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The effect of active versus passive screen time on learning disabilities in preschool Egyptian children: a cross-sectional study

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Abstract

Background Following the advent of COVID-19, concern has escalated over the developmental consequences of screen time exposure in preschool children; although existing studies report associations between excessive screen use and learning disabilities, they have not rigorously assessed individual cognitive domains or contrasted the effects of active (interactive) versus passive (viewing-only) forms of engagement. Nearly 16.5% of Egyptian preschool children have learning disabilities, which is a major public health concern. The study set out to evaluate how active and passive forms of screen exposure distinctly affect several learning-related cognitive domains in preschoolers aged 4.5–6.5 years.

Methods A multicenter cross-sectional study was conducted between May 2024 and April 2025 at three Egyptian institutions. A total of 260 preschoolers with average IQ were subjected to full neuropsychological testing that included auditory and visual processing and memory using the Stanford-Binet-4, working memory and its components using the Arabic Working Memory Tasks Scale. Prereading skills related to the included age group were evaluated using the validated batteries for phonological processing and emergent literacy. The screen exposure was categorized by duration (less than two hours, two to four hours, more than four hours per day) and type (active versus passive).

Results Effects were greater in passive users than active users and increased with time of exposure, with significant deficits in auditory processing ($p < 0.001$), auditory memory ($p < 0.001$), executive function (10 vs 14, $p < 0.001$), and phonological processing ($p = 0.001$) in > 4 h group; dose–response analysis revealed steep deterioration in passive users across all levels of exposure, while active users appeared to demonstrate relative cognitive resilience, with visual memory intact across all conditions. Sleep onset screen exposure resulted in significant impairment of auditory processing, auditory memory, and working memory following adjustment for duration.

Conclusion This differentiation between active versus passive screen effects, indicates that passive exposure is far more risky for developing cognitive systems, particularly auditory-verbal domains critical to academic readiness, and that interactive engagement is associated with measurable protective effects, whereas visual systems may be more resilient. They found that precision-based interventions are required that target at-risk domains, rather than across-the-board restrictions.

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Introduction

The proliferation of digital technology has fundamentally transformed childhood experiences in the twenty-first century, with screen-based devices becoming increasingly ubiquitous in the daily lives of preschool children [1]. Since the emergence of COVID-19, children have been using screens more frequently than ever before, raising significant concerns about the potential impact on their developing neurological and cognitive systems [2]. This sharp increase in screen time has led to international research in to the correlation of digital media use and early childhood, with a focus in the crucial preschool years where the early stages of learning are being developed [3].

To the basic categories of screen time mentioned above is often added a distinction based on interactivity, that is, between active and passive screen time. Passive screen time is that which does not require direct interaction or feedback from the child (television, videos, DVDs). Active screen time is associated with direct, usually touchscreen, interaction with screens via apps or games requiring active engagement from the child, such as by touching, pressing or swiping the screen, or educational applications which require a response, for example, to questions or instructions [4]. Emerging research has found that active and passive screen time have distinct neurophysiological correlates, with passive screen time having more negative associations with child development [5].

Learning disabilities (LDs) constitute a heterogeneous spectrum of disorders marked by persistent difficulties in acquiring and applying skills in speech, writing, reading, and mathematics. They are commonly observed among school-aged children worldwide, affecting approximately 5% of this demographic. In Egypt, recent research indicates that LDs impact around 16.5% of preschool-aged children [6]. The processes by which screen exposure may affect LDs are likely both direct and indirect (impacting time away from important experiences). Play and social engagement with the environment in the preschool years foster the advancement of social and cognitive competencies; moreover, adult–child interactions serve as the principal conduit for exposing children to diverse linguistic and learning experiences during this critical window of language and literacy acquisition [7].

The preschool period's accelerated neural maturation heightens worries about the neurobiological effects of early screen exposure. MRI evidence shows that higher screen use is associated with reduced microstructural integrity within brain white matter networks essential for language and literacy abilities [8], In addition, longitudinal analyses reveal that extensive screen exposure during infancy modifies brain network topology particularly the integration between emotion-processing and cognitive-control systems which later diminishes socio-emotional competence [9]. They may also last long after the period of excessive exposure. Studies have shown that babies exposed to too much screen time have brain activity that is different from that of others, even after the age of 8 [8].

Investigations involving Egyptian preschool cohorts reveal that extended screen exposure correlates with learning disabilities, mediated through adverse effects on auditory and visual processing, working memory, and emergent literacy skills [3]. Comparable patterns appear in global research, which indicates that excessive screen use among children younger than five hampers cognitive development, most notably in problem-solving and communication domains [10].

The above screen dose–response principle has been further supported by a growing body of evidence from epidemiological studies, such as a recent one in which prevalence of developmental delay was monotonically increasing after 2 h/day of screen exposure and with particularly strong effects for communication, fine motor, and problem-solving delays [11]. In contrast to children with limited screen exposure, children with more than 4 h of screen time per day have significantly higher rates of behavioral problems, attention difficulties and learning disabilities [3]. These data have led pediatric organizations worldwide to make strong recommendations for strict limits on screen time for preschoolers, with many recommending no screen time for children younger than two years of age [12].

Current screen time studies fail to distinguish between active versus passive engagement when examining specific learning disabilities (language processing, attention deficits, emergent literacy) in preschool children, focusing instead on broad developmental measures. Limited research exists in Egyptian and Middle Eastern populations, where cultural, socioeconomic, and technological usage patterns differ significantly from Western populations that dominate existing literature. There is an urgent need for culturally appropriate research that can inform evidence-based recommendations for optimizing learning outcomes in preschool children while acknowledging modern digital realities.

Aim of the study

1. To examine the different effects of both active and passive screen time exposure on different aspects of learning disabilities among preschool children aged 4.5–6.5 years.
2. To examine the effect of exposure to different types of screens on different aspects of learning disability

close to sleep time among preschool children aged 4.5–6.5 years.

Patients and methods

A multi central cross-sectional study was carried out between May 2024 and April 2025 in the Phoniatric and Audiology departments of the Hearing and Speech Institute, Giza, Egypt, Otorhinolaryngology department, Misr University for science and Technology, Cairo Egypt and Pediatric department, Banha University, Egypt. 260 preschoolers, ages 4.5 to 6.5 years were included in this study.

The children included had an average intelligence quotient (IQ) of 90 or higher in the Stanford-Binet test, Fourth Edition (SB4) [13], they were native Arabic speakers, and their average language age (as determined by the modified PLS4) [14] was in line with their chronological age and normal hearing (20–30 db and 2–4 k/hz).

The study excluded any children with a history of mental, Psychiatric, neurological, or metabolic abnormalities; it also did not include any children with visual or auditory dysfunctions. Written informed consent was signed by all parents whose children were part of the study.

All study procedures received approval from the General Organization of Teaching Hospitals and Institutes (GOTHI) Research Ethics Committee in April 2024 (approval no. IHS00061) and were conducted in accordance with the 2013 Helsinki Declaration and the ethical standards of the responsible human experimentation committee. Informed written consent to participate in the study was provided by parents or legal guardians of all participating children.

No funding was given for this research.

There are no conflicts of interest.

Methods

History taking

A comprehensive questionnaire regarding the child's name, birth date, gender, number of siblings, language skills, learning capabilities, attention span, behavior, and developmental history was given to parents to fill out.

Furthermore, parents were questioned regarding their child's overall daily screen usage (measured in hours), which included time spent on TV, smartphones, and tablets to differentiate between active and passive screen time. The inquiry was formulated as follows: How much time did your child spend in front of screens daily? The kids' screen usage was divided into three groups (< 2 h, 2–4 h, > 4 h). The length of screen exposure in years was another question posed to the parents by "since birth". The query was formulated as follows: How long has the child interacted with screens?

Learning disabilities assessed by

- Assessment of auditory memory, auditory processing, visual memory, and visual processing was conducted using the Stanford Binet test, Fourth Edition (SB4) [13].
- The Arabic version of the Working Memory Tasks Scale a validated and reliable instrument was employed to assess overall working memory as well as its specific elements of executive function, phonological memory, and visuospatial memory [15]. A composite score of 75 is the maximum possible result from the total working memory, from the central executive (22), Phonological memory (24), and Visuospatial memory (29). The median values of the entire battery were computed; a child's score is below average if scores are less than the median. Nonetheless, average performance is indicated if scores are equal or above the median.
- "Prereading skills" related to the included age group were evaluated using the test battery proposed by Afsah [16], a valid and reliable screening tool for preschoolers to identify children at risk of subsequent reading problems by assessing both phonological processing and emergent literacy skills. A composite score of 59 is the maximum possible result from the emergent literacy (22) and phonological processing (37) tests. The median values of the entire battery were computed; a child's score is below average if scores are less than the median. Nonetheless, average performance is indicated if scores are equal or above the median.

Sample size

Literature indicating a 16.5% prevalence of learning disabilities among Egyptian preschoolers exposed to screen time provided the basis for sample size estimation [6]. Assuming a 95% confidence level, $\alpha = 5\%$, and 80% power, an online calculator (https://www.calculator.net/sample-size-calculator.html) yielded a requirement of 212 participants. The current study exceeded this threshold by enrolling 260 children.

Statistical analysis

All data were collected, verified, coded, and entered into IBM SPSS Statistics version 27. Parametric quantitative variables are summarized by means, standard deviations, and ranges, whereas non-parametric counterparts are described by medians and interquartile ranges (IQR). Qualitative variables are reported as absolute and relative frequencies. Categorical group differences were examined with the Chi-square test, substituting Fisher's exact test whenever an expected cell count fell below 5. Comparisons among more than two groups for parametric quantitative data employed One-Way ANOVA followed by LSD post hoc analysis; for non-parametric distributions, the Kruskal–Wallis test served as the omnibus test with subsequent pairwise Mann–Whitney comparisons. Spearman correlation coefficients assessed associations between two quantitative measures within the same group. Statistical decisions were based on a 95% confidence interval and a 5% margin of error: p-values < 0.05 were considered significant, p-values < 0.01 highly significant, and p-values > 0.05 non-significant.

Table 1 Demographic data and characteristics of the studied children

		Total no. = 260
Age (years)	Mean ± SD	5.7 ± 0.57
Sex	Female	101 (38.8%)
	Male	159 (61.2%)
IQ	Mean ± SD	97.22 ± 6.31
Screen time	Screen time < 2 h	120 (46.2%)
	Screen time (2–4) hours	61 (23.5%)
	Screen time > 4 h	79 (30.4%)
Screen type	Active	147 (56.5%)
	Passive	113 (43.5%)
Sleep time	Not before sleep time	124 (47.7%)
	Before sleep time	136 (52.3%)

Results

The study included 260 participants with a mean age of 5.7 ± 0.57 years. The sample comprised 159 males (61.2%) and 101 females (38.8%), with a mean IQ of 97.22 ± 6.31. Regarding screen exposure patterns, 120 participants (46.2%) used screens for less than 2 h daily, 61 (23.5%) for 2–4 h, and 79 (30.4%) for more than 4 h. Active screen engagement was observed in 147 participants (56.5%), while 113 (43.5%) engaged passively. Screen use before bedtime was reported in 136 participants (52.3%) (Table 1).

Within the low screen exposure group (< 2 h), passive screen users demonstrated significantly higher auditory processing scores compared to active users (p = 0.015), while active users showed superior executive function performance (p = 0.039). No significant differences were observed between groups in auditory memory, visual processing, visual memory, visuospatial memory, phonological memory, total working memory, phonological processing, or emergent literacy measures (Table 2).

Within the moderate screen exposure group (2–4 h), active users demonstrated significantly superior performance compared to passive users across multiple cognitive domains. Highly significant differences were observed in auditory processing (median 84 vs 68, p < 0.001) and auditory memory (p < 0.001). Significant advantages for active users were also evident in executive function (p = 0.021), phonological memory (p = 0.029), total working memory (p = 0.013), and total phonological

Table 2 Comparison between active and passive screen type regarding Stanford-binet4, working memory, phonological assessment and emergent literacy test among children use screens less than 2 h

		Screen time < 2 h		**Test value**	**P-value**	**Sig**
		Active	**Passive**			
		No. = 67	**No. = 53**			
Stanford-Binet 4						
Auditory processing	Median (IQR)	92 (89–98)	98 (94–99)	−2.443 ≠	0.015	S
Auditory memory	Median (IQR)	87 (82–92)	90 (89–92)	−1.421 ≠	0.155	NS
Visual processing	Median (IQR)	92 (84–95)	87 (82–96)	−1.316 ≠	0.188	NS
Visual memory	Median (IQR)	91 (85–96)	91 (83–94)	−1.252 ≠	0.211	NS
Working memory						
Executive function	Median (IQR)	16 (13–19)	15 (14–16)	**−2.067 ≠**	**0.039**	**S**
Visio special	Median (IQR)	26 (21–27)	25 (22–26)	−0.174 ≠	0.862	NS
Phonological memory	Median (IQR)	12 (10–13)	12 (10–13)	−0.866 ≠	0.387	NS
Total working memory	Median (IQR)	47 (44–52)	48 (44–51)	−0.376 ≠	0.707	NS
Phonological Processing						
Total phon. proc. Scores	Median (IQR)	24 (21–27)	22 (17–27)	−1.555 ≠	0.120	NS
Emergent Literacy						
Total Emergent Literacy score	Median (IQR)	16 (13–18)	17 (12–19)	−0.714 ≠	0.475	NS

P-value > 0.05: Non-significant; P-value < 0.05: Significant; P-value < 0.01: Highly significant

≠: Mann–Whitney test

processing scores (p = 0.012). Visual processing, visual memory, visuospatial memory, and emergent literacy showed no significant differences (Table 3).

Within the high screen exposure group (> 4 h), passive users demonstrated significantly poorer performance across nearly all cognitive domains compared to active users. Highly significant differences favoring active users were observed in auditory processing (p < 0.001), auditory memory (p < 0.001), executive function (median 14 vs 10, p < 0.001), and total phonological processing (median 21 vs 16, p = 0.001). Significant differences were also noted in visual processing (p = 0.012), visuospatial memory (p = 0.010), phonological memory (p = 0.034), total working memory (p = 0.018), and emergent literacy (p = 0.020). Only visual memory showed no significant difference between groups (Table 4).

Among active screen users, increasing duration of exposure was associated with progressive decline in cognitive performance. Significant differences across duration groups were observed in auditory processing (p = 0.020), auditory memory (p = 0.020), executive function (p = 0.026), and total phonological processing (p = 0.029). Post-hoc pairwise comparisons revealed that significant differences were primarily between the < 2 h and > 4 h groups for auditory processing (p = 0.009), auditory memory (p = 0.012), executive function (p = 0.012), and phonological processing (p = 0.008), as well as between 2–4 h and > 4 h groups for auditory processing (p = 0.035) and auditory memory (p = 0.025). Visual processing, visual memory, visuospatial memory, phonological memory, total working memory, and emergent literacy showed no significant differences across duration groups (Table 5).

Among passive screen users, increasing exposure duration was associated with highly significant deterioration across nearly all cognitive domains. Auditory processing (p < 0.001) and auditory memory (p < 0.001) showed the most pronounced effects, with visual processing (p = 0.010), all working memory components (executive p < 0.001, visuospatial p = 0.001, phonological p = 0.001, total p = 0.006), phonological processing (p = 0.006), and emergent literacy (p = 0.001) also demonstrating highly significant differences. Post-hoc analysis revealed that for auditory measures, all pairwise group comparisons reached significance (all p < 0.001). For other domains, the most consistent significant differences were observed between < 2 h and > 4 h groups, with intermediate findings for the 2–4 h group. Visual memory remained unaffected by duration of passive screen exposure (Table 6).

Close to sleep time screen exposure was associated with significantly poorer performance in auditory processing (p < 0.001), auditory memory (median 80 vs 89, p < 0.001), and total working memory (p = 0.024) compared to participants away from close to sleep screen use. No significant differences were observed in visual processing, visual memory, phonological processing, or emergent literacy measures (Table 7).

Table 3 Comparison between active and passive screen type regarding Stanford-binet4, working memory, phonological assessment and emergent literacy test among children use screens from 2 to 4 h

		Screen time (2–4) hours		Test value	P-value	Sig
		Active	**Passive**			
		No. = 33	**No. = 28**			
Stanford-Binet 4						
Auditory processing	Median (IQR)	84 (80–92)	68 (66–72.5)	−5.797≠	0.000	HS
Auditory memory	Median (IQR)	85 (84–90)	68 (65–70)	−6.580≠	0.000	HS
Visual processing	Median (IQR)	90 (84–93)	84 (78–92.5)	−1.950≠	0.051	NS
Visual memory	Median (IQR)	90 (85–95)	90 (85–95)	−0.167≠	0.867	NS
Working memory						
Executive function	Median (IQR)	15 (13–16)	13 (12–14.5)	−2.306≠	0.021	S
Visio special	Median (IQR)	25 (22–26)	24 (22–25)	−1.176≠	0.240	NS
Phonological memory	Median (IQR)	11 (10–12)	9 (7.5–11.5)	−2.188≠	0.029	S
Total working memory	Median (IQR)	46 (44–50)	42 (40–47.5)	−2.495≠	0.013	S
Phonological assessment						
Total phon proc. Scores	Median (IQR)	23 (20–26)	20 (15.5–24.5)	−2.508≠	0.012	S
Emergent Literacy Test						
Total Emergent Literacy score	Median (IQR)	15 (13–16)	15 (14–17)	−0.219≠	0.827	NS

P-value > 0.05: Non-significant; P-value < 0.05: Significant; P-value < 0.01: Highly significant

≠: Mann–Whitney test

Table 4 Comparison between active and passive screen type regarding Stanford-binet4, working memory, phonological assessment and emergent literacy test among children use screens more than 4 h

		Screen time > 4 h		Test value	P-value	Sig
		Active	Passive			
		No. = 47	No. = 32			
Stanford-Binet 4						
Auditory processing	Median (IQR)	79 (70–88)	60 (55–65)	−6.537≠	0.000	HS
Auditory memory	Median (IQR)	81 (77–89)	60 (58–68)	−7.278≠	0.000	HS
Visual processing	Median (IQR)	89 (86–92)	79 (67–90)	−2.508≠	0.012	S
Visual memory	Median (IQR)	86 (85–90)	88 (85–96.5)	−1.094≠	0.274	NS
Working memory						
Executive function	Median (IQR)	14 (13–17)	10 (8.5–13)	−4.702≠	0.000	HS
Visio special	Median (IQR)	24 (21–26)	21.5 (20–23)	−2.563≠	0.010	S
Phonological memory	Median (IQR)	10 (8–13)	8.5 (7–11.5)	−2.120≠	0.034	S
Total Working memory	Median (IQR)	46 (42–49)	41 (38–47.5)	−2.366≠	0.018	S
Phonological assessment						
Total phon proc. Scores	Median (IQR)	21 (18–24)	16 (12–20)	−3.262≠	0.001	HS
Emergent Literacy Test						
Total Emergent Literacy score	Median (IQR)	14 (12–18)	12 (10–15)	−2.331≠	0.020	S

P-value > 0.05: Non-significant; P-value < 0.05: Significant; P-value < 0.01: Highly significant

≠: Mann–Whitney test

The scatter plot demonstrates positive correlation (r = 0.273, p < 0.001) between auditory processing and total phonological working memory (Fig. 1).

The scatter plot reveals positive correlation (r = 0.313, p < 0.001) between auditory processing and phonological processing (Fig. 2).

Discussion

Learning disabilities denote a heterogeneous group of disorders marked by persistent impediments to mastering and using speaking, writing, reading, and mathematics skills. In Egypt, recent research indicates that LDs impact around 16.5% of preschool-aged children [6].

Recently, there has been risen in screen time and it's becoming a regular feature of children's lives, especially those in preschool age. Prolonged screen exposure, defined as engaging with electronic media (television, computers, or mobile devices) for more than 2–3 h, has been associated with decreased participation in developmental activities [17]. In addition, prolonged screen exposure may impair the developing brain, resulting in detrimental effects on cognitive development and on learning and memory functions [18].

there is limited research on how different types of screen time, active and passive, may influence the development of learning disabilities in different ways specially in preschoolers, so in this study we assessed the different effects of both active and passive screen time exposure on different aspects of learning disabilities among preschool children aged 4.5–6.5 years.

The mean IQ of children in this study was 97.22, indicating overall average cognitive ability for this age group [13]. There was a significant IQ difference only in the < 2 h group suggests that higher-IQ children may be more likely to engage actively with screens when exposure is limited. This could reflect that more cognitively sophisticated children seeking stimulating rather than purely entertainment-based screen activities. The disappearance of IQ differences in higher exposure groups is particularly telling. Even children with initially higher cognitive abilities show convergence toward lower IQ levels when screen time exceeds 2 h daily, suggesting that excessive screen exposure may override individual cognitive advantages.

The results underscore the ubiquity of digital media in early childhood and indicate that assessments of screen exposure must account for its magnitude as well as its specific modality and temporal distribution.

The differential impact of screen time-type across durations and dose response effect

Auditory processing

Auditory processing was the cognitive domain most vulnerable to screen-related detriment, being the most susceptible to the effect of both duration and type of screen, with passive users in the < 2 h group having statistically higher auditory processing scores than active users and

Table 5 Relation of screen time groups with Stanford-Binet4, working memory, phonological assessment and emergent literacy test among active screen users' group

		Active			Test value	P-value	Sig
		Screen time < 2 h	Screen time (2–4) hours	Screen time > 4 h			
		No. = 67	No. = 33	No. = 47			
Stanford-Binet 4							
Auditory processing	Median (IQR)	90 (77–93)	84 (80–92)	79 (70–88)	7.828≠	0.020	S
Auditory memory	Median (IQR)	87 (81–91)	85 (84–90)	81 (77–89)	7.815≠	0.020	S
Visual processing	Median (IQR)	92 (85–96)	90 (84–93)	89 (87–92)	4.468≠	0.107	NS
Visual memory	Median (IQR)	91 (85–96)	90 (85–95)	86 (85–90)	4.502≠	0.105	NS
Working memory							
Executive function	Median (IQR)	16 (13–19)	15 (13–16)	14 (13–17)	7.337≠	0.026	S
Visio special	Median (IQR)	26 (21–27)	25 (22–26)	24 (21–26)	1.406≠	0.495	NS
Phonological memory	Median (IQR)	12 (10–13)	11 (10–12)	10 (8–13)	3.106≠	0.212	NS
Total working memory	Median (IQR)	47 (44–52)	46 (44–50)	46 (42–49)	3.617≠	0.164	NS
Phonological assessment							
Total phon. proc Scores	Median (IQR)	24 (21–27)	23 (20–26)	21 (18–24)	7.115≠	0.029	S
Emergent Literacy Test							
Total Emergent Literacy score	Median (IQR)	16 (13–18)	15 (13–16)	14 (12–18)	2.467≠	0.291	NS

Post Hoc analysis by LSD and multi-comparison between groups

Parameters	Screen time < 2 h Vs Screen time (2–4) hours	Screen time < 2 h Vs Screen time > 4 h	Screen time (2–4) hours Vs Screen time > 4 h
Auditory processing	0.695	**0.009**	**0.035**
Auditory memory	0.564	**0.012**	**0.025**
Executive function	0.094	**0.012**	0.334
Total phon. proc Scores	0.689	**0.008**	0.098

P-value > 0.05: Non-significant; P-value < 0.05: Significant; P-value < 0.01: Highly significant

≠: Kruskal–Wallis test

thus, requires further investigation. Braz et al. (2021) [19] also suggested that passive content could involve high-quality music programs, cartoons (generally containing high-quality sound content), songs, narration, and sound effects, which could assist with auditory discrimination and processing when taken in moderation with supervision.

A huge drop in auditory processing was seen in the passive users group consuming for 2–4 h daily, and in fact, this worsening was even more amplified in the > 4 h group compared to the active users group.

The dose–response analysis within passive users alone revealed progressive deterioration across all exposure levels, while active users showed more modest decline. This mean that greater exposure among passive users correlates with steadily worse outcomes, whereas greater exposure among active users still relates to some decline but with a notably flatter, less harmful slope, implying that active interaction mitigates though does not eliminate adverse effects and that purely passive consumptive use reflects higher underlying risk.

This is in line with Kuhl's (2021) [20] findings of an auditory-visual mismatch while learning via screens. The damage to auditory abilities over visual is due to the background noise of the screens, which interrupts the rapid temporal processing required for phoneme discrimination.

Passive screen content also typically provides fewer opportunities for turn taking, responsive communication, and rich prosodic and phonological input, all of which are important for supporting auditory processing development [21]. The disruption of caregiver-child verbal interaction during screen time may further compound these effects, leading to a "double deficit" scenario where children receive both poorer quality

Table 6 Relation of screen time groups with Stanford-Binet4, working memory, phonological assessment and emergent literacy test among passive group

		Passive			Test value	P-value	Sig
		Screen time < 2 h No. = 53	Screen time (2–4) hours No. = 28	Screen time > 4 h No. = 32			
Stanford-Binet 4							
Auditory processing	Median (IQR)	99 (98–105)	68 (66–72.5)	60 (55–65)	90.039	0.000	HS
Auditory memory	Median (IQR)	90 (89–93)	68 (65–70)	60 (58–68)	85.219	0.000	HS
Visual processing	Median (IQR)	85 (78–95)	84 (78–92.5)	71.5 (65–90)	9.182	0.010	S
Visual memory	Median (IQR)	91 (83–94)	90 (85–95)	88 (85–96.5)	0.882	0.643	NS
Working memory							
Executive function	Median (IQR)	15 (14–16)	13 (12–14.5)	10 (8.5–13)	38.903≠	0.000	HS
Visio special	Median (IQR)	25 (22–26)	24 (22–25)	21.5 (20–23)	13.467≠	0.001	HS
Phonological memory	Median (IQR)	12 (10–13)	9 (7.5–11.5)	8.5 (7–11.5)	13.189≠	0.001	HS
Total Working memory	Median (IQR)	48 (44–51)	42 (40–47.5)	41 (38–47.5)	10.137≠	0.006	HS
Phonological assessment							
Total phon proc. Scores	Median (IQR)	22 (17–27)	20 (15.5–24.5)	16 (12–20)	10.274≠	0.006	HS
Emergent Literacy Test							
Total Emergent Literacy score	Median (IQR)	17 (12–19)	15 (14–17)	12 (10–15)	14.089≠	0.001	HS

Post Hoc analysis by LSD and multi-comparison between groups

Parameters	**Screen time < 2 h Vs Screen time (2–4) hours**	**Screen time < 2 h Vs Screen time > 4 h**	**Screen time (2–4) hours Vs Screen time > 4 h**
Auditory processing	0.000	0.000	0.000
Auditory memory	0.000	0.000	0.000
Visual processing	0.585	0.005	0.019
Executive function	0.003	< 0.001	< 0.001
Visio special	0.106	0.001	0.017
Phonological memory	0.002	0.004	0.517
Total Working memory	0.012	0.007	0.572
Total phon proc. Scores	0.108	0.002	0.092
Total Emergent Literacy score	0.135	0.001	0.008

P-value > 0.05: Non-significant; P-value < 0.05: Significant; P-value < 0.01: Highly significant

≠: Kruskal–Wallis test

and reduced quantity of language input during critical developmental periods.

Auditory memory

Auditory memory recapitulated the near-identical pattern of auditory processing, further confirming the susceptibility of auditory circuits to screen time–induced dysfunction. In the < 2 h group, active and passive users did not significantly differ from each other, but the two exposure groups began to drastically diverge at higher exposures. Passive users in the 2–4 h group were severely impaired, while those in the > 4 h group were even more dysfunctional than the active users.

For auditory memory, the dose–response pattern for passive users is steep and monotonic, but the active users' pattern only slightly dips, showing that the deleterious effects of more screen time are buffered by being an active user but not completely negated.

The findings further support Rai et al. (2023) [21] and Christakis et al. (2018) [22] who found that each hour increases in daily screen time in early childhood predicted greater attention problems and lower memory performance. The parallel pattern of auditory processing and memory impairment suggests a shared neural substrate of disruption that may impact auditory-phonological networks essential for learning and academic performance.

Increased passive screen exposure during preschool years is consistent with Muppalla et al. (2023) [23], who reviewed theoretical and empirical evidence that

Table 7 Relation of using passive or active before sleep time with Stanford-binet4, working memory, phonological assessment and emergent literacy test

		Sleep time		Test value	P-value	Sig
		Away from sleep time	Close to sleep time			
		No. = 124	No. = 136			
Stanford-Binet 4						
Auditory processing	Median (IQR)	91 (78–98)	76.5 (67–91)	−4.856≠	0.000	HS
Auditory memory	Median (IQR)	89 (78.5–91)	80 (70.5–90)	−3.806≠	0.000	HS
Visual processing	Median (IQR)	88.5 (82.5–94.5)	88.5 (82–93)	−0.604≠	0.546	NS
Visual memory	Median (IQR)	89 (83.5–95)	89 (85–95)	−0.474≠	0.636	NS
Working memory						
Total Working memory	Median (IQR)	47 (42–51)	45 (41–49)	−2.250≠	0.024	S
Phonological assessment						
Total phon proc. Scores	Median (IQR)	22 (18–25.5)	21 (18–26)	−0.958≠	0.338	NS
Emergent Literacy Test						
Total Emergent Literacy score	Median (IQR)	15 (13–18)	15 (12–17)	−1.707≠	0.088	NS

P-value > 0.05: Non-significant; P-value < 0.05: Significant; P-value < 0.01: Highly significant

≠: Mann–Whitney test

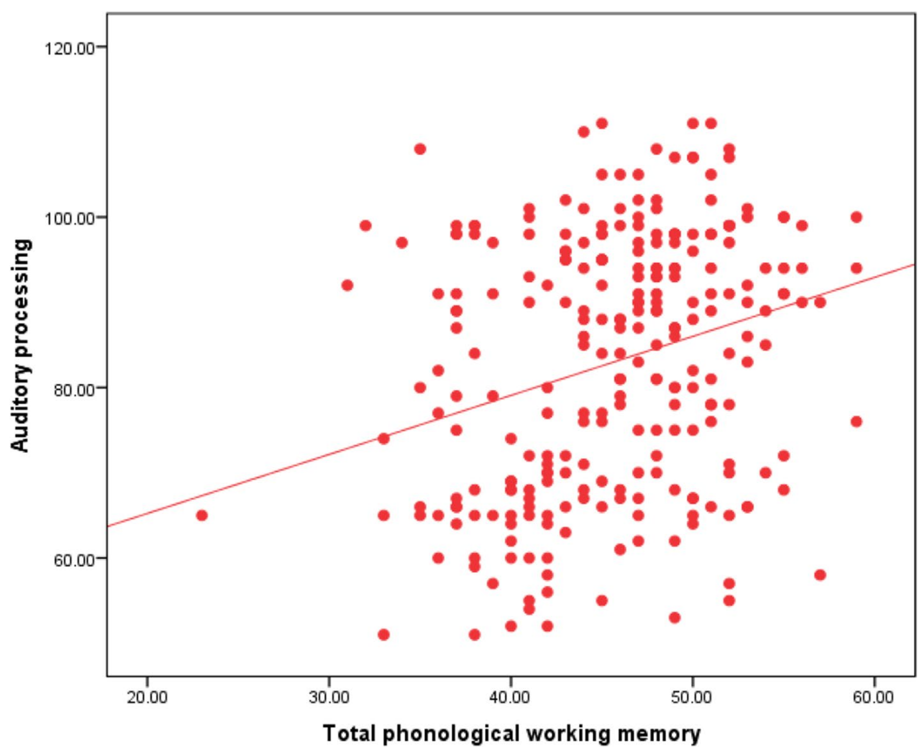

Fig. 1 Correlation between auditory processing and total phonological working memory

limited contingent interaction and increased rapid, non-contingent media impairs development of auditory-verbal and language-attention systems, which may lead to dose-related auditory processing and memory deficits.

Visual processing

Visual processing demonstrated relative resilience compared to auditory domains, with significant differences emerging only at the highest exposure levels. The < 2 h and 2–4 h groups showed no significant differences

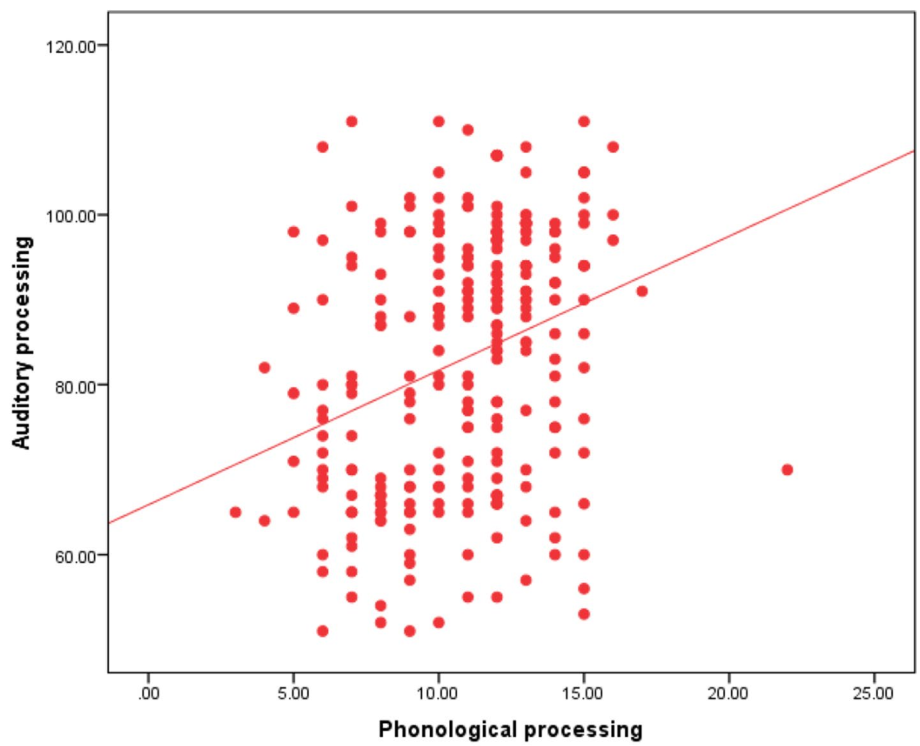

Fig. 2 Correlation between auditory processing and phonological processing

between active and passive users, indicating potential protective effects of visual screen content on visual processing abilities. However, although they showed less impairment than active participants, passive users in the > 4 h group did reach statistical significance for meaningful impairment.

For the dose–response effect, we only found a trend for more exposure to be associated with greater impairment of visual processing for passive users, by contrast with the relative stability in visual performance for active users. The relative preservation of visual processing for active users may be linked to the interactive nature of screen use for these individuals, which requires sustained visual attention.

These results contrast some prior studies reporting visual benefits associated with screen exposure. For instance, Anderson and Subrahmanyam (2017) [24], found that visual skills were higher in children with high amounts of screen use for educational purposes, whereas our study suggests a lack of protection with heavy non-interactive screen time. Another study found higher screen exposure at school age was associated with better contrast sensitivity [25]. These results might reflect a positive adaptive plasticity of the visual system under more engaging conditions, as opposed to a uniform decrement with increased exposure.

Visual memory

Visual memory was the least impaired ability by screens. No significant differences were found between active/passive at any exposure level. Differences in the > 4 h group were extremely small and non-significant with passive users scoring higher than active users.

Visual memory does not show a harmful dose–response pattern with increasing exposure in either group: across low, moderate, and high exposure, passive users' visual memory remains statistically unchanged, and active users also show no significant trend, indicating stability rather than deterioration even with high exposure.

This resilience may reflect the inherently visual nature of screen content, which could provide incidental training for visual memory systems. Reich et al. (2016) [26], similarly found that visual memory tasks were less impaired by screen exposure. preservation of visual memory across exposure levels indicates that screen-related cognitive impairment is not globally distributed but selectively affects specific processing systems.

Miller et al. (20,230) [27], reported neurobiological explanations reinforce this distinction between visual processing and visual memory: Rapid, non-contingent screen input tends to strain fronto-parietal attention and executive networks involved in on-the-spot visual processing, while visual memory systems appear comparatively preserved likely because occipital-parietal pathways that support encoding and consolidation remain active under typical screen stimulation so moderate, high-quality use may not harm visual memory, yet limits are still warranted to protect vulnerable processing functions in developing attentional systems.

So, from our results we can say that both visual domains are far more resilient than auditory domains, and this came parallel to the results of study by Veraksa et al. (2021) [28], who reported that human memory capacity for acoustic information is somewhat limited compared to visual stimuli and passive screen time negatively associated with verbal/phonological processing, while interactive use showed no adverse effect, consistent with greater vulnerability of auditory functions compared to visual memory stability.

Working memory

Total working memory composite scores showed cumulative impairment for all working memory components and worsening with increasing screen time. The between group differences were significant for the 2–4 h passive users, however, we also found stronger effects in the > 4 h group. The within passive group comparisons were significant across screen time duration categories, whereas there was little to no decline in the active group. The effect size for the active group comparisons was significantly smaller, indicating a smaller effect of being an active user. The results are in line with the findings of Azzam et al. (2024) [3], who found a significant difference in working memory between preschoolers across three screen time groups. The present study found a more pronounced decline in working memory performance among passive users, with an effect size that is approximately 2–3 times larger than in Azzam et al. This difference could be explained by the fact that Azzam et al. did not distinguish between active and passive screen time use in their analysis. The cumulative screen time duration showed consistent negative correlations with working memory in both studies, highlighting the potential long-term negative impact of high screen time on working memory in preschool-aged children.

Executive function

The strongest and most significant trend was observed in the executive function domain, where a trend of increasing impairment was observed for all screen exposure durations, and where a modality effect was observed at the low end of the screen exposure scale, with active users performing better than passive users on the executive function test, and where performance deteriorated among passive users with increasing screen exposure time between 2 and 4 h, but remained relatively stable for active users, and where the largest differences were seen in the high exposure group (> 4 h), with passive users performing significantly worse than active users.

For the dose–response pattern, opposite trends were seen for active vs. passive users. Active users showed a steady decline across duration groups, which suggests that engagement and interaction may offer some protection, while passive users showed a sharp decline, which may indicate they are more susceptible to high levels of passive screen time.

These results corroborate Diamond (2013) [29], in which he suggests that executive function is the most susceptible domain of environmental disturbance in early years. This progressive detrimental effect in conjunction with passive viewing time may be a consequence of interference with the mechanisms for vigilance and cognitive control necessary for the development of executive function, as suggested by Swing et al. (2010) [30] when studying the impact of media multitasking.

Lillard and Peterson (2011) [31] showed that after just 9 min of viewing a fast-paced television cartoon, executive function in preschool children was immediately impaired, with the children who had just watched the show performing significantly worse on tests of self-regulation, working memory, delay of gratification, and problem-solving than children who had just watched educational programming or engaged in drawing. Lillard et al. (2011) [32] provided evidence for two such mechanisms. First, because the fast-paced cartoons changed scenes rapidly (every 11 s on average), this required more cognitive resources to encode the presented events and thus would use up more attentional resources, which are thought to be necessary for executive function to operate. Second, "the barrage of fantastical, novel events" also impaired executive function because encoding these events has no "engrained neural circuitry to run on autopilot" and thus the orienting response to novel events is repeatedly elicited, eventually leading to cognitive depletion that interferes with self-regulation.

Hutton et al. (2020) [33] proposed that at the neurobiological level, overexposure to screens impacts white matter tracts that support the development of executive function, with effects ranging from 14 months to 9 years of age. The prefrontal cortex is particularly sensitive to environmental disruption during early childhood, and the preschool years are an especially important time to develop healthy screen time habits.

Phonological working memory

Phonological working memory demonstrated intermediate vulnerability, with significant differences emerging at moderate to high screen exposures. No differences were observed in the low exposure group (< 2 h), but the 2–4 h group showed impairment in passive users, and the > 4 h group revealed continued impairment than in active users.

There was little dose–response decline for active screen users across exposure categories, whereas passive users had a steep and statistically significant dose–response decline, suggesting that interactive engagement may shield phonological working memory from duration-dependent decline. These results are consistent with the longitudinal study by Suggate and Martzog (2021) [34], in which passive screen time was negatively related to phonological memory capacity, but active screen time was not related to phonological memory deficits. Veraksa et al. (2021) [35] proposed that the rapid image changes common in passive screen content may interfere with sensory processing and attentional abilities, making it harder for children to filter out irrelevant stimuli and disrupting the rehearsal mechanisms required for phonological working memory.

The close relationship between phonological working memory and auditory processing deficits (Fig. 1) supports Baddeley's (2012) [36] model of working memory, where the phonological loop depends critically on intact auditory processing for both the phonological store (inner ear) and articulatory rehearsal processes (inner voice). The decline in passive users across exposure levels versus in active users suggests that passive screen engagement specifically disrupts the rehearsal mechanisms underlying phonological working memory.

Visuospatial working memory

Of the different types of working memory, visuospatial working memory is the least sensitive to screen exposure. In active users, the median score was nearly unchanged for < 2 h, 2–4 h, and declined only for > 4 h, with no statistically significant dose–response relationship, suggesting that visuospatial working memory in active users is extremely resistant to duration effects. In passive screen exposure, there was a significant dose-dependent decline in visuospatial working memory, the most dramatic differences were in the > 4 group, which suggests that visuospatial working memory was relatively preserved at low-to-moderate passive exposure, but declined markedly at high exposure levels. However, both active and passive users declined at similar rates, suggesting that visuospatial working memory may be more susceptible to total screen exposure than to mode of engagement.

This is consistent with Karbach et al. (2015) [37], who found that visuospatial working memory was less susceptible to intervention effects than other functions, and Swider-Cios et al. (2023) [38], who found that although visual-spatial working memory was lower at higher levels of total screen media use and television viewing, the effect sizes were smaller than those found in other cognitive domains, indicating that visuospatial processing systems may be more resistant to effects. Zhang et al. (2021) [39] also supported this conclusion, as they found that total screen time had detrimental associations with working memory in preschoolers, but the visuospatial components showed less deterioration than phonological working memory, with effects only becoming significant at the highest exposure levels. This relative resilience may be due to the visual nature of screen content itself, as even passive viewing activates visual processing pathways, and the constant audio stimulation and decreased linguistic interaction associated with overexposure to screens actively disrupt phonological rehearsal mechanisms.

Phonological processing

This pattern of results showed a decrease in phonological processing abilities as screen exposure increased, consistent with the known importance of such skills for language and literacy, and no difference for the < 2 h group, impairment in the 2–4 h group for passive users, and severe deterioration in the > 4 h group, as well as decline across exposure levels for the within-passive group, and more modest deterioration for active users.

The results are also consistent with Fielding-Barnsley & Purdie (2005) [40], study that have shown that phonological processing predicted reading disability in preschoolers, also Massaroni et al. (2023) [41] expanding on this idea in their systematic review to note that excessive passive screen time without parental mediation leads to delayed expressive vocabulary and poor phonological processing, which suggests that the quality and context of screen engagement are significant for phonological development.

The findings indicated a gradual breakdown in phonological processing abilities with increasing passive screen exposure, as would be expected given the foundational nature of these skills in language and literacy, with no difference in the < 2 h group, some impairment in the 2–4 h group, and severe deterioration in the > 4 h group, with the within-passive group analysis showing deterioration across exposure levels, and more modest deterioration in active users.

The strong overlap in deficits in phonological processing and auditory processing (Fig. 2) suggest a pattern of cascading disruption: screen-based disruption of core auditory processing that then leads to subsequent disruption in higher-level phonological processing abilities that are foundational for literacy acquisition, consistent with the dual-route account of reading acquisition, which posits phonological processing as the mediator between auditory processing and reading.

Emergent literacy

Screen exposure exerted a cumulative influence across various cognitive domains, and it was associated with clinically meaningful impairment in passive users, with the most pronounced differences observed in the > 4 h group when compared to active users (the within-passive group analysis revealed a decline across exposure levels in comparison to active users). The relatively intact emergent literacy in active users, even at high levels of screen time, indicates that interactive engagement with screens may provide some degree of scaffolding for pre-academic skills.

The correlation pattern provides evidence that emergent literacy is the downstream effect of disrupted auditory processing, Phonological working memory and phonological processing.

The results of this study support the longitudinal work of Christakis et al. (2004) [42], which showed that high levels of television exposure in early childhood was predictive of reading difficulties later in childhood. In addition, Hutton et al. (2020) [33], provided evidence in the form of neuroimaging data to show that more screen time exposure in preschool-aged children was associated with lower microstructural integrity of white matter tracts subserving language and emergent literacy skills. These white matter abnormalities were in turn associated with poorer emergent literacy performance. They found that higher screen time was related to poorer functional connectivity in networks subserving reading readiness, a finding which biologically underpins the behavioral deficits observed in the present study.

Furthermore, Lin et al. (2023) [43], also reported a bidirectional association between screen exposure and reading engagement in preschoolers, showing that increased screen use coincided with reduced reading activity, thereby creating a self-perpetuating cycle detrimental to literacy development.

Sleep-time screen effects

In the present study, it has been determined that the duration of the daily screen use was not the sole factor for predicting the negative outcomes as the most substantial deficits were observed in auditory processing and auditory memory followed by working memory, which aligns with the research of Carter et al. (2016) [44] demonstrating that screen light exposure in the hours before bedtime disrupted circadian rhythms and sleep architecture, resulting in memory consolidation and cognitive performance deficits.

Gomes and Goldman, (2024) [45], also provided some mechanistic insights into these deficits. Gomes and Goldman (2024) [45] employed regression models to illustrate that screentime use was a significant predictor of sleep problems, accounting for 35% of the variance in sleep quality in preschoolers. These sleep problems disrupt cognitive consolidation processes that occur during sleep, including auditory memory encoding and retrieval mechanisms. Similarly, a large-scale study of toddlers found that screen use before bedtime is linked to poorer sleep and poorer performance on attention/executive function tasks (Carter et al., 2024) [46].

Clinical and educational implications

The observed differential vulnerability patterns across cognitive domains indicate the need for targeted intervention strategies:

- Auditory processes and short-term memory require urgent intervention for children with > 2 h of daily passive screen time, as this domain shows the earliest and most pronounced decline.
- Executive function control interventions should prioritize children exceeding 4 h of daily passive screen time, given that this represents the most underdeveloped cognitive domain in this population.
- Working memory interventions must address all three core components comprehensively, as deficits typically affect the phonological loop, visuospatial sketchpad, and central executive equally.
- Visual and visual-spatial skills demonstrate minimal impairment and should not be the primary focus of intervention programs.

Limitations

- Cross-sectional design: The study's cross-sectional methodology prevents establishment of causality.
- Self-reported screen time: Parental reports of daily screen duration and engagement type are subject to recall bias and may not accurately reflect actual exposure patterns.
- Active versus passive categorization: While the study distinguished between active and passive engagement, the specific content characteristics within each category were not analyzed, limiting understanding of which content features drive observed effects.

Future directions

- Prospective studies incorporating fMRI, and structural MRI, potentially identifying critical developmental windows of neurobiological vulnerability.
- Controlled interventions systematically manipulating screen time and type would establish causality.
- Future research should dissect active and passive categories further, investigating whether specific content features produce differential cognitive outcomes within each modality.

Conclusion

The current study is the first to disentangle these complex and differentially sensitive learning effects of active and passive screen exposure in preschool-aged children. Passive screen exposure appeared to be more detrimental for auditory processing, auditory memory, executive function, phonological working memory, phonological processing, and early literacy relative to active screen exposure. At lower doses, active screen users may be more resilient, due to the contingent, reciprocal nature of active screen activities. Visual processing and visual memory were not affected at any dose or screen type and may represent the spared processing systems that can serve as compensatory areas for learning. With respect to the timing of screen exposure, deficits were most salient for screens used in the hour before bedtime, which was particularly true for auditory and working memory systems. This may be secondary to effects related to sleep loss and sleep-dependent memory consolidation tied to these systems. These findings emphasize the need to design learning-based interventions for preschool children based on areas of known vulnerability (auditory-verbal systems) and strength (visual systems) rather than simple screen-time curfews during this critical age range for making specific, informed choices about modality, timing, and duration of screen use to conserve sensitive cognitive systems and leverage spared processes.

Authors' contributions

Shaimaa Mostafa: Research idea, data collection and analysis, revised the results and shared in manuscript writing and editing. **Naglaa Ghareeb:** Data collection, data analysis and shared in writing manuscript. **Shaimaa Reda:** Data collection, data analysis and interpreting the results. **Ahamed Negm:** Data collection, sample size calculation, revised the results and shared in manuscript writing and editing. All authors read and approved the final manuscript.

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Data availability

All data and materials used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

All study procedures received approval from the General Organization of Teaching Hospitals and Institutes (GOTHI) Research Ethics Committee in April 2024 (approval no. IHS00061) and were conducted in accordance with the 2013 Helsinki Declaration and the ethical standards of the responsible human experimentation committee.
Informed written consent to participate in the study was provided by parents or legal guardians of all participating children.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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