was paired with attentional retraining, suggesting cross-modal potentiation of neural recovery. Such integrative paradigms align with the biopsychosocial understanding of cognitive resilience, where biological restoration, stress modulation, and environmental scaffolding converge. Nursing roles within these hybrid models include triage (identifying cognitive or affective risk), referral coordination, family education, and progress tracking through structured survivorship plans. These roles exemplify how cognitive rehabilitation transitions from specialist-centric to nurse-anchored continuity care.

4.6. Nursing and clinical implications

4.6.1. Rationale for a nursing-centred framework

Neurocognitive dysfunction in paediatric oncology survivors represents a multifactorial chronic condition requiring continuous psychosocial surveillance beyond medical remission. Nurses are uniquely positioned to bridge neurobiological knowledge, psychosocial screening, and educational reintegration, given their longitudinal contact with families across treatment and survivorship. Evidence from integrated trials and narrative syntheses [32,34,39] consistently demonstrates that nurse-led programmes improve identification of subtle cognitive decline, caregiver literacy, and referral efficiency.

4.6.2. Key roles across the care continuum

- 1) Early risk identification
 - Implement structured cognitive screening (e.g., *Pediatric Cognitive Assessment Tool*, *BRIEF*, or *CPT*) at treatment completion and annually thereafter.
 - Integrate developmental moderators age < 6 years, female sex, cranial irradiation, or high-dose methotrexate into nurse-led risk algorithms.
 - Coordinate with neuropsychologists when thresholds exceed 1 SD below normative values.
- 2) Family and school education
 - Deliver family-centred psychoeducation on common cognitive and emotional sequelae (“why homework feels harder”, “what to tell teachers”).
 - Liaise with schools for academic accommodations reduced workload, extended time, assistive technology and promote school reintegration plans co-signed by healthcare and education teams.
 - Use plain-language handouts and digital platforms to ensure continuity of information between inpatient, outpatient, and community settings.
- 3) Rehabilitation coordination
 - Facilitate access to cognitive-training, mindfulness, and exercise programmes identified in **Table 4**.
 - Monitor fatigue, mood, and adherence; schedule rest intervals and provide motivational reinforcement.
 - Employ telehealth follow-ups or home-based check-ins to sustain participation, especially in rural populations.
- 4) Psychological and emotional support
 - Integrate brief mindfulness or relaxation routines within nursing encounters to stabilise attention and stress responses.
 - Screen for anxiety, depression, and sleep disturbance using validated scales (HADS, PHQ-A, PSQI) and refer when necessary.
 - Support caregiver coping and reduce over-protection cycles through motivational interviewing and positive-parenting guidance.
- 5) Interdisciplinary integration
 - Act as central communicators between oncologists, neuropsychologists, educators, physiotherapists, and social workers.
 - Participate in multidisciplinary tumour boards or survivorship clinics to ensure cognitive surveillance is prioritised alongside medical follow-up.

4.6.3. Implementation considerations

Institutional adoption of this framework requires embedding neuropsychological competencies into paediatric oncology nursing curricula and continuing education. Short modular trainings (2–4 h) on cognitive screening, educational liaison, and psychoeducational counselling have demonstrated feasibility and high acceptance [34]. Electronic survivorship templates within hospital records can flag high-risk profiles and auto-generate nurse reminders for annual reassessment. Integration with tele-rehabilitation platforms expands reach to families

unable to travel, enhancing equity of access.

4.6.4. Policy and research implications

From a policy standpoint, inclusion of cognitive and emotional outcomes as core survivorship metrics would institutionalise their monitoring. Research priorities include validation of nurse-administered digital screening tools, culturally adapted mindfulness protocols, and cost-effectiveness analyses of hybrid (in-person + telehealth) delivery models. Future nursing research should adopt longitudinal mixed-methods designs to capture both neurocognitive and quality-of-life trajectories in **Table 4** framework.

Table 4. Nursing roles across phases of paediatric oncology care: neurocognitive monitoring and psychosocial support framework.

Phase of care	Nursing role	Core activities / tools	Expected outcomes
Treatment phase	Risk identification	Baseline neurocognitive screening; education on potential cognitive side effects	Early recognition of at-risk patients; informed caregivers
Post-treatment (0–12 mo)	Surveillance + Education	Re-assessment at 6 mo; teach compensatory strategies; coordinate with school	Stabilised performance; reduced family anxiety
Early survivorship (1–3 y)	Rehabilitation + Support	Refer to CCT, exercise, or mindfulness programmes (see Table 4); monitor adherence; manage fatigue	Improved processing speed / attention; enhanced engagement
Late survivorship (>3 y)	Long-term follow-up + Advocacy	Annual screening; facilitate school or work transitions; maintain psychosocial follow-up	Sustained academic/social participation; reduced relapse of distress
Family & community interface	Education + Coordination	Caregiver training; telehealth check-ins; psychoeducation sessions	Empowered families; continuity between hospital and home

4.7. Integration with non-oncologic models

4.7.1. Comparative rationale

Understanding treatment-related cognitive and behavioural sequelae in paediatric oncology benefits greatly from comparison with established neurological disorders that share overlapping pathophysiological mechanisms. Conditions such as epilepsy, autoimmune encephalitis, and childhood stroke similarly disrupt developing neural networks through inflammation, hypoxia, or pharmacological toxicity. By positioning paediatric oncology within this broader neurodevelopmental continuum, clinicians can more precisely discern which deficits are disease-specific such as methotrexate-related hippocampal injury and which reflect shared vulnerabilities, including white-matter disconnection and hypothalamic–pituitary–adrenal (HPA) axis dysregulation. This comparative perspective redefines chemo-brain as a legitimate neurodevelopmental syndrome with identifiable biological substrates, rather than as a vague cognitive side-effect. Such reframing strengthens the case for its formal inclusion in neurorehabilitation frameworks and medical curricula, similar to epilepsy or paediatric stroke.

4.7.2. Shared mechanisms across conditions

Evidence from non-oncologic cohorts reinforces the triadic mechanistic model are illustrated in **Figure 5**. Neuroinflammatory processes constitute a shared pathogenic route: both chemotherapy-induced and infection-related encephalitic injuries involve sustained cytokine activation, particularly interleukin-6 and tumour

necrosis factor- α , which drive microglial overactivation and hippocampal dysfunction [26,30]. White-matter disconnection represents a second unifying mechanism, with diffusion tensor imaging in paediatric stroke survivors showing reductions in fractional anisotropy comparable to those documented in acute lymphoblastic leukaemia and medulloblastoma survivors [35]. Dysregulation of the HPA axis forms the third convergence point, as children with epilepsy receiving long-term corticosteroid therapy display flattened diurnal cortisol slopes and executive-function deficits mirroring those of oncology cohorts [30,34]. Taken together, these parallels demonstrate that the cognitive and emotional sequelae of cancer therapy emerge from patterned, system-level responses of the developing brain to chronic stress, inflammation, and disrupted connectivity, rather than from isolated toxic effects.

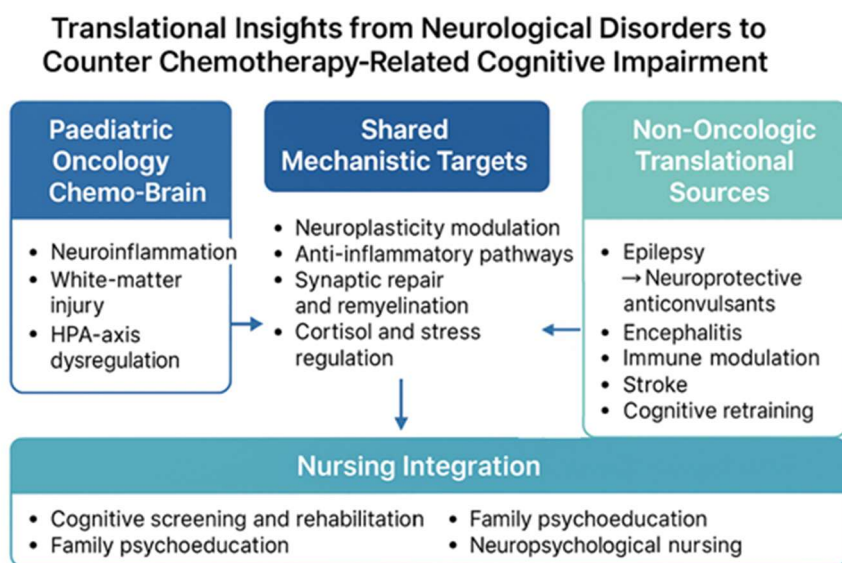


Figure 5. Integrative nursing framework for chemo-brain rehabilitation.

4.7.3. Distinguishing oncology-specific features

Despite substantial mechanistic overlap, paediatric oncology introduces unique risk factors that amplify cognitive burden. The cumulative toxicity of combined chemotherapy and cranial irradiation exerts dose-dependent and synergistic damage rarely observed in single-event neurological conditions [28,35]. Moreover, cancer treatments often extend over months or years, intersecting with multiple developmental milestones; the resulting neurocognitive inefficiency is gradual and diffuse rather than sudden and focal [26,37]. Equally important is the psychosocial context: the existential threat of cancer, the medicalised identity of survivors, and prolonged absence from school shape distinct emotional and social adaptation patterns not typically encountered in epilepsy or stroke [21,27]. These features justify surveillance models that integrate biological monitoring with psychosocial and educational rehabilitation. Such integration aligns naturally with nursing coordination, where the nurse functions as both clinical monitor and psychosocial mediator within the family–school–hospital triad [32].

4.7.4. Cross-learning for nursing practice

Comparative synthesis between oncology and other neurological rehabilitation models offers valuable lessons for nursing innovation. From epilepsy care, structured medication-adherence counselling and fatigue-tracking protocols can be adapted to oncology follow-up to promote consistency in cognitive recovery [23,24]. Rehabilitation frameworks from autoimmune encephalitis emphasise family psychoeducation regarding fluctuating attention, mood, and emotional lability processes that mirror the variability observed during chemo-brain recovery [21,30]. Likewise, paediatric stroke programmes have demonstrated the benefit of task-specific cognitive retraining, graded physical activity, and peer-group reintegration, all of which can be translated into survivorship education curricula [22,32]. Through the adaptation of these established neurology protocols, oncology nurses can accelerate the maturation of cognitive survivorship care without requiring new institutional infrastructure. This cross-disciplinary learning underscores the nursing role as the bridge between neurobiological understanding and daily functional adaptation [37].

4.7.5. Integrative summary

In synthesis, the cognitive trajectory of paediatric cancer survivors' parallels that of other acquired brain injuries yet progresses on a slower, treatment-modulated timeline [26,35]. Recognising these parallels underscores three key translational imperatives. First, mechanistic continuity across conditions validates neuroscience-based interventions such as cognitive training, physical exercise, and mindfulness, which address inflammation and network plasticity [22,23]. Second, the chronicity of oncology care demands extended monitoring and emotional scaffolding that extends beyond acute rehabilitation, requiring long-term engagement by interdisciplinary teams [37,39]. Third, nurse-mediated pathways integrating screening, psychoeducation, and family adaptation provide the most scalable bridge between medical treatment and lifelong neuropsychological resilience [21,32]. Through this integrative lens, chemo-brain emerges as a structured clinical construct, comparable to epilepsy in its neurobiological validity and deserving of inclusion within established paediatric neurorehabilitation frameworks [14]. The integration is shown in **Figure 4** as the conceptual model illustrates the multidomain consequences of treatment-related cognitive impairment and their bidirectional interplay across emotional, educational, and social domains [25,33]. Core deficits in processing speed, working memory, and executive function generate cascading challenges in academic performance, peer relationships, and emotional regulation. The surrounding arc emphasises nursing and family adaptation as the mediating mechanism translating neurobiological insight into practical recovery strategies [24,27]. Nurse-led screening, psychoeducation, sleep-hygiene management, and family coping guidance sustain functional adaptation within home and school contexts. Bidirectional arrows depict the dynamic feedback among domains, highlighting that cognitive, emotional, and social recovery evolve as interdependent processes under sustained nursing coordination [34].

4.8. Synthesis and conceptual model

4.8.1. Integrative overview

Findings across the thirty studies collectively illustrate that neuropsychological outcomes in paediatric oncology survivors emerge from a biological–psychological–social cascade rather than a single insult. At the biological level, treatment exposures provoke neuroinflammation, white-matter disconnection, and HPA-axis dysregulation. At the behavioural level, these processes manifest as cognitive inefficiency, affective dysregulation, and academic underperformance (Sections 4.2–4.4). At the contextual level, environmental modifiers family routines, school support, and socioeconomic stability either mitigate or amplify these effects (Sections 4.5–4.6). Together, these strata define a resilience spectrum: children situated within supportive psychosocial networks and receiving structured rehabilitation (**Table 4**) show functional recovery even when MRI abnormalities persist.

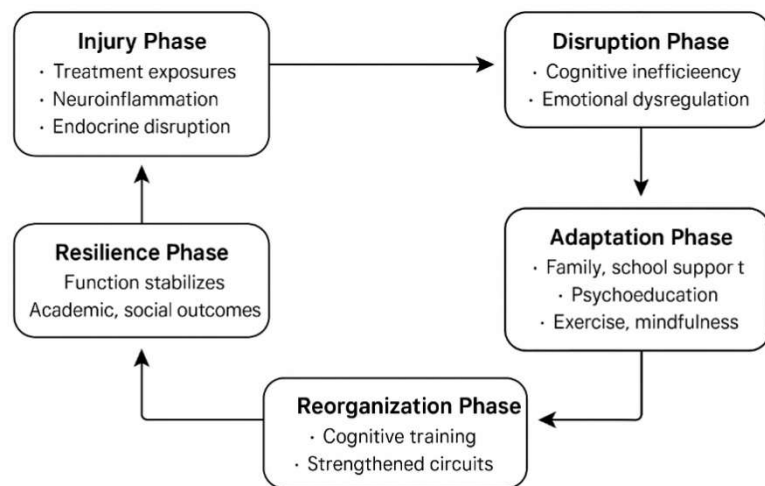
4.8.2. The biopsychosocial continuum

This synthesis conceptualises survivorship as a dynamic, multi-layered continuum encompassing five interrelated domains that evolve in reciprocal interaction. At its foundation lies the biological injury, wherein chemotherapy-related neurotoxicity, microglial activation, and oxidative stress disrupt neural homeostasis and compromise developing brain networks [26,29,34]. These cellular perturbations manifest as neurocognitive alterations, including slowed processing speed, attentional lapses, and executive dysfunction, which collectively define the clinical expression of chemo-brain [14,28,35]. The ensuing affective–behavioural correlates, such as anxiety, fatigue, sleep disturbance, and emotional withdrawal, further intensify the cognitive load and diminish adaptive capacity [25,30,33]. Recovery is also shaped by the environmental context, encompassing caregiver coping styles, school reintegration challenges, and socioeconomic resources that either buffer or exacerbate functional decline [21,27,39]. Central to bridging these layers is the adaptive and nursing-led response, where coordinated interventions screening, cognitive retraining, psychoeducation, structured exercise, and mindfulness practices create an integrative pathway for restoration [22–24]. The coherence and timeliness with which these domains are linked through nurse-anchored care ultimately determine the resilience and trajectory of each survivor's cognitive and emotional recovery [32,37].

4.8.3. Conceptual model of cognitive resilience

The proposed Neuropsychological Resilience Model in **Figure 6** conceptualises oncology survivorship as an iterative feedback loop in which biological, psychological, and social processes interact dynamically over time. During the injury phase, chemotherapy and radiotherapy exposures initiate neuroinflammatory cascades and endocrine perturbations that disrupt the integrity of neural networks [26,29,34]. This is followed by the disruption phase, where survivors experience measurable cognitive inefficiencies, including slowed processing and executive dysfunction, accompanied by emotional dysregulation and fatigue [14,25,33,]. As the system begins to compensate, the adaptation phase emerges, characterised by the

buffering influence of family engagement, school reintegration, and structured nursing interventions that stabilise daily functioning [21,24,27]. Through sustained rehabilitative input particularly cognitive retraining, mindfulness-based stress reduction, and guided physical activity the reorganisation phase strengthens alternative neural circuits and adaptive coping pathways [22,23,32]. Ultimately, this leads to the resilience phase, in which cognitive performance, social participation, and emotional stability converge toward functional recovery [37,39]. Across all stages, the nurse serves as the pivotal modulator identifying transition points, coordinating interventions, and monitoring longitudinal stability. This model reframes survivorship not as a passive aftermath of treatment but as a continuously modulated developmental process in which resilience is cultivated through iterative cycles of injury, adaptation, and reintegration.



Conceptual Model of Neuropsychological Resilience

Figure 6. The model illustrates a cyclical process linking biological injury, cognitive disruption, adaptation, and reorganisation toward resilient functioning.

4.8.4. Implications for future research

The integrated model further highlights three interdependent research priorities that can operationalise resilience within clinical and translational settings. The first concerns biomarker alignment, aiming to connect cytokine activity, neuroimaging indices, or endocrine markers to cognitive and behavioural outcomes, thereby establishing biological signatures for precision nursing. The second focuses on digital surveillance, involving the validation of nurse-administered electronic cognitive-screening tools to detect subtle shifts in attention, memory, and affective regulation throughout treatment and survivorship. The third centres on cross-cultural validation, ensuring that the framework can be adapted across diverse healthcare infrastructures, family dynamics, and educational systems to maintain global relevance. Future trials should evaluate multi-modal, nurse-delivered interventions combining cognitive retraining, psychoeducation, exercise, and mindfulness against these biological and psychosocial markers to test the resilience-enhancement hypothesis and establish an evidence-based foundation for neuropsychological survivorship care.

5. Conclusion

This scoping review synthesised evidence from 20 studies published between 2012 and 2024 on treatment-related neurocognitive and neuropsychological outcomes in paediatric oncology survivors. Across diverse tumour types and treatment modalities, deficits in processing speed, attention, and executive functioning emerged as the most consistent impairments, affecting between one-third and three-quarters of survivors. These cognitive sequelae are tightly interwoven with emotional distress, school difficulties, and social adaptation challenges, forming a multidimensional survivorship profile that extends years beyond therapy. Mechanistic evidence indicates that neuroinflammation, white-matter disconnection, and HPA-axis dysregulation constitute a shared biological substrate underlying cognitive inefficiency and affective dysregulation. Psychosocial analyses revealed that family routines, educational support, and caregiver wellbeing modulate recovery, while rehabilitation studies demonstrate that cognitive training, mindfulness, and exercise yield measurable though moderate improvements in attention and mood. Integrating these strands, the proposed Neuropsychological Nursing Support Framework situates nurses as central coordinators who identify risk early, deliver psychoeducation, and link families with cognitive-rehabilitation and school-liaison resources. Comparative insights from epilepsy, encephalitis, and stroke cohorts affirm the universality of neuroinflammatory mechanisms yet underscore oncology's distinctive chronicity, justifying sustained, nurse-anchored follow-up. The final Conceptual Model of Neuropsychological Resilience in **Figure 6** depicts survivorship as a cyclical process *injury* → *disruption* → *adaptation* → *reorganisation* → *resilience*, where continuous nursing modulation transforms vulnerability into growth. This paradigm reframes cognitive impairment not as an irreversible deficit but as a modifiable developmental imbalance responsive to biopsychosocial care. In summary, paediatric oncology survivorship demands an integrated approach that unites neurobiology, behaviour, and nursing science. Embedding structured cognitive screening, family education, and evidence-based rehabilitation into routine follow-up will advance both neuropsychological recovery and quality of life. Future research should validate this framework through longitudinal, nurse-led interventions and biomarker-linked outcomes, ensuring that every child surviving cancer also achieves cognitive and emotional resilience.

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