Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Ecological Momentary Assessment of Working Memory in Childhood Cancer Survivors: A Proof-of-Concept Study

Rachel-Tzofia Sinvani

Rachel-Tzofia.sinvani@mail.huji.ac.il

Talpiot Academic College of Education

Bracha Auerbach-Lawee

Hebrew University of Jerusalem

Sapir Marom

Hebrew University of Jerusalem

Gal Goldstein

Hebrew University of Jerusalem

Mor Nahum

Hebrew University of Jerusalem

Yafit Gilboa

Hebrew University of Jerusalem

Article

Keywords: Ecological Momentary Assessment, Working memory, Childhood cancer survivors, Smartphone-based assessment

Posted Date: September 16th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-10679471/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

Abstract

Purpose

Childhood cancer survivors (CCS) are at elevated risk for persistent deficits in working memory (WM). However, traditional neuropsychological assessments, conducted in controlled settings, may fail to capture daily fluctuations in WM performance, leading to mixed findings. We examined the feasibility and acceptability of a mobile Ecological Momentary Assessment (EMA) for evaluating visuospatial WM in CCS within naturalistic contexts. In addition, we assessed its comparability to existing cognitive and behavioral, lab-based measures.

Methods

N = 50 participants (18 CCS; 20 girls; age range: 10–18 years), completed a 10-day EMA protocol, assessing their visuospatial WM performance twice/day. Baseline assessments included performance-based visuospatial working memory, processing speed, and response inhibition (assessed via the Adaptive Cognitive Evaluation Explorer [ACE-X]) and parent- and self-reported executive functions (using the Behavior Rating Inventory of Executive Function [BRIEF]).

Results

EMA compliance was high (87%), yet significantly lower in CCS than healthy controls (HC) (76.9% vs. 93%; $z = 4.30$, $p < .001$). Mean WM performance across the EMA session was lower in CCS compared to HC ($t(48) = 3.48$; $p < .001$). EMA performance correlated moderately to strongly with ACE-X scores ($r_s = -.47$ to $-.67$ in HC; $r_s = -.57$ to $-.64$ in CCS) but not with BRIEF subscales.

Conclusion

These results provide early, promising evidence of the feasibility and acceptability of EMA for capturing real-world cognitive deficits that the ACE-X overlooks yet participants subjectively report. These findings lay the foundation for future research examining the clinical utility of EMA-based cognitive monitoring in pediatric oncology and in further rehabilitation trials.

Introduction

Childhood cancer survivors (CCS) are at a significant risk for cancer-related cognitive impairment (CRCI), particularly reduced working memory (WM), which may persist for years after treatment completion (Agelink van Rentergem et al., 2025). Such persistent cognitive deterioration carries significant implications for one's intellectual development, academic attainment, and overall quality of life

(Sciancalepore et al., 2023). Despite this, WM is often assessed using one-time, laboratory-based measures administered in controlled settings, which may fail to capture context-dependent performance fluctuations which are characteristic of everyday life (Lewandowski, 2024). The current proof-of-concept study assessed the feasibility and acceptability of an Ecological Momentary Assessment (EMA) approach to measuring WM in CCS and its capacity to detect real-world cognitive challenges as they unfold in naturalistic environments. To examine comparability to one-time lab-based measures of cognitive control (ACE-X and BRIEF) correlations were tested.

Literature Review

Cancer-related cognitive impairment (CRCI) encompasses a broad range of cognitive challenges frequently experienced by cancer patients and survivors, including deficits in attention, processing speed, and executive functions (EFs) (Scriney et al., 2025) (Hardy et al., 2018; Hutterer & Oberndorfer, 2021). Recent meta-analytic evidence indicates that childhood cancer survivors (CCS) consistently perform less well than matched non-CCS samples across various cognitive domains, with impairment rates ranging from 20% to 58% (Gandy et al., 2023; Sciancalepore et al., 2023). Deficits in WM, one of the most studied domains in relation to CCS (Egset et al., 2025), have been consistently documented in cancer patients and survivors compared to their matched healthy peers (Bi et al., 2025; Schuerch et al., 2025; Siegwart et al., 2021).

Being a core component within EF, WM is a multi-compartment system providing temporary storage and manipulation of information to support complex cognitive tasks such as reasoning, comprehension, and learning (Baddeley, 2020). More specifically, *WM updating* is defined as the ability to continuously monitor and revise WM contents in response to changing task demands (Friedman et al., 2016). WM deficits can lead to cascading adverse effects on overall cognitive function and adaptive behavior, including patterns of inattentiveness, forgetfulness, and poor academic performance across reading, mathematics, and language domains (Alloway et al., 2013; Carpenter & Alloway, 2023).

Recent neuroimaging studies employing fMRI during WM task performance reveal significant group differences between CCS and matched healthy controls in both brain activation patterns and task accuracy (Habibi et al., 2025; Silverman et al., 2025). Notably, altered activation patterns in CCS include reduced engagement in prefrontal cortical regions essential for WM, such as the dorsolateral prefrontal cortex (DLPFC), as well as attenuated activity in hippocampal and amygdala circuits associated with learning and emotion regulation (McKenna et al., 2026). Additionally, atypical increases in activity in parietal regions during incorrect trials have been found, consistent with inefficient or compensatory neural processing (Stefancin et al., 2020).

The specific WM impairments seen in CCS vary in magnitude across WM components (Schuerch et al., 2025). Specifically, on verbal WM tasks such as Digit Span Backward, survivors score approximately 0.5 SD below controls on, reflecting difficulties with mental manipulation of verbal information (Conklin et al., 2012; van der Plas et al., 2021). Comparable deficits are found on visuospatial WM tasks, particularly

under high cognitive load, with survivors exhibiting reduced accuracy on spatial span tasks and prolonged response times (Siegwart et al., 2021). WM updating abilities are especially compromised: on n-back tasks, survivors demonstrate 10–25% more errors, increased omissions, and response times 200-400ms slower than controls (Gandy et al., 2023; King et al., 2015). These deficits manifest across diagnostic groups, with approximately 34% of long-term survivors performing more than 1.5SD below norms (Kanellopoulos et al., 2016; Satragno et al., 2024; Schuerch et al., 2025). In addition, WM impairment shows a dose-dependent relationship with radiation exposure: higher cumulative cranial doses correlate significantly with reduced white matter tract integrity, which directly predicts lower WM scores (Dockrell et al., 2025; Habibi et al., 2025).

A fundamental limitation of traditional WM measurements used in most previous studies is that assessments are often administered as single-session evaluations in controlled laboratory or clinical settings (Sliwinski et al., 2018). Additionally, cognitive performance is characterized by intra-individual variability (IIV), fluctuating over multiple time scales due to short-term internal and external processes (Burnett et al., 2025). However, although factors such as fatigue, mood, and environmental stressors drive IIV, routine testing seldom accounts for them in real time (Weizenbaum et al., 2020). Ecological Momentary Assessment (EMA), which facilitates repeated, objective assessments in naturalistic settings, addresses these limitations by capturing real-world cognitive performance as it unfolds in daily life (Henneghan et al., 2025; Henneghan et al., 2023). Unlike one-time lab tests, EMA provides a high-resolution window into the temporal fluctuations of WM, effectively bridging the gap between objective cognitive capacity and subjective functional impairments. While studies in adult clinical populations confirm the feasibility of task-based WM EMA with high adherence (80–94%) and strong reliability (ICCs > 0.85) (Agelink van Rentergem et al., 2025; Cobden et al., 2025; García de la Garza et al., 2025), application in pediatric populations remains limited. Consequently, the use of active EMA to assess WM has yet to be applied to CCS, representing a notable gap in understanding the daily cognitive fluctuations of this population.

The current proof-of-concept study examines the feasibility and validity of a task-based WM EMA for assessing cognitive performance in pediatric CCS compared to matched controls. To provide a clear framework for our investigation, we address three primary research questions:

(1) Feasibility and compliance: We evaluate the feasibility of a 10-day EMA protocol in a pediatric oncology population, with the expectation that compliance rates will be comparable between groups to established benchmarks in clinical EMA research.

(2) Group differences in performance: We investigated group differences in WM performance, using both laboratory-based tasks (the Adaptive Cognitive Evaluation- Explore ;ACE-X cognitive control battery) and real-world performance (EMA). We hypothesized that CCS would demonstrate significantly worse performance across all cognitive control measures.

(3) Comparability to existing one-time lab-based measures: We examined the association between WM as it is performed in laboratory settings (efficiency) and in real-world settings (accuracy and stability).

We predicted that average EMA performance would correlate with baseline assessments, thereby demonstrating comparability between real-world and laboratory-based WM measures. Furthermore, we hypothesized that measures of IIV will not correlate with lab-based metrics.

Methods

Study Design and Participants

A correlative and comparative study design was employed to examine differences in WM between children and adolescents with a history of cancer (CCS) and matched healthy controls. Data collection included standardized objective and subjective cognitive measures at baseline, along with EMA reports over a 10-day period. The CCS group was recruited from the follow-up oncology unit at Hadassah Hospital in Jerusalem, Israel, while healthy comparison participants (HC group) were recruited through snowball sampling targeting children of acquaintances and their peers.

Inclusion criteria for both groups were: (a) age 10–18 years; (b) Hebrew- or Arabic-speaking; (c) sufficient intellectual functioning to comprehend and perform the baseline EMA training task as evaluated by the researcher. Additional inclusion criteria for the CCS group were: (a) diagnosis of cancer without central nervous system involvement within the past 10 years; (b) completion of active cancer treatment (e.g., chemotherapy, radiation, surgery, biological therapies) at least six months prior to participation; (c) subjective concerns about cognitive decline due to cancer diagnosis or treatment. These concerns were identified via parent-report, requiring a “yes” response to the question: “Do you have concerns about your child’s memory or other thinking abilities following cancer or cancer treatment?”. Exclusion criteria for the HC group included any past or present cancer diagnosis. Participants in both groups were excluded if they had a significant and/or unstable medical or psychiatric diagnosis, whether ongoing or past.

Instruments

Demographic Questionnaire

A demographic questionnaire was developed specifically for this study to collect descriptive data about participants. Variables included age, gender, date of diagnosis, date of last treatment, and type of treatment received (e.g., chemotherapy, radiation, biological therapy). Information regarding inclusion and exclusion criteria was also collected, along with the participant's or parent's phone number for sending EMA prompts.

Behavior Rating Inventory of Executive Function (BRIEF;(Gioia et al.,))

The BRIEF is a gold-standard, norm-referenced questionnaire for children and adolescents ages 5–18 that measures EF across multiple domains, including inhibition, shifting, WM, planning, and monitoring. The Hebrew translation (Linder et al., 2010) was administered in both parent- and self-report formats. The parent version comprises 86 items, while the self-report version contains 80 items. Items describe behaviors rated on a three-point Likert scale based on the frequency of occurrence during the previous six months. Raw scores are converted to T-scores (normative mean = 50, SD = 10), with clinical thresholds indicated by T-scores ≥ 65. The BRIEF has demonstrated high internal consistency and convergent validity in normative and clinical samples (Gioia et al., 2002), with moderate to high internal reliability reported for the Hebrew version (Linder et al., 2010). BRIEF has been shown to be sensitive to EF deficits in children with various disorders, including cancer (Viola et al., 2017). Both parent and self-report versions were administered online and required approximately 10–15 minutes to complete.

Adaptive Cognitive Evaluation Explorer (ACE-X; (O'Laughlin et al., 2025))

ACE Explorer (ACE-X) is a mobile assessment battery containing adaptive subtests designed to assess various aspects of EF across ages 7–107 (O'Laughlin et al., 2025). For the present study, four subtests were administered during the baseline laboratory session, taking approximately 20 minutes to complete. All assessments are adaptive, hence allowing for more precise measurement of individual abilities. ACE-X demonstrated moderate to good test-retest reliability (ICCs = 0.45–0.79) and strong construct validity in adult populations (O'Laughlin et al., 2025). We administered the following 4 subtests from the ACE-X battery:

(1) Boxed - Assesses visual WM (Visual Search Efficiency; VSE). Participants view an array of green and red squares with side openings and are instructed to attend only to green boxes with bottom or top openings while ignoring distractors, responding as quickly as possible to indicate opening direction.

(2) Response inhibition – the Color Tricker assessment This assessment measures response inhibition based on the Stroop paradigm (Stroop, 1935). Participants identify the color of words that spell color names while ignoring the word's meaning.

(3) Cognitive flexibility – the Sun and Moon task. Participants identify stimulus features (color or shape) based on a preceding cue.

(4) Visuospatial WM capacity – the Backwards Gem Chaser. Participants view an array of orange diamonds that light up sequentially and are instructed to recall and select the targets in reverse order. The primary outcome is the maximum object span recalled in reverse order.

All subtest scores except for Backwards Gem Chaser are calculated as rate-correct scores (RCSs). RCS integrates speed and accuracy to measure processing efficiency, representing the average number of correct responses per second. Raw scores were extracted via the ACE-X interface and standardized into z-scores using R. Subsequently, a global composite score was derived by averaging the standardized z-

scores across all subtests, with higher composite scores indicating better overall performance (O'Laughlin et al., 2025).

Ecological Momentary Assessment (EMA) of Visuospatial WM

Our EMA protocol followed previous protocols in pediatric and clinical populations with similar sampling frequencies (Hakun et al., 2025; Ray et al., 2025). Participants were prompted twice daily over a 10-day period (Sunday-Friday, excluding weekends), resulting in a total of 20 potential EMA sessions, each consisting of two consecutive trials of the visuospatial WM task. To ensure flexibility while maintaining consistency, prompts were sent out during two fixed time windows every day: 13:00–15:00 and 19:00–21:00.

[Add Fig. 1 here]

Figure 1. The visuo-spatial working memory task administered during Ecological

Momentary Assessment (EMA).

Note

(1) Encoding phase: Three red dots are displayed in a 5 X 5 grid for 1,000 ms; participants are required to memorize their spatial locations. (2) Distractor task: A cancellation task where participants identify and tap the letter "F" among "E" distractors. (3) Recall phase: An empty grid is presented, and participants mark the previously shown dot locations.

The visuospatial WM task applied over EMA was modeled after Schuster et al. (2015) to assess visuospatial storage and maintenance capacity under interference (see Fig. 1). Participants viewed a 5X5 square grid with three red dots displayed for 1s, followed by an 8s distractor task, which was used to prevent active rehearsal. Each EMA session included two trials, taking approximately one minute to complete. WM performance was quantified for each trial by calculating the mean Euclidean distance between the original and recalled locations. A score of zero represents perfect accuracy, while higher scores indicate poorer performance. For data analysis, an overall EMA score was calculated by averaging these distances across all completed sessions. IIV of EMA performance was calculated as the standard deviation (SD) of each participant's performance. Consistent with a previous report, such ultra-brief assessments provide reliable estimates even with limited administrations (Hakun et al., 2025).

Procedure

Ethics approval

was obtained from the Helsinki Committee of Hadassah Medical Center in Jerusalem (0129-20-HMO). All methods were performed in accordance with the relevant guidelines and regulations. Eligible

participants met inclusion criteria, and their parents were approached within the follow-up clinic or by telephone and offered participation. Parents provided written informed consent, and adolescents ages 16–18 years provided additional written assent. Subsequently, parents completed online questionnaires including the demographic questionnaire and parent-report BRIEF. Children completed the self-report version of BRIEF followed by the ACE-X battery using a tablet or personal smartphone in a quiet setting.

Thereafter, instructions and guidance for downloading and operating the EMA application were provided by the researcher. Participants received training on the EMA application and completed a guided trial on their mobile device. They were then asked to complete the visuo-spatial WM task, twice daily via their mobile devices for a 10-day active EMA period. Each participant was compensated at a rate of 200 ILS upon completion of all study activities.

Data Analysis

All data was collected electronically via the hospital network and coded to ensure participant anonymity. Data was analyzed using IBM SPSS Statistics, version 30. EMA response rate was calculated as the percentage of completed entries for the total sample and each group separately. Entries with scores exceeding 3 SDs above the sample mean were excluded to improve accuracy, under the assumption that extremely high scores reflected random responding (see Cook et al., 2025; Schinkel-Bielefeld et al., 2024). Statistical analyses were conducted in three stages corresponding to study research questions:

First, to assess feasibility and compliance (Q1), descriptive statistics and Z-tests for independent proportions were performed, comparing response rates between groups. Second, to examine group differences in performance (Q2), non-parametric Mann-Whitney U tests were employed for baseline measures due to the small sample size (Kim et al., 2025), while independent samples t-tests were used for aggregated EMA data. Chi-square tests were used for demographic comparisons. Third, to evaluate construct validity and stability (Q3), Spearman rank-order correlations were conducted to examine associations between baseline assessments and EMA WM performance.

A False Discovery Rate (FDR) correction was applied to address the potential for inflated Type I error due to multiple comparisons between EMA and the four ACE-X subtests.. For all other analyses, a two-sided significance level of $\alpha = .05$ was used.

Results

Sample Characteristics

Fifty-four participants completed the study protocol and met the inclusion criteria for analysis: 18 childhood cancer survivors (CCS) and 32 healthy comparison participants (HC). This final sample size is consistent with recent pediatric EMA feasibility studies (King-Dowling et al., 2025; Ray et al., 2025). Four participants (CCS n = 3; HC n = 1) were excluded from the performance analyses because they

completed fewer than 8 EMA trials, although their data were included in the initial compliance calculations.

Demographic and clinical characteristics of the sample are given in Table 1. Groups did not differ significantly on demographic variables. However, the HC group consisted exclusively of Hebrew-speaking participants, while the CCS group included 15 Hebrew-speaking and 3 Arabic-speaking participants.

[Add Table 1 here]

Table 1
Demographic and clinical characteristics of the control and CCR groups.

Demographics characteristics	**HC (*N = 32*)**	**CCS (*N = 18*)**	**Z (p)**
Age, M (SD)	13.64 (1.9)	14.34 (2.2)	-1.06(.29)
Sex, *n (%)*	12 (37.5)	8 (44.4)	.23(.63)
Female	20 (62.5)	10 (55.6)	
Male			
First Language, *n (%)*	32 (100)	15 (83.3)	
Hebrew		3 (16.7)	
Arabic		18 (100)	
Treatment type, *n (%)*		5 (27.7)	
Chemotherapy		2 (11.1)	
Surgery		5.2 (3.9)	
Biological treatment		6 m-10 y	
Time since last treatment, years M(SD*)* range			
Age at diagnosis, years: M (SD)		7.7 (4.7)	

Note. M = Mean; SD = Standard deviation; HC= Healthy Controls; CCS= Childhood Cancer Survivors.

Feasibility and Compliance of EMA Procedures

We first examined the feasibility and compliance of EMA in our sample (Q1). A total of 974 EMA entries were collected from both groups in response to 1,120 prompts sent. The overall response rate for the total sample was 87%. However, initial compliance differed significantly between groups, with 76.9% in the CCS group and 93% in the HC group ($z = 4.30$, $p < .001$). After the predefined exclusion of participants with fewer than eight entries (CCS n = 3, HC n = 1) and the removal of individual outlier entries (> 3 SD above the mean; total n = 2), corrected compliance rates were calculated. The corrected compliance rates were 81.4% and 90.8% for the CCS and HC groups, respectively, showing significantly higher

compliance in the HC group ($z = 4.30$, $p < .001$). The final analysis consisted of 581 clean entries for the HC and 293 for the CCS.

Group Comparisons of Baseline and EMA Measures

Comparison between groups on both baseline and EMA metrics is given in Table 2. At baseline, the CCS group demonstrated significantly greater difficulty (i.e., higher scores) on the parent-reported BRIEF WM ($z = -2.40$, $p = .02$) and shifting ($z = -1.96$, $p = .05$) subscales compared to HC. No other significant group differences emerged on BRIEF parent- or self-report subscales. Performance on all four ACE-X subtests did not differ significantly between groups.

During the 10-day EMA period, the CCS group showed significantly poorer mean WM performance than the HC group (mean Euclidean distance of 1.74 + 1.19 and 1.44 + 1.17 for the CCS and HC group, respectively; $t(48) = 3.483$, $p < .001$). However, while intra-individual variability (IIV) of WM performance over EMA was numerically larger for the CCS group (0.98 + 0.08 vs. 0.82 + 0.06 for the CCS and HC groups, respectively), it did not reach statistical significance ($t(48) = 1.58$, $p = .121$). Still, the higher SD in the CCS group suggests a trend toward less stable cognitive performance in daily life.

Table 2
Group Comparisons of EMA Performance Metrics, Parent- and Self-Reported Executive Functions (BRIEF), and Baseline Cognitive Assessments (ACE-X) Between Childhood Cancer Survivors (CCS) and Healthy Controls (HC)

	CCS (N = 18)		**HC (N = 32)**		**Statistic*(p)***
	***M* (n)**	***SD***	***M* (n)**	***SD***	
EMA	1.74 (18)	1.19	1.44 (32)	1.17	t *(p)*
Mean					**3.48(.00)**
Variability	0.98 (18)	0.08	0.82 (32)	0.06	1.58
BRIEF					(.12)
					Z *(p)*
P- GEC	52.31 (13)	9.66	46.96 (26)	9.45	-1.58(.11)
P- WM	53.08 (13)	8.81	46.08 (26)	8.11	**-2.40(.02)**
P- Shifting	60.77 (13)	13.9	51.88 (26)	11.79	**-1.96(.05)**
SR- GEC	50.36 (14)	10.65	52.93 (29)	12.3	− .43(.67)
ACE-X					
Boxed	0.98 (15)	0.22	0.93 (23)	0.28	− .76 (.45)
Color Tricker	1.35 (15)	0.27	1.34 (23)	0.49	− .7 (.48)
Sun and Moon	1.3 (15)	0.45	1.24 (23)	0.56	− .16(.87)
Backwards Gem Chaser	5.86 (14)	1.92	6 (23)	2.13	− .58(.56)

Note. CCS= Childhood Cancer Survivors; HC= Healthy Controls; EMA =Ecological Momentary Assessment; BRIEF=Behavior Rating Inventory of Executive Function; P=parent report; SR- GEC= Self-report Global Executive Composite; ACE-X= Adaptive Cognitive Evaluation Explorer; Independent t-tests were used to analyze EMA mean and SD scores, while all other group differences were assessed using Mann-Whitney U tests.

Associations Between Lab-based and Ecological WM Measurements

Given the limited sample size within the CCS group, we first examined the associations across the entire sample, followed by exploratory group-specific analyses. No significant correlations emerged between EMA performance and BRIEF subscales in either group.

Across the entire sample, significant negative correlations were observed between mean WM performance over EMA and all four ACE-X subtests (Table 3). Specifically, higher baseline efficiency

(higher RCS scores) was associated with better mean EMA accuracy (lower Euclidean distances). Correlations remained significant for all ACE-X subtests after applying the False Discovery Rate (FDR) correction (Benjamini-Hochberg, $q < .05$).

We next examined the association between baseline measures and performance variability (EMA SD). For the entire sample, higher baseline efficiency across the ACE-X was significantly associated with lower EMA variability (greater stability). After applying FDR correction, significant negative correlations were maintained between EMA SD and ACE-X subscales, except for the Backward Gem Chaser task, which did not reach significance (Table 3).

When examining groups separately, the HC group demonstrated significant correlations between WM mean over EMA and all ACE-X subtests (FDR corrected; all p's < .05). Notably, in the CCS group, significant correlations emerged between WM mean over EMA and the ACE-X assessments of the Boxed task ($r_s = -.64$, $p = .010$) and the Color Tricker task ($r_s = -.59$, $p = .022$). Regarding performance variability (EMA SD), distinct patterns of association were observed between the two groups. In the CCS group, a robust and statistically significant negative correlation was found between EMA SD and the Boxed task. No significant correlations were found within the HC group (Table 3).

Table 3
Spearman Correlations Between EMA mean (accuracy), variability and ACE-X Subtests by Group

	EMA mean			**EMA variability**		
	CCS N = 15 (rs)	**HC N = 23 (rs)**	**Total Sample N = 38 (rs)**	**CCS N = 15 (rs)**	**HC N = 23 (rs)**	**Total Sample N = 38 (rs)**
ACE	− .64*	− .67**	− .59*	− .70*	− .40	− .49*
Boxed						
Color Tricker	− .59*	− .55*	− .57*	− .50	− .47	− .46*
Sun and Moon	− .35	− .47*	− .39*	− .39	− .37	− .37*
Backwards Gem Chaser	− .05	− .58*	− .42*	− .18	− .13	− .13

Note. r_s = Spearman's rho. * Indicates correlations that remained statistically significant after False Discovery Rate (FDR) correction (Benjamini-Hochberg) at the $q < .05$ level

Discussion

This proof-of-concept study examined the feasibility and acceptability of using Ecological Momentary Assessment (EMA) to examine WM performance in childhood cancer survivors (CCS). Our findings demonstrate that EMA successfully captured WM deficits in CCS compared to healthy controls, with

significantly poorer mean spatial accuracy in the CCS group, demonstrating its capacity to differentiate between clinical and healthy populations in real-world settings. Furthermore, EMA performance correlated moderately-to-strongly with laboratory-based cognitive assessments across the entire sample, supporting comparability to existing measures. These results provide early, promising evidence of the feasibility and acceptability of EMA for capturing real-world cognitive deficits overlooked by the ACE-X, yet subjectively reported by participants.

Regarding feasibility and acceptability, compliance rates were encouraging: 76.9% in CCS and 93% in healthy controls. Exploring feasibility in real-world settings is a necessary prerequisite for implementing EMA-based tools in clinical practice, and the present findings demonstrate that smartphone-based active behavioral monitoring is feasible in a pediatric oncology population. These rates align with those reported across diverse clinical EMA studies (75%–94%), which vary by population characteristics and protocol demands (Campbell et al., 2025; Han et al., 2022; Luna et al., 2025). Moreover, recent evidence demonstrates that ultra-brief smartphone-based WM tasks yield reliable capacity estimates with as few as 2–3 EMA administrations while maintaining moderate comparability with full-length laboratory assessments (Hakun et al., 2023).

As hypothesized (Agelink van Rentergem et al., 2025; Gandy et al., 2023; Sciancalepore et al., 2023) our findings confirm WM deficits in CCS, supporting the capacity of the EMA WM-task to capture real world cognitive performance that is not detected by single-session laboratory testing, as underscored by its ability to detect significant group differences that were absent in laboratory-based performance (ACE-X) but consistently reported by parents via the BRIEF. These results suggest that CCS participants performed comparably to controls when completing a singular task in a quiet, controlled environment, however, demonstrated marked deficits when real-life demands required functioning in dynamic settings. Similar discrepancies between laboratory and real-world performance have been documented in other clinical populations (Goverover et al., 2018; Lee et al., 2025), underscoring the importance of assessment approaches demonstrating both verisimilitude (i.e., similarity to daily task demands) and veridicality (i.e., statistical relationship to real-world performance; (Crist, 2015)).

In addition, the CCS group demonstrated a trend toward higher intra-individual variability (IIV) (less stability) compared to the HC group. This variability significantly correlated with baseline processing efficiency, suggesting that cognitive instability is a hallmark of functional impairment in this population. Our results are in line with previous studies demonstrating that temporal dynamics in cognitive EMA extend beyond mean performance (Campbell et al., 2025). For instance, in young adults with ADHD, momentary fluctuations in WM and inhibitory control assessed via EMA contributed to real-world emotion dysregulation beyond what one-time assessments captured (Ben-Dor Cohen et al., 2023).

The moderate-to-strong correlations between EMA (accuracy and stability) and ACE-X subtests, particularly those measuring VSE and response inhibition, provide support for the comparability of real-world EMA performance with existing lab-based measures. It further confirms that EMA performance is grounded in established executive processes, such as processing efficiency and inhibitory control, and

reinforces the sensitivity of smartphone-based assessments in capturing the core components of functional cognition (Dupuy et al., 2022; Schuster et al., 2015). These findings provide early promising evidence that smartphone-based EMA is a feasible and acceptable tool for capturing cognitive performance comparable to traditional laboratory assessments.

Despite parent and self-reported BRIEF revealing significant group differences in WM and shifting abilities, consistent with CRCI literature (Siegwart et al., 2021; Stefancin et al., 2020), EMA did not correlate with BRIEF subscales in either group. This pattern reflects fundamental assessment differences, whereas questionnaires capture broader behavioral patterns over extended timeframes, EMA samples momentary cognitive performance. Such dissociations between performance-based and questionnaire-based measures have been previously documented across clinical populations (Cormack et al., 2019; Schmitter-Edgecombe et al., 2020), further highlighting limitations of relying solely on questionnaire reports (Wallisch et al., 2018). These findings underscore that EMA provides unique information beyond laboratory testing and subjective report, aligning with the conceptual shift toward top-down, contextually embedded assessment of functional cognition (Poon et al., 2018). Consequently, comprehensive cognitive profiling requires integrating objective performance-based EMA with subjective measures from both children and caregivers.

Limitations

While this study provides a novel proof-of-concept, its preliminary findings have several limitations. First, the modest sample size, particularly within the CCS group, may have limited the statistical power to detect group-specific correlations. We addressed this by conducting primary analyses on the entire sample and applying a conservative Bonferroni correction to ensure the reliability of our findings. Secondly, methodological heterogeneity, including varied recruitment, remote data collection, and language differences, may limit generalizability. Additionally, the lower EMA response rate in the CCS group and the reliance on a single visuospatial WM task should be considered, as multiple task domains might reveal broader cognitive fluctuations. Finally, the two-week window may not capture long-term variability, and the absence of detailed treatment data (e.g., radiation dose or chemotherapy protocols) limits the identification of moderating factors associated with cognitive late effects in this population.

Future research should employ larger, uniform samples to enhance generalizability. Moreover, investigating relationships between EMA metrics and occupational outcomes, such as academic achievement and daily-life participation, would establish veridicality and clinical relevance for oncology rehabilitation. Finally, examining EMA's sensitivity to intervention effects could establish its utility as an outcome measure for cognitive rehabilitation.

Conclusion

This proof-of-concept study establishes the feasibility and acceptability of using EMA to detect WM deficits in CCS. EMA offers an ecologically valid method to repeatedly assess WM in naturalistic

contexts, capturing performance and intra-individual fluctuations that reflect daily demands (Ram & Gerstorf, 2009). The findings support EMA's comparability to traditional measures and highlight its capacity to reveal functional difficulties not apparent in single-session testing. Based on the current study results clinicians are recommended to integrate EMA data with subjective reports from both children and caregivers and laboratory measures. Moreover, EMA findings can inform pediatric rehabilitation clinicians to deliver context-specific interventions by revealing environmental and temporal patterns.

Declarations

The authors have no relevant financial or non-financial interests to disclose.

Funding Declaration

This study was supported by a grant from the Joint Research Fund of the Hebrew University of Jerusalem and Hadassah Medical Center.

Author Contribution

Study conception and design were performed by Yafit Gilboa and Mor Nahum. Funding acquisition and ethics approval were secured by Yafit Gilboa and Gal Goldstein. Material preparation and data collection were carried out by Bracha Auerbuch-Lawee and Sapir Marom. Data analysis was performed by Rachel-Tzofia Sinvani. The first draft of the manuscript was written by Rachel-Tzofia Sinvani. All authors commented on earlier versions of the manuscript, and all read and approved the final version

Acknowledgement

We thank all participants and their families for their time, efforts and valuable feedback. We also thank Hadassah Medical Center fortheir collaboration, with special recognition to the Pediatric Hematology-Oncology department at The Hadassah university hospital at Jerusalem.

Data Availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request

References

1. van Agelink, J. A., Li, Y. & Small, B. J. Improving detection of cancer-related cognitive impairment (CRCI) in non-CNS cancer: current trends and future directions. *J. Clin. Exp. Neuropsychol.* **47** (8), 898–915 (2025).
2. Alloway, T. P., Bibile, V. & Lau, G. Computerized working memory training: Can it lead to gains in cognitive skills in students? *Comput. Hum. Behav.* **29** (3), 632–638 (2013).
3. Baddeley, A. Working memory. *Memory*, 71–111. (2020).
4. Bashore, L. et al. Chronic Health Conditions and Academic Achievement: A Childhood Cancer Survivor Study Report. *JCO oncology practice*, OP-25-00414. (2025).
5. Ben-Dor Cohen, M., Maeir, A., Eldar, E. & Nahum, M. Everyday cognitive control and emotion dysregulation in young adults with and without adhd: an ecological momentary assessment study. *J. Atten. Disord.* **27** (5), 539–553 (2023).
6. Bi, R. et al. Association between hippocampal subfield volumes and working memory in middle-aged and older adult cancer patients. *Front. Hum. Neurosci.* **19**, 1681302 (2025).
7. Burnett, J., Cobden, A. L., Burmester, A., Akhlaghi, H. & Caeyenberghs, K. Intraindividual variability in daily cognitive performance is associated with white matter organization of the superior longitudinal fasciculus in healthy adults. *cortex*. (2025).
8. Campbell, L. M. et al. Exploring the relationship between mean performance and within-person variability on smartphone-based cognitive testing in adults across the lifespan. *NPP—Digital Psychiatry Neurosci.* **3** (1), 15 (2025).
9. Carpenter, R. K. & Alloway, T. P. Exploring working memory, self-criticism, and rumination as factors related to self-harm. *Psychol. Rep.* **126** (4), 1642–1660 (2023).
10. Cass, M. & Prabhu, R. Looking Beyond Self-Reported Cognitive Load: Comparing Pupil Diameter Against Self-Reported Cognitive Load in Design Tasks. *J. Mech. Des.* **147** (4), 044503 (2025).
11. Chang, W. H. et al. Late effects of cancer in children, teenagers and young adults: population-based study on the burden of 183 conditions, in-patient and critical care admissions and years of life lost. *The Lancet Regional Health–Europe*, *12*. (2022).
12. Cobden, A. L. et al. A novel ecological momentary assessment app for the investigation of daily cognitive functioning in breast cancer survivors: a feasibility study. *Support. Care Cancer*. **33** (5), 1–12 (2025).
13. Conklin, H. et al. Cognitive outcomes following contemporary treatment without cranial irradiation for childhood acute lymphoblastic leukemia. *J. Natl Cancer Inst.* **104** (18), 1386–1395 (2012).
14. Cook, D. et al. Understanding the Relationship Between Ecological Momentary Assessment Methods, Sensed Behavior, and Responsiveness: Cross-Study Analysis. *JMIR mHealth uHealth*. **13** (1), e57018 (2025).
15. Cormack, F. et al. Wearable technology for high-frequency cognitive and mood assessment in major depressive disorder: longitudinal observational study. *JMIR mental health*. **6** (11), e12814 (2019).

16. Crist, P. A. Framing ecological validity in occupational therapy practice. *Open. J. Occup. Therapy*. **3** (3), 11 (2015).
17. Dockrell, S., McCabe, M. G., Kamaly-Asl, I., Kilday, J. P. & Stivaros, S. M. Radiological Predictors of Cognitive Impairment in Paediatric Brain Tumours Using Multiparametric Magnetic Resonance Imaging: A Review of Current Practice, Challenges and Future Directions. *Cancers* **17** (6), 947 (2025).
18. Drexl, K. et al. Readdressing the Ongoing Challenge of Missing Data in Youth Ecological Momentary Assessment Studies: Meta-Analysis Update. *J. Med. Internet. Res.* **27**, e65710 (2025).
19. Dupuy, M. et al. Real-time cognitive performance and positive symptom expression in schizophrenia. *Eur. Arch. Psychiatry Clin. NeuroSci.* **272** (3), 415–425 (2022).
20. Egset, K. S., Røkke, M. E., Reinfjell, T., Stubberud, J. E. & Weider, S. Cognitive and behavioural rehabilitation interventions for survivors of childhood cancer with neurocognitive sequelae: A systematic review. *Neuropsychological Rehabilitation*. **35** (1), 131–158 (2025).
21. Friedman, N. P. et al. Stability and change in executive function abilities from late adolescence to early adulthood: A longitudinal twin study. *Dev. Psychol.* **52** (2), 326 (2016).
22. Gandy, K. et al. Genetic variants, neurocognitive outcomes, and functional neuroimaging in survivors of childhood acute lymphoblastic leukemia. *JNCI Cancer Spectr.* **7** (4), pkad039 (2023).
23. de la García, Á. et al. Enhanced associations between subjective cognitive concerns and blood-based AD biomarkers using a novel EMA approach. *Alzheimers Res. Ther.* **17** (1), 82 (2025).
24. Gioia, G. A., Isquith, P. K., Retzlaff, P. D. & Espy, K. A. Confirmatory factor analysis of the Behavior Rating Inventory of Executive Function (BRIEF) in a clinical sample. *Child Neuropsychol.* **8** (4), 249–257 (2002).
25. Goverover, Y., Chiaravalloti, N., Genova, H. & DeLuca, J. A randomized controlled trial to treat impaired learning and memory in multiple sclerosis: The self-GEN trial. *Multiple Scler. J.* **24** (8), 1096–1104 (2018).
26. Habibi, A. T. et al. Impact of Pediatric Posterior Fossa Tumor Treatments on Working Memory Tracts Using Resting-State fMRI and Tractography. *J. Neuroimaging*. **35** (1), e70007 (2025).
27. Hakun, J. G. et al. The physical activity, imaging, and ambulatory testing (PHIAT) project: Protocol for a high-frequency ambulatory assessment study. *JMIR Res. Protocols*. **14** (1), e66290 (2025).
28. Hakun, J. G., Roque, N. A., Gerver, C. R. & Cerino, E. S. Ultra-brief assessment of working memory capacity: ambulatory assessment study using smartphones. *JMIR Formative Res.* **7**, e40188 (2023).
29. Han, Y. et al. Towards visualization of time–series ecological momentary assessment (EMA) data on standalone voice–first virtual assistants. Proceedings of the 24th International ACM SIGACCESS Conference on Computers and Accessibility, (2022).
30. Hardy, S. J., Krull, K. R., Wefel, J. S. & Janelsins, M. Cognitive changes in cancer survivors. *Am. Soc. Clin. Oncol. educational book.* **38**, 795–806 (2018).
31. Henneghan, A. M. et al. Feasibility and psychometric quality of smartphone administered cognitive ecological momentary assessments in women with metastatic breast cancer. *Digit. Health*. **11**,

20552076241310474 (2025).

32. Henneghan, A. M., Van Dyk, K. M., Ackerman, R. A., Paolillo, E. W. & Moore, R. C. Assessing cancer-related cognitive function in the context of everyday life using ecological mobile cognitive testing: A protocol for a prospective quantitative study. *Digit. health*. **9**, 20552076231194944 (2023).
33. Hutterer, M. & Oberndorfer, S. Cognitive impairment in cancer patients and survivors—clinical presentation, pathophysiology, diagnosis and management. *memo-Magazine Eur. Med. Oncol.* **14** (2), 157–167 (2021).
34. Kanellopoulos, A. et al. Neurocognitive outcome in very long-term survivors of childhood acute lymphoblastic leukemia after treatment with chemotherapy only. *Pediatr. Blood Cancer*. **63** (1), 133–138 (2016).
35. Kim, H., Kwon, S., Park, S., Kang, C. & Kim, H. Feasibility and adherence to ecological momentary assessment among community-dwelling adults with suicide risk. *BMC Nurs.* **24** (1), 807 (2025).
36. King, T. Z., Na, S. & Mao, H. Neural underpinnings of working memory in adult survivors of childhood brain tumors. *J. Int. Neuropsychol. Soc.* **21** (7), 494–505 (2015).
37. King-Dowling, S. et al. A pilot study of device-assessed physical activity and ecological momentary assessment among adolescent and young adult survivors of childhood cancer. *Ann. Behav. Med.* **59** (1), kaaf002 (2025).
38. Lee, Y. et al. Performance-Based Assessments of Functional Cognition in Adults, Part 2—Psychometric Properties: A Systematic Review. *Am. J. Occup. Therapy*. **79** (4), 7904205140 (2025).
39. Lewandowski, K. E. Ecological validity in cognitive assessment and treatment. *Schizophrenia Research: Cognition*. **40**, 100341 (2024).
40. Linder, N., Kroyzer, N., Maeir, A., Wertman-Elad, R. & Pollak, Y. Do ADHD and executive dysfunctions, measured by the Hebrew version of Behavioral Rating Inventory of Executive Functions (BRIEF), completely overlap? *Child Neuropsychol.* **16** (5), 494–502 (2010).
41. Luna, C., Dai, S., Pagan, C., Liu, C. & Schmitter-Edgecombe, M. Examining intra-individual variability of ecological momentary assessment with multilevel modeling: A systematic review and recommendations for research and practice. *The Clin. Neuropsychologist*, 1–26. (2025).
42. McKenna, F. et al. Microvascular and microstructural brain abnormalities in paediatric haematological cancer survivors are related to cognitive deficits: An IVIM-FWI MRI study. *British J. Haematology* (2026).
43. O'Laughlin, K. D. et al. Validation of an Adaptive Assessment of Executive Functions (Adaptive Cognitive Evaluation-Explorer): Longitudinal and Cross-Sectional Analyses of Cognitive Task Performance. *J. Med. Internet. Res.* **27**, e60041 (2025).
44. Peterson, R. K., Choi, J. H., Jacobson, L. A., Acharya, S. & King, T. Z. Neighborhood resources are associated with neuropsychological outcomes among pediatric brain tumor survivors. *Clin. Neuropsychol.* **39** (4), 899–914 (2025).
45. Poon, L. W., Welke, D. J. & Dudley, W. N. What is everyday cognition? In Mechanisms of everyday cognition (19–32). Psychology. (2018).

46. Prabhu, N., Vijayan, V. & Mythili, N. A review on understanding chemobrain and neuroprotection effects on breast cancer therapies on cognitive function. *Discover Appl. Sci.* **7** (12), 1391 (2025).
47. Ram, N. & Gerstorf, D. Time-structured and net intraindividual variability: tools for examining the development of dynamic characteristics and processes. *Psychol. Aging*. **24** (4), 778 (2009).
48. Ray, M. K. et al. Assessing Dynamic Cognitive Function in the Daily Lives of Youths With and Without Type 1 Diabetes: Usability Study. *JMIR Formative Res.* **9**, e60275 (2025).
49. Satragno, C. et al. QOL-29. COGNITIVE DEVELOPMENT WITHIN TWO YEARS AFTER CRANIOSPINAL IRRADIATION IN CHILDREN TREATED FOR MEDULLOBLASTOMA: A COMPREHENSIVE ASSESSMENT USING AGE-APPROPRIATE SCALES. *Neuro-Oncology* **26** (Suppl 4), 0 (2024).
50. Schinkel-Bielefeld, N. et al. Implementing ecological momentary assessment in audiological research: Opportunities and challenges. *Am. J. Audiol.* **33** (3), 648–673 (2024).
51. Schmitter-Edgecombe, M., Sumida, C. & Cook, D. J. Bridging the gap between performance-based assessment and self-reported everyday functioning: An ecological momentary assessment approach. *Clin. Neuropsychol.* **34** (4), 678–699 (2020).
52. Schuerch, K. et al. Development of working memory, processing speed, and psychosocial functions in patients with pediatric cancer. *Pediatr. Res.* **97** (5), 1659–1667 (2025).
53. Schuster, R. M., Mermelstein, R. J. & Hedeker, D. Acceptability and feasibility of a visual working memory task in an ecological momentary assessment paradigm. *Psychol. Assess.* **27** (4), 1463 (2015).
54. Sciancalepore, F. et al. Frequency and characterization of cognitive impairments in patients diagnosed with paediatric central nervous system tumours: a systematic review. *Front. Oncol.* **13**, 1198521 (2023).
55. Scriney, A., Gurren, L., Gallagher, P., Loughney, L. & Boran, L. Pretreatment cancer related cognitive impairment and associated psychological factors: a systematic review. *Front. Psychol.* **16**, 1682455 (2025).
56. Siegwart, V. et al. The working memory network and its association with working memory performance in survivors of non-CNS childhood cancer. *Dev. Neuropsychol.* **46** (3), 249–264 (2021).
57. Silverman, D. H. et al. Neuroimaging studies of cognitive dysfunction following cancer and treatment. *Journal Clin. Experimental Neuropsychology*, 1–27. (2025).
58. Sliwinski, M. J. et al. Reliability and validity of ambulatory cognitive assessments. *Assessment* **25** (1), 14–30 (2018).
59. Stefancin, P. et al. Neural correlates of working memory function in pediatric cancer survivors treated with chemotherapy: an fMRI study. *NMR Biomed.*, **33**(6), e4296. (2020).
60. Stroop, J. R. Studies of interference in serial verbal reactions. *J. Exp. Psychol.* **18** (6), 643 (1935).
61. Trapani, J. A. & Murdaugh, D. L. Processing efficiency in pediatric cancer survivors: A review and operationalization for outcomes research and clinical utility. *Brain Behav.* **12** (12), e2809 (2022).

62. van der Plas, E. et al. Cognitive and behavioral risk factors for low quality of life in survivors of childhood acute lymphoblastic leukemia. *Pediatr. Res.* **90** (2), 419–426 (2021).
63. Viola, A. et al. The Behavior Rating Inventory of Executive Function (BRIEF) to identify pediatric acute lymphoblastic leukemia (ALL) survivors at risk for neurocognitive impairment. *Journal of pediatric hematology/oncology*, *39*(3), 174–178. (2017).
64. Wallisch, A., Little, L. M., Dean, E. & Dunn, W. Executive function measures for children: A scoping review of ecological validity. *OTJR: Occupation Participation Health*. **38** (1), 6–14 (2018).
65. Weizenbaum, E., Torous, J. & Fulford, D. Cognition in context: understanding the everyday predictors of cognitive performance in a new era of measurement. *JMIR mHealth uHealth*, **8**(7), e14328. (2020).

Figures

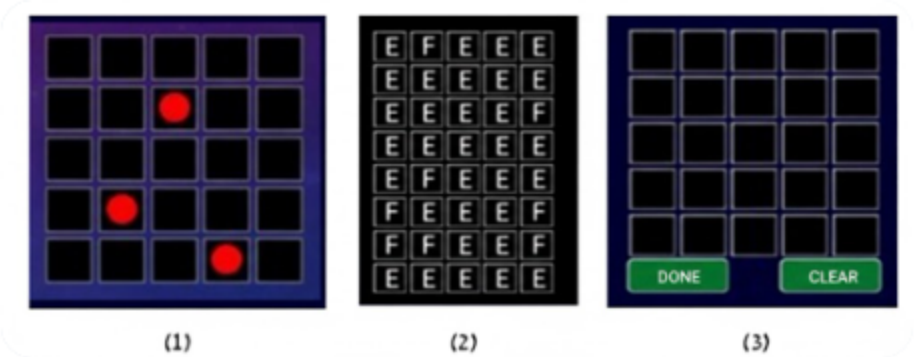


Figure 1

The visuo-spatial working memory task administered during Ecological Momentary Assessment (EMA).

Note. *(1) Encoding phase: Three red dots are displayed in a 5 X 5 grid for 1,000 ms; participants are required to memorize their spatial locations. (2) Distractor task: A cancellation task where participants identify and tap the letter "F" among "E" distractors. (3) Recall phase: An empty grid is presented, and participants mark the previously shown dot locations.*