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Moderate Home Computer Use Linked with Children's Optimal Cognitive, Academic Outcomes: Evidence of U-Shaped Associations

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While excessive screen time is often viewed as harmful, moderate digital engagement may be associated with more favorable developmental outcomes. This aligns with the Goldilocks hypothesis, which proposes that cognitive and academic outcomes are optimized at moderate – rather than minimal or excessive – levels of digital use. Yet, many studies rely on linear models, potentially overlooking non-linear associations. Using a large sample of 11,332 Czech primary school pupils, we sought to strengthen the evidence for non-linear associations between computer use and cognitive, academic outcomes. Cognitive outcomes, assessed via the Invenio diagnostic system – a gamified battery measuring inductive and quantitative reasoning, spatial skills, and associative memory – exhibited an inverted U-shaped pattern in three of four domains, with peak scores among every-other-day users. These effects persisted after controlling for parental education and test completion times. Academic outcomes showed less consistent patterns: Czech and math performance peaked at lower usage frequencies – once or twice a month or weekly – while English scores increased across all levels, suggesting subject-specific associations.

Key words: home computer use, screen time, cognitive development, academic achievement, non-linear associations, Goldilocks hypothesis, primary school children

Introduction

Information and Communication Technologies (ICT) have become integral parts of modern life. While parenting practices differ on how much screen time is acceptable, a vast and growing number of children are spending significant parts of their day in front of a screen. Public discourse often frames this trend in binary terms – either beneficial or harmful for children's development – with the negative effects frequently receiving more attention, particularly in popular media narratives (see

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Haidt, 2024). Scientific literature has offered a more balanced perspective, identifying both the potential benefits and risks of digital media use in childhood (e.g., Agasisti et al., 2020; Sauce et al., 2022). The conflicting findings may partly be explained by the fact that many studies still employ linear regression models, despite evidence of a non-linear relationship between ICT use and cognitive, academic, and well-being outcomes (Clemente-Suárez et al., 2024). Given the conflicting literature and increasing public concern regarding children's use of modern technology, this study seeks to provide new evidence for the 'moderate ICT use' hypothesis using a large sample of Czech primary school pupils (*N* = 11,332). Specifically, we aim to contribute on two fronts: substantively, by demonstrating that moderate usage is associated with optimal outcomes; and methodologically, by illustrating the necessity of non-linear analyses in this research area.

The Goldilocks Principle in ICT Use

An emerging consensus in the literature centers around what is often called the "inverted U-shaped" hypothesis or the Goldilocks principle: Moderate exposure to screen time is associated with the most favorable cognitive, academic, and well-being outcomes, while both low and high exposure levels may lead to suboptimal performance (Clemente-Suárez et al., 2024). One way of putting it is that moderate exposure balances the risks and opportunities reported in the literature.

Clemente-Suárez et al. (2024) support the inverted U-shaped model in their narrative review of over 150 studies on digital device use and cognitive development. They report that moderate digital engagement can enhance core cognitive functions – such as attention, information processing, and memory – especially when children use educational apps or structured tools, rather than passively watching videos or scrolling. In contrast, excessive or unregulated use may displace key developmental activities (e.g., reading, physical play, socializing), impair attention, and lead to cognitive overload. Frequent exposure to fast-paced digital content may also disrupt self-regulation.

Przybylski and Weinstein (2017) documented a similar inverted U-shaped trend in their analysis of data from over 120,000 British adolescents, examining the link between screen time and mental well-being. Their study found that well-being peaked with moderate daily digital use – around one to three hours per day – but declined with both low and high usage. Using non-linear regression, they showed that life satisfaction and psychosocial functioning were highest at moderate levels of ICT use. While their focus was on well-being rather than cognition or academics, the pattern reinforces the idea that both minimal and excessive use may be suboptimal.

Risks Associated with ICT Use

On the risks side, various sources warn that excessive screen time may be associated with negative impacts on children's cognitive and psychosocial development (American Academy of Pediatrics, 2016; Huber et al., 2018; Oswald et al., 2020). Excessive screen time has been linked to issues such as poorer executive functioning, attention problems, and reduced academic performance (Huber et al., 2018; Walsh et al., 2018). Similarly, a multi-country analysis found that elevated screen time correlated with increased sedentary behavior and less favorable health markers, which, in turn, can affect other life outcomes (LeBlanc et al., 2015). A study of over 11,000 children highlighted that time spent watching videos or using social media (although not gaming) was associated with weaker cognition (Walsh et al., 2020). These findings suggest that the displacement of important developmental activities – such as reading, homework, sleep, and face-to-face social interactions – may outweigh any initial cognitive benefits associated with computer use (Clemente-Suárez et al., 2024; Dibben et al., 2023; Oswald et al., 2020).

Accordingly, public health organizations, including the World Health Organization (WHO) and the American Academy of Pediatrics (AAP), have advised parents to limit recreational screen exposure to safeguard children's well-being (American Academy of Pediatrics, 2016; World Health Organization, 2019).

Recent studies based on PISA data highlight academic risks associated with home ICT use. Hua et al. (2018) found that increased access to ICT at home correlated negatively with student performance, especially when used for school-related purposes. Agasisti et al. (2020), analyzing twelve EU countries, reported that frequent computer use for homework was associated with lower scores in reading, mathematics, and science. Likewise, Courtney et al. (2022), drawing on four PISA cycles, concluded that home ICT use – whether academic or recreational – showed no measurable benefit and was often associated with poorer outcomes. Notably, all three studies report a linear negative relationship between home ICT use and academic achievement. This contrasts with earlier findings from PISA 2009, which identified a U-shaped relationship – where moderate ICT use was associated with the highest performance, and both low and high levels with weaker outcomes (Steffens, 2014). Similar results were also reported by Gorjón and Osés in 2023, although with ICT use at school, not at home. We believe that focusing on the overall negative correlation, as opposed to the optimal level of exposure, might risk drawing the wrong conclusion.

Benefits of Moderate ICT Use

Balanced against the concerns are studies reporting neutral or even positive effects of ICT use on children's cognitive functioning and school achievement (Adelantado-Renau et al., 2019; Sauce et al., 2022; Walsh et al., 2020). Digital technologies facilitate interactive learning through educational software, online research, and problem-solving tasks, which may foster higher-order thinking, better visual-spatial abilities, and stronger academic engagement (Clemente-Suárez et al., 2024). Additionally, a large-scale analysis of Chinese children's data indicated that weekend internet entertainment may be beneficial for cognitive development, although more frequent use is potentially detrimental (Hu et al., 2022). A longitudinal study found that video gaming and computer use in early adolescence were positively associated with later working memory performance in boys, primarily mediated by general intelligence (Soares et al., 2021). Gaming has also been associated with enhanced broad visual-spatial skills (Spence et al., 2010).

Regarding school performance, Adelantado-Renau et al. (2019) found no overall association between total screen media use and academic achievement. Additionally, internet use for educational purposes showed a beneficial relationship with academic performance. This aligns with PISA data indicating that moderate ICT use is associated with the best results in mathematics (Gorjón & Osés, 2023; Steffens, 2014). Moreover, tablet-based gamified learning applications have been shown to enhance children's mathematical and literacy competencies (Niklas et al., 2025). Providing more granularity on the underlying mechanism, Hales and Hampton (2025) found that while social media use had a small negative direct effect on SAT reading and writing scores, it was outweighed by a larger positive indirect effect mediated by digital skills. The authors suggest a compensatory explanation: unstructured digital leisure builds digital competencies that ultimately support achievement.

Goals and Hypotheses

Our main goal was to examine the relationship between computer use and cognitive, educational outcomes to provide evidence of non-linear, inverted U-shaped relationships. We based our expectations on previous demonstrations of such relationships between ICT use and well-being (Przybylski & Weinstein, 2017) and mathematics skills (Gorjón & Osés, 2023), as well as the need to reconcile conflicting findings from studies that rely on linear methodologies (Agasisti et al., 2020; Hales & Hampton, 2025; Niklas et al., 2025). Theoretically, we argue that the "Goldilocks" level of moderate use represents a functional equilibrium: it provides enough digital engagement to enhance cognitive functions like attention and information processing, yet stops short of the "displacement" threshold where excessive screen time begins to replace activities such as sleep, reading, and physical play. We weighed the meticulous examination of risks and benefits by Clemente-Suárez et al. (2024), which logically leads to the hypothesis that moderate use is plausible where benefits are realized, while risks associated with overuse are not yet substantiated. To account for potential confounders, we included controls for the time children took to complete the tests, as a proxy for familiarity with digital devices, and for parental socioeconomic status (SES), a well-established correlate of both cognitive ability and academic achievement (Nisbett et al., 2012; Pace et al., 2017; Stumm et al., 2020), which may also influence parental practices regarding children's computer use. We formulated the following hypotheses:

H1 Cognitive Outcomes: Children's computer use at home follows an inverted U-shaped relationship with cognitive performance, such that moderate use yields the strongest results.

H1a: Moderate computer use is associated with the highest inductive reasoning performance.

H1b: Moderate computer use is associated with the highest quantitative reasoning performance.

H1c: Moderate computer use is associated with the highest spatial skills performance.

H1d: Moderate computer use is associated with the highest associative memory performance.

H2 Academic Outcomes: Children's computer use at home follows an inverted U-shaped relationship with school grades, such that moderate use corresponds to the highest achievement.

H2a: Moderate computer use is associated with the highest grades in the Czech language.

H2b: Moderate computer use is associated with the highest grades in the English language.

H2c: Moderate computer use is associated with the highest grades in Mathematics.

Methods

Participants

The data come from an anonymized internal database of the *Invenio* diagnostic system and include four cognitive tests described in *Measures*. The tests were administered in 2022 and 2023 to a convenience sample of primary schools (1st–6th grade). Testing was conducted at the schools' request, primarily to map pupils' cognitive profiles and identify high-ability learners. Collection of additional research-relevant data was carried out with the explicit consent of the parents.

The sample size was N = 11,332, with a mean age of around 10 years (M = 10.32, SD = 1.05). Not all tests were administered to the entire sample; individual non-missing test sample sizes and the sample size for the parents' questionnaire are provided in Table 1. Participation was limited to children whose parents provided informed consent via online registration, which also included a questionnaire for the parents. Not all students or schools in a region participated, potentially introducing selection bias toward more motivated participants and institutions. This also means that the sample does not contain data on all measured cognitive abilities for each school grade. We address concerns about a potential age–computer-use interaction by providing a robustness check in the attachment, where we re-run the main analyses on a subsample of fourth-grade students.

Measures

All cognitive ability tests in this study come from the *Invenio* diagnostic system, developed by psychologists at the Faculty of Social Studies at Masaryk University in the Czech Republic, using IRT methodology. The system is used to screen cognitive profiles and identify high-ability primary school students. It employs game-based assessment, which lowers test anxiety and increases engagement (Portešová et al., 2022). The tests are administered in groups via a web browser, with each child working individually under the supervision of trained school staff. Ability scores were estimated using the Weighted Likelihood Estimation (WLE) method, converted to IQ scores based on test norms, and standardized by test and grade to a mean of 100 and a standard deviation of 15.

Inductive Reasoning

The test *Glyphy and the Mysterious Script* (Jabůrek et al., 2022) focuses on inductive reasoning, a specific aspect of fluid intelligence. In this game, children join the archaeologist Glyphy on the planet Hiero to explore and decipher an ancient script by identifying patterns and relationships among various symbols through odd-one-out tasks, logical sequences, or pictorial analogies. The test has high internal consistency (split-half r_{xx} = 0.89) and adequate invariance of its Rasch model across grades (Palíšek et al., 2023).

Quantitative Reasoning

The *Triton and the Hungry Ocean* (Portešová et al., 2021) test focuses on quantitative reasoning, a specific aspect of fluid intelligence.

Table 1 *Descriptive characteristics of the sample*

Grade level	***N* Questionnaire**	**Age *M* (*SD*)**	**% girls**	***N* Inductive Reasoning**	***N* Quantitative Reasoning**	***N* Associative Memory**	***N* Spatial Skills**
1	103	7.32 (0.44)	43.7%	0	0	0	84
2	446	8.14 (0.51)	47.3%	397	0	0	229
3	1,736	9.29 (0.50)	48.7%	1,608	953	0	636
4	5,844	10.22 (0.48)	48.4%	5,310	5,196	4,336	359
5	2,484	11.30 (0.46)	48.6%	2,311	2,159	1,383	224
6	718	12.15 (0.48)	47.2%	504	353	31	290
Total	11,332	10.32 (1.05)	48.3%	10,130	8,661	5,750	1,822

In this game, children assist Professor Triton in balancing the strength of hungry sea creatures to distribute food fairly. The tasks involve applying simple mathematical operations such as addition, subtraction, and multiplication to solve problems, focusing on logical reasoning rather than learned mathematical knowledge. The test has adequate internal consistency (split-half r_{xx} = 0.83) and adequate invariance of its Rasch model across grades (Ťápal et al., 2022a).

Associative Memory

The *Ulrik and the Study of Birds* (Straka et al., 2025) is a test that measures associative memory – a component of long-term memory involving the ability to learn and remember relationships between unrelated elements. In this game, children assist *Ulrik*, a bird observer, in pairing various birds with their unique characteristics or habitats. The tasks involve memorizing and recalling these associations, thereby evaluating the children's capacity to form and retrieve associative links. The test shows adequate internal consistency (split-half r_{xx} = 0.81) (Ťápal et al., 2022b).

Spatial Skills

The *Lin and Space Navigation* (Černický et al., 2022) is a test designed to assess spatial reasoning skills. In this game, players find themselves on a planet dedicated to recording the movements of celestial bodies for navigation purposes. They meet the astronomer *Lin*, who is facing a malfunctioning computer that displays multiple paths for each celestial body. Players assist Lin in identifying and matching the correct paths. The test has adequate internal consistency (split-half r_{xx} = 0.83) and adequate invariance of its Rasch model across grades and genders (Černický et al., 2024).

Home Computer Use

The frequency with which the child uses a desktop computer or laptop at home, as reported by parents in response to a questionnaire item. Responses were recorded on a five-point scale ranging from 0 (none) to 4 (daily).

Other Measures

In addition, we collected the following:

Academic evaluations: In the parents' questionnaire, we collected data on students' most recent school report grades in the Czech language, English, and mathematics. These grades reflect final evaluations issued at the end of each school term.

Parental highest education level: A proxy for socioeconomic status (SES), reported via parents' questionnaire and coded on a four-point ordinal scale: 1 = primary or lower secondary education; 2 = upper secondary or post-secondary vocational education; 3 = bachelor's or master's degree; and 4 = doctoral degree.

Time to solve: The duration between the start and end of each test, counted in the background. Shorter times were interpreted as reflecting possible greater familiarity with computers and/or the digital environment in which the tasks were administered.

Results

As shown in Table 2, younger students were more frequently reported as not using computers, while regular use increased progressively with grade level. By fourth grade, daily use had become the most common response, and by sixth grade, nearly half of the students were reported as using a computer daily.

Table 3 presents Pearson correlations between cognitive outcomes, parental education, and children's computer use. The IQ measures were positively interrelated, aligning with the expected relationships among CHC factors as reported in the literature (Atit et al., 2022; Schneider & McGrew, 2018). Computer use showed weak but statistically significant associations with several cognitive outcomes.

To assess the relationship between home computer use and cognitive functioning, one-way analyses of variance (ANOVAs) were conducted separately for each of the four cognitive domains. Where significant effects were observed, Tukey HSD post hoc tests were used to explore pairwise differences between frequency groups. The distribution of means is visualized in Figure 1. The post hoc comparisons are shown in detail in Figures 1–4 in the Online Supplement.

For inductive reasoning, the ANOVA revealed a significant main effect of computer use frequency, $F(4, 7270) = 13.69$, $p < .001$. Tukey HSD post hoc comparisons indicated that all groups reporting any level of computer use (1–2 times per month, weekly, every other day, and daily) scored significantly higher than children who reported no computer use at home, with mean differences ranging from 2.17 to 4.08 points (all $p < .001$). The highest scores were observed in the every-other-day group, which performed significantly better than both the no-use group ($p < .001$, $d = -0.27$, 95% CI [-0.35, -0.19]) and the daily-use group ($p = .002$, $d = -0.13$, 95% CI [-0.19, -0.06]). This result supports hypothesis H1a.

For quantitative reasoning, the ANOVA was also significant, $F(4, 6330) = 7.19$, $p <$

Table 2 *Frequency of home computer use by grade*

Computer Use	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5	Grade 6	Total
None	36 (35.0%)	142 (45.2%)	316 (27.9%)	515 (11.8%)	115 (6.4%)	26 (5.6%)	1,150
1–2x/month	12 (11.7%)	54 (17.2%)	221 (19.5%)	671 (15.4%)	227 (12.6%)	56 (12.1%)	1,241
Weekly	12 (11.7%)	59 (18.8%)	237 (20.9%)	930 (21.4%)	390 (21.6%)	83 (18.0%)	1,711
Every other day	4 (3.9%)	28 (8.9%)	140 (12.4%)	871 (20.0%)	346 (19.2%)	92 (19.9%)	1,481
Daily	2 (1.9%)	31 (9.9%)	217 (19.2%)	1,358 (31.2%)	728 (40.3%)	205 (44.4%)	2,541
Total	66	314	1,131	4,345	1,806	462	8,124

Note. Percentages represent the proportion of students within each grade who reported a given frequency of home computer use. Totals are based on available responses without missing data.

Table 3 *Pearson correlation table with corresponding sample sizes*

	Inductive Reasoning	Quantitative Reasoning	Associative Memory	Spatial Skills	Par. Highest Education	Computer Use
Inductive Reasoning	1	1,380	5,457	8,023	9,025	7,275
Quantitative Reasoning	0.53***	1	213	297	1,602	1,268
Associative Memory	0.37***	0.30***	1	5,408	5,206	4,297
Spatial Skills	0.59***	0.40***	0.32***	1	7,769	6,335
Parents' Highest Education	0.27***	0.20***	0.14***	0.28***	1	7,756
Computer Use	0.03*	0.08**	0.00	0.05***	0.00	1

Note. ** $p < .01$; *** $p < .001$.

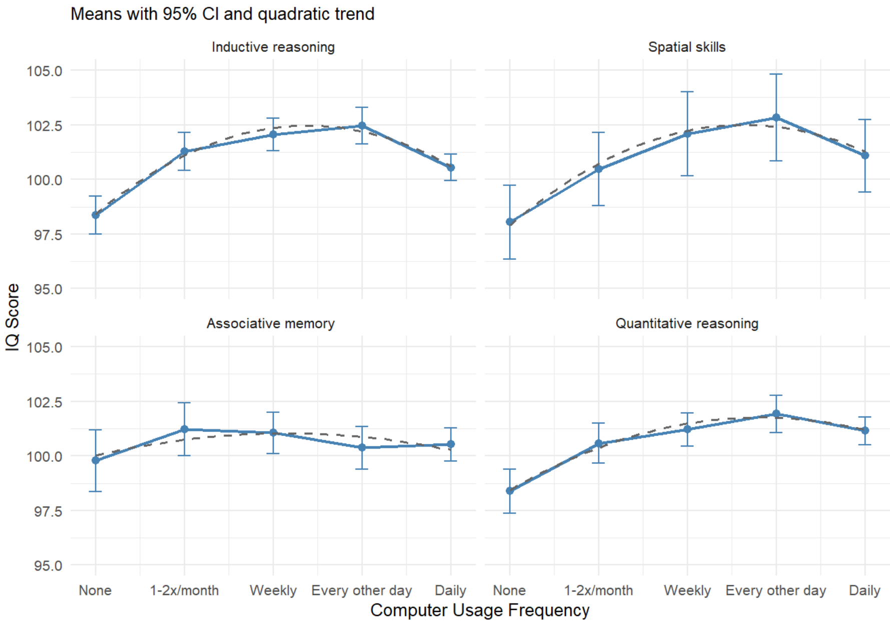

Figure 1 The distribution of IQ means by computer use.

.001. Post hoc tests revealed that children in all groups with any level of computer use scored significantly higher than non-users ($p < .02$ for all), with effect sizes ranging from d = -0.16, 95% CI [-0.25, -0.06] to d = -0.24, 95% CI [-0.33, -0.15]. However, none of the pairwise comparisons between moderate- and high-use groups (e.g., weekly vs. daily, or every other day vs. daily) were statistically significant. Therefore, hypothesis H1b is partially supported: moderate use was beneficial compared to no use, but not significantly superior to daily use.

In the spatial skills domain, the ANOVA yielded a significant effect of computer use frequency, $F(4, 1263) = 4.25$, $p = .002$. Tukey HSD comparisons indicated that children using computers weekly ($p = .010$, $d = -0.26$, 95% CI [-0.43, -0.10]) and every other day ($p = .004$, $d = -0.32$, 95% CI [-0.50, -0.14]) scored significantly higher than those who reported no computer use. No significant differences were found between the daily-use group and any of the other levels of use, including the non-user group ($p = .068$, d = -0.20, 95% CI [-0.36, -0.04]). These findings partially support hypothesis H1c, as moderate computer use was beneficial compared to no use, but the expected decline at high (daily) use was not statistically significant.

For associative memory, the ANOVA was not significant, $F(4, 4292) = 0.88$, $p = .474$. Tukey HSD tests confirmed that no pairwise group comparisons reached significance (all $p > .51$). Therefore, the hypothesis H1d was not supported.

We did not expect age, or more precisely school grade, to act as a confounder, given that the IQ scores were drawn from grade-based norms. However, to rule it out entirely, we conducted robustness checks using data from fourth-graders only. The results are provided in the attachment. They replicate the main findings with one exception: spatial skills follow the same general trend as in the full sample but do not reach statistical significance, likely due to the limited sample size in this subsample. To explore further potential confounders, we examined patterns in children's computer use across levels of parents' highest education, a proxy for SES, as illustrated in Figure 2. The proportion of children in moderate use categories (weekly or every other day) increased with parental education, suggesting that this pattern of digital engagement is more common in families with higher education.

We also investigated whether the time taken to complete the tests varied with computer use frequency, as shown in Figure 3, and observed a general linear trend of faster completion times among more frequent computer users. We interpreted this as potentially indicating greater familiarity with the computer interface.

Based on these observations, we specified nonlinear regression models, treating computer use as a nonlinear predictor, including parental education and test completion time as linear predictors.

We conducted a series of hierarchical regression models to test whether the nonlinear relationship between computer use and inductive reasoning persisted after adding additional predictors. As shown in Table 4, both the linear ($\beta = 2.68$, $p = .007$) and the quadratic ($\beta = -6.72$, $p < .001$) terms were significant in Model 1. The pattern held in Model 2 with the addition of Parental highest education ($\beta = 0.25$, $p < .001$), and in Model 3, which included Solving time ($\beta = 0.19$, $p < .001$). In Model 3, both computer use terms remained significant ($p < .001$), indicating a consistent nonlinear trend supporting H1a. Although statistically significant, computer use alone accounted for less than 1% of the variance

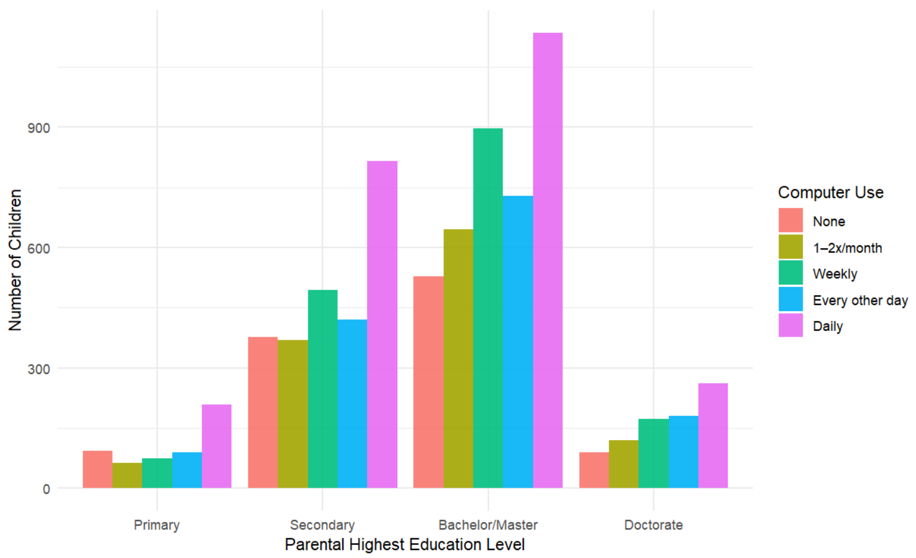

Figure 2 Differences in children's computer use at home by parents' highest education.

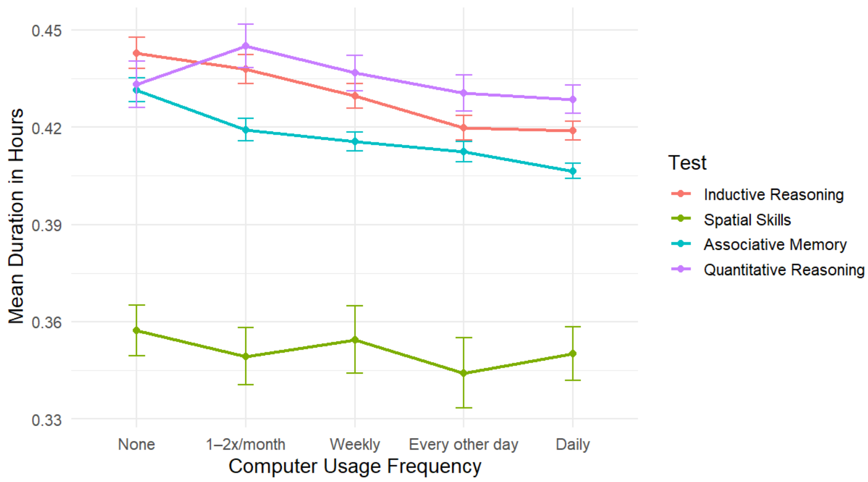

Figure 3 Differences in children's time to complete a test by their computer use at home.

Table 4 *Coefficients for regression models predicting inductive reasoning*

***N* = 6,795**	**Model 0**	**Model 1**	**Model 2: + Par. Education**	**Model 3: + Solving Time**
Computer use (linear)	2.68**	2.68**	2.66**	4.65***
Computer use (quadratic)		-6.72***	-5.08***	-5.34***
Parents' highest education			0.25***	0.24***
Solving time				0.19***
R^2	.001	.008	.070	.105
Adj. R^2	.001	.007	.070	.105

Note. The outcome and covariates (parental education, solving time) were standardized. Computer-use predictors are orthogonal polynomial components derived from the standardized computer-use variable and, therefore, are not on a standardized scale. R^2 represents the proportion of variance explained; Adjusted R^2 accounts for model complexity.
** $p < .01$; *** $p < .001$

in reasoning scores, and the full model explained only 10.5%, suggesting that while these factors are relevant, the greater part of individual differences in inductive reasoning are driven by other influences.

Regression results for spatial skills followed a similar but weaker pattern, shown in Table 5. In Model 1, both computer use terms were significant, indicating a nonlinear trend peaking at moderate use (linear: $\beta = 2.40$, $p = .016$; quadratic: $\beta = -2.67$, $p = .007$). When parental education was added in Model 2, the quadratic term dropped to non-significance ($p = .116$), and parental education showed a strong positive effect ($\beta = 0.22$, $p < .001$). In Model 3, solving time emerged as an additional significant predictor ($β = 0.23$, $p < .001$), and again only the linear computer use term remained significant. The full model explained 11.0% of the variance (Adj. $R^2 = .107$). The non-significance of the quadratic term in later models may be attributable to the smaller sample size for this test compared to the others. The term retained its negative direction, partially supporting H1c.

The models for quantitative reasoning revealed a robust and consistent inverted U-shaped pattern, shown in Table 6. In Model 1, both computer use terms were highly significant (linear: $β = 3.40$, $p < .001$; quadratic: $β = -3.37$, $p < .001$). These effects remained in Model 2 after adjusting for parental education ($β = 0.27$, $p < .001$). Model 3 showed that solving time also contributed independently ($β = 0.22$, $p < .001$), and both computer use terms retained significance, supporting H1b. The full model accounted for 12.0% of the variance.

Table 5 *Coefficients for regression models predicting spatial skills*

***N* = 1,186**	**Model 0**	**Model 1**	**Model 2: + Par. Education**	**Model 3: + Solving Time**
Computer use (linear)	2.40*	2.40*	1.99*	2.29*
Computer use (quadratic)		-2.67**	-1.55	-1.79
Parents' highest education			0.22***	0.19***
Solving time				0.23***
R^2	.004	.011	.057	.110
Adj. R^2	.004	.009	.054	.107

Note. The outcome and covariates (parental education, solving time) were standardized. Computer-use predictors are orthogonal polynomial components derived from the standardized computer-use variable and, therefore, are not on a standardized scale. R^2 represents the proportion of variance explained; Adjusted R^2 accounts for model complexity. ** $p < .01$; *** $p < .001$.

Table 6 *Coefficients for regression models predicting quantitative reasoning*

***N* = 916**	**Model 0**	**Model 1**	**Model 2: + Par. Education**	**Model 3: + Solving Time**
Computer use (linear)	3.40***	3.40***	3.84***	4.48***
Computer use (quadratic)		-3.37***	-2.21*	-2.03*
Parents' highest education			0.27***	0.24***
Solving time				0.22***
R^2	.002	.004	.074	.120
Adj. R^2	.002	.004	.074	.120

Note. The outcome and covariates (parental education, solving time) were standardized. Computer-use predictors are orthogonal polynomial components derived from the standardized computer-use variable and, therefore, are not on a standardized scale. R^2 represents the proportion of variance explained; Adjusted R^2 accounts for model complexity. ** $p < .01$; *** $p < .001$.

We further examined the relationship between computer use and academic performance in Czech, English, and mathematics. School grades were recoded into two categories: a) top grades and b) all other grades. This binary approach was chosen due to the non-normal distribution of grades and the lack of standardization in grading practices across schools.

One-way ANOVAs revealed statistically significant differences for all three subjects: Czech, $F(4, 7283) = 23.16$, $p < .001$; mathematics, $F(4, 7298) = 8.07$, $p < .001$; and English, $F(4, 6961) = 2.88$, $p = .021$. The magnitude of these effects – particularly in Czech – exceeded those observed for several of the cognitive outcomes.

Tukey HSD post hoc tests showed that, for the Czech language, students who used computers daily performed significantly worse than all other groups, including non-users (e.g., daily vs. weekly: d = 0.18, $p < .001$). The highest proportion of top grades was observed in the weekly and 1–2×/month groups. For mathematics, daily users again underperformed relative to moderate users, especially those using a computer 1–2×/month (e.g., daily vs. 1–2×/month: d = 0.19, $p < .001$). The English results showed only one statistically significant contrast (daily vs. 1–2×/month), with a small effect size (d = 0.12, $p = .013$). The distribution of top grades across computer use levels is visualized in Figure 4.

To account for variation in grading standards across student grade levels and adjust for socioeconomic background, we fitted mixed-effects logistic regression models predicting the likelihood of top grades (grade = 1) in Czech, mathematics, and English. Each model included computer use and parental education as fixed effects, and student grade level as a random intercept.

The results, summarized in Table 7, were broadly consistent with the group comparisons, but also offered more precision. In the Czech language, students using computers 1–2×/month or weekly had significantly higher odds of receiving top grades than non-us-

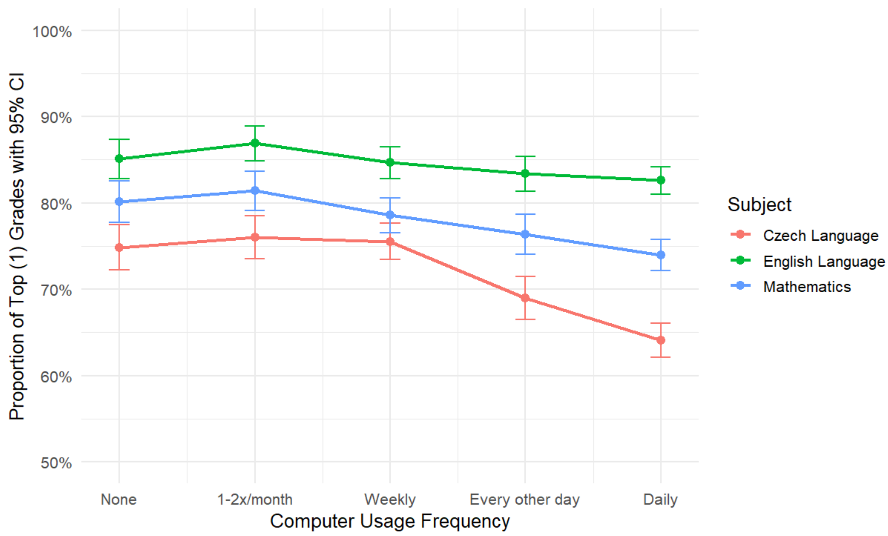

Figure 4 The proportion of top grades in school subjects by computer use.

Table 7 *Mixed-effects logistic regression models predicting top grades in school subjects*

Predictor	**Czech Language OR (95% CI)**	**Math OR (95% CI)**	**English Language OR (95% CI)**
PC Use 1–2×/month	1.29* [1.04, 1.61]	1.31* [1.04, 1.64]	1.51** [1.15, 1.97]
PC Use Weekly	1.31** [1.07, 1.60]	1.08 [0.87, 1.34]	1.31* [1.02, 1.68]
PC Use Every other day	0.96 [0.79, 1.17]	1.00 [0.81, 1.24]	1.23 [0.96, 1.58]
PC Use Daily	0.87 [0.74, 1.04]	1.06 [0.87, 1.30]	1.39** [1.10, 1.75]
Parents' Education	1.99*** [1.84, 2.15]	2.32*** [2.14, 2.51]	1.93*** [1.76, 2.12]
Marginal R^2	0.054	0.072	0.035
Conditional R^2	0.423	0.433	0.569

Note. Reference category for computer use is no use (0). All models include random intercepts for student grade level.
* $p < .05$; ** $p < .01$; *** $p < .001$

ers (OR = 1.29*, 95% CI [1.04, 1.61] and OR = 1.31**, 95% CI [1.07, 1.60], respectively), while daily use showed no benefit (OR = 0.87, 95% CI [0.74, 1.04]). For mathematics, only the 1–2×/month group differed significantly from non-users (OR = 1.31*, 95% CI [1.04, 1.64]). In contrast, the English language showed a uniformly positive pattern: all frequency levels were associated with significantly higher odds of top grades compared to non-users (OR range: 1.23–1.51; all $p < .05$), with the strongest effect for the 1–2×/month group (OR = 1.51**, 95% CI [1.15, 1.97]). These results suggest that the relationship between computer use and academic outcomes is subject-specific and sensitive to control variables such as grade level and socioeconomic background.

Parental education was a strong and consistent positive predictor of top grades across all three subjects (ORs between 1.93 and 2.32, all $p < .001$). Marginal R^2 values – representing the variance explained by fixed effects – ranged from .035 (English) to .072 (math), while conditional R^2 values – which include both fixed and random effects – ranged from .423 to .569.

Overall, the results support a nonlinear relationship between computer use and both cognitive and academic outcomes, though the patterns differ in their specifics. Cognitive performance typically peaked at moderate use – especially every-other-day – while academic performance peaked at lower levels, such as weekly or 1–2×/month.

Hypothesis H1 (an inverted U-shaped relationship between computer use and cognitive performance) was supported for inductive reasoning, and partially supported for quantitative reasoning and spatial skills, where moderate use was associated with better outcomes than no use, but the expected decline at high usage levels was not consistently significant. No support was found for associative memory.

Support for hypothesis H2 (an inverted U-shaped relationship between computer use and school grades) was also partial. In Czech and mathematics, moderate computer use was linked to higher odds of top grades compared to non-use, though the effects were not consistent across all levels. In English, most usage levels – including 1–2×/month, weekly, and daily – were associated with significantly higher odds of receiving top grades. However, every-other-day use was not statistically significant, and the overall pattern did not follow the expected inverted U-shape. Therefore, H2b was not supported. These findings suggest that while frequent use may be detrimental in some academic areas, for English language performance, even regular use may confer benefits.

Discussion

This study provides new evidence showing a non-linear relationship between home computer use and cognitive performance in school-aged children. For inductive reasoning, quantitative reasoning, and spatial skills, moderate computer use was consistently associated with higher scores, supporting an inverted U-shaped pattern (Clemente-Suárez et al., 2024; Sauce et al., 2022).

Academic outcomes displayed more mixed patterns. For Czech and mathematics, students with moderate computer use – particularly those using a computer 1–2 times per month or weekly – tended to achieve higher grades than both non-users and daily users. However, these differences were modest in size, and the expected decline at high levels of use (e.g., daily) was not always statistically significant. Thus, while there was some support for a nonlinear trend, the pattern was less robust than in cognitive outcomes.

In contrast, the results for English diverged from this pattern. Students across most levels of computer use, including daily users, were significantly more likely to receive top grades than non-users. The strongest effect was observed in the 1–2×/month group, but even daily use was positively associated with academic performance in English. This suggests a general positive relationship rather than an inverted U-shape, indicating that frequent home computer use may provide unique benefits for English language acquisition – possibly through exposure to digital media and games in English.

Children's home computer use is often recreational. Bedrošová et al. (2018) reported that Czech children primarily watch videos, use social media, or play online games. This recreational emphasis may explain why moderate use yields some benefits, while excessive use risks displacing academic activities. As Clemente-Suárez et al. (2024) note, excessive screen time can lead to cognitive overload, diminished attention control, and reduced academic engagement.

Overall, our data suggest that moderate computer use at home is not associated with cognitive or academic harm and may even offer specific advantages – particularly when aligned with subject-relevant digital engagement. However, the nature of computer activities remains a key determinant of their educational value. Precautionary measures – such as educating children on effective digital habits, managing digital distractions, and avoiding screen use before bedtime – should be encouraged.

Although the observed relationships were not strong, they were statistically significant across three of the four cognitive domains. For spatial skills in particular, the difference between no ICT use and every-other-day use was nearly 5 IQ points – an effect that, while modest, may have practical implications. These nonlinear effects remained significant even after controlling for socioeconomic status and test environment familiarity.

Spatial skills showed the most pronounced gains with moderate computer use. Many games and digital environments emphasize visual-spatial challenges, which may offer practice not available through traditional instruction. These skills are crucial for STEM achievement (Wai et al., 2009), and digital engagement could support spatially talented children who are underserved by current school curricula (Lakin & Wai, 2020).

By contrast, associative memory did not show any significant relationship with computer use. This may reflect the fact that most digital activities are not designed to foster the deliberate, structured encoding and recall that associative memory requires. Future interventions could explore targeted memory-enhancing applications.

Limits and Recommendations

Several limitations should be considered. First, the sample is not nationally representative, and participation was limited to children whose parents provided informed consent, potentially introducing selection bias toward more motivated families. Second, test completion time was used as a proxy for ICT familiarity, but this measure may also reflect other factors such as motivation or processing speed. Third, the study relied on parent-reported estimates of children's home computer use, which may be subject to recall bias or social desirability. These limitations highlight the need for future research employing more objective and representative measures.

Future research should offer a more nuanced analysis of both beneficial and potentially problematic digital activities that children engage in. Only then can the potential general recommendation of "moderate use" be translated into specific, evidence-based practices. Our findings underscore the importance of testing for nonlinear relationships in ICT research, rather than relying on linear models – as evidenced by the increased variance explained when a quadratic term was included in the regression analyses.

Blank and Groselj (2014) propose that internet use can be understood along three dimensions: the amount of use, the types of activities, and the variety of those activities. We argue that this framework can be extended to encompass broader ICT use. As the Internet of Things expands, most technologies increasingly rely on internet connectivity, blurring the line between online and general ICT engagement. A useful categorization of children's ICT activities is provided by the EU Kids Online project (Šmahel et al., 2020), which distinguishes between entertainment, social interaction, informational/educational use, and creative activities. Ideally, future studies should examine these categories using longitudinal designs to better understand their impact on cognitive, academic, and well-being outcomes – and the interplay between them.

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