

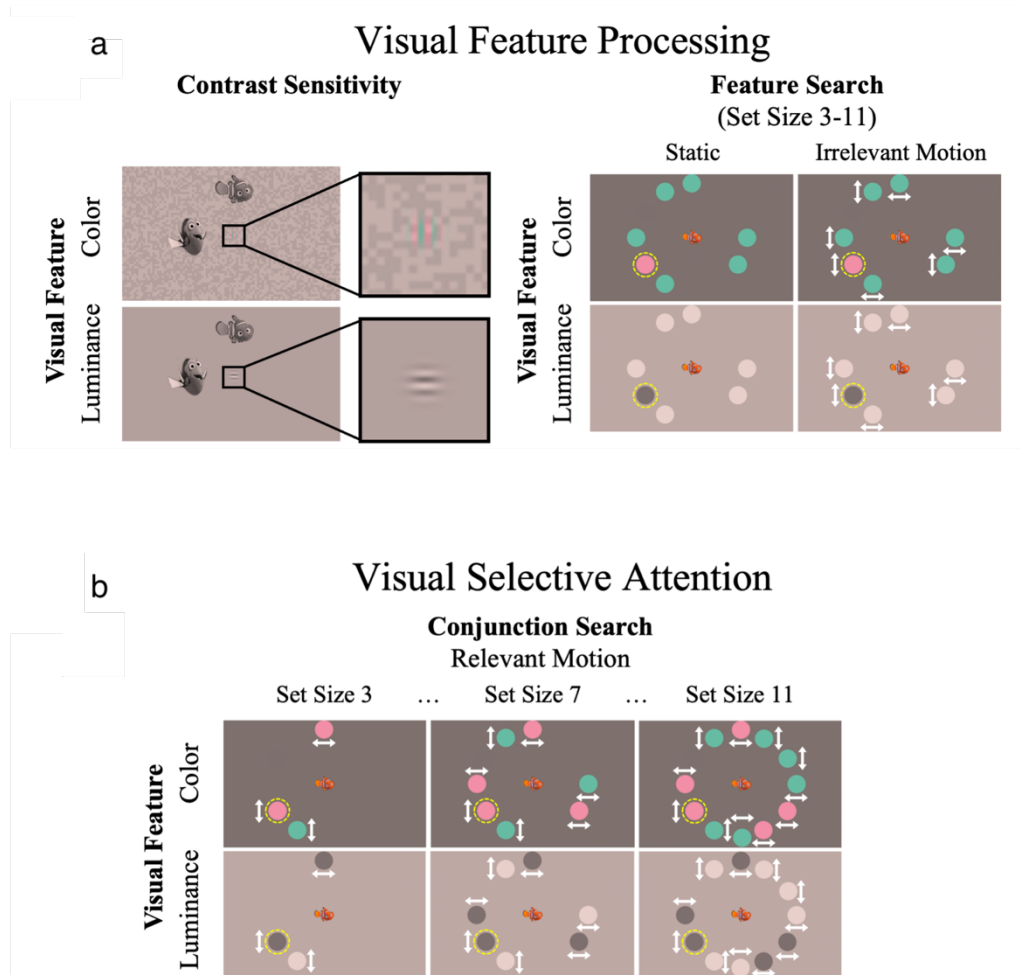
Supplementary Information

Screen time is differentially related to visual selective attention and visual feature processing across middle childhood

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Supplementary Figure S1.

Overview of the experimental procedure and example stimuli



Note. Children first completed a contrast sensitivity task, followed by a feature search task and a conjunction visual search task.

(a) Illustration of tasks measuring visual feature processing. Left, contrast sensitivity trials. Luminance probe trials were presented without noise. Color-r/g probe trial presented with luminance noise. Not depicted: Color-b/y trials and the 5Hz temporal noise masks presented between each probe to disrupt the respective feature channel. Children completed 64 trials for each Visual Feature condition. (b) Illustration of the task measuring visual selective attention. Only Set Size 3, 7, and 11 trials are depicted. Not depicted: Set Size 5 and 9 trials. Images are for illustrative purposes only. Circles did not overlap during motion. Only target present trials are depicted. Yellow dashed circles = target. White arrows = motion direction (Lynn et al., 2024).

Supplementary Table S1.

Type III analysis of variance for the contrast sensitivity linear mixed-effects model with categorical screen time

Effect	df1	df2	<i>F</i>	<i>p</i>
Visual Feature	2	98	5.59	.005
Age	1	49	2.82	.099
Screen Time	4	49	1.95	.117
Visual Feature × Age	2	98	1.86	.161
Visual Feature × Screen Time	8	98	1.38	.214
Age × Screen Time	4	49	0.98	.425
Visual Feature × Age × Screen Time	8	98	0.93	.497

Supplementary Table S2.

Type III analysis of variance for the feature search linear mixed-effects model with categorical screen time

Effect	df1	df2	<i>F</i>	<i>p</i>
Visual Feature	1	1165	2.43	.119
Motion	1	1165	3.46	.063
Set Size	1	1165	1.30	.254
Age	1	55	2.12	.151
Screen Time	4	55	0.19	.943
Visual Feature × Motion	1	1165	0.47	.492
Visual Feature × Set Size	1	1165	0.62	.431
Motion × Set Size	1	1165	1.03	.310
Visual Feature × Age	1	1165	4.38	.037
Motion × Age	1	1165	2.20	.138
Set Size × Age	1	1165	1.44	.231
Visual Feature × Screen Time	4	1165	1.26	.283
Motion × Screen Time	4	1165	1.84	.119
Set Size × Screen Time	4	1165	0.85	.495
Age × Screen Time	4	55	0.38	.822
Visual Feature × Motion × Set Size	1	1165	0.33	.563
Visual Feature × Motion × Age	1	1165	0.80	.371
Visual Feature × Set Size × Age	1	1165	0.78	.379
Motion × Set Size × Age	1	1165	0.88	.349
Visual Feature × Motion × Screen Time	4	1165	0.30	.879
Visual Feature × Set Size × Screen Time	4	1165	1.21	.306
Motion × Set Size × Screen Time	4	1165	1.10	.354
Visual Feature × Age × Screen Time	4	1165	1.01	.399

Effect	df1	df2	<i>F</i>	<i>p</i>
Motion × Age × Screen Time	4	1165	1.00	.407
Set Size × Age × Screen Time	4	1165	0.95	.432
Visual Feature × Motion × Set Size × Age	1	1165	0.33	.567
Visual Feature × Motion × Set Size × Screen Time	4	1165	1.19	.314
Visual Feature × Motion × Age × Screen Time	4	1165	0.22	.927
Visual Feature × Set Size × Age × Screen Time	4	1165	0.39	.818
Motion × Set Size × Age × Screen Time	4	1165	0.48	.751
Visual Feature × Motion × Set Size × Age × Screen Time	4	1165	1.82	.123

Supplementary Table S3.

Type III analysis of variance for the conjunction search linear mixed-effects model with categorical screen time

Effect	df1	df2	<i>F</i>	<i>p</i>
Visual Feature	1	518.53	0.46	.497
Set Size	1	57.30	2.07	.155
Age	1	60.29	9.17	.004
Screen Time	4	60.56	1.29	.284
Visual Feature × Set Size	1	518.54	0.00	.964
Visual Feature × Age	1	518.55	0.81	.369
Set Size × Age	1	57.32	0.04	.841
Visual Feature × Screen Time	4	519.22	3.16	.014
Set Size × Screen Time	4	57.97	0.56	.690
Age × Screen Time	4	60.91	1.99	.107
Visual Feature × Set Size × Age	1	518.55	0.00	.955
Visual Feature × Set Size × Screen Time	4	519.37	0.48	.750
Visual Feature × Age × Screen Time	4	519.93	6.89	< .001
Set Size × Age × Screen Time	4	58.90	2.58	.046
Visual Feature × Set Size × Age × Screen Time	4	520.29	0.44	.780

Supplementary Table S4.

Type III analysis of variance for the contrast sensitivity linear mixed-effects model

Effect	df1	df2	<i>F</i>	<i>p</i>
Visual Feature	2	110	508.13	< .001
Age	1	55	17.66	< .001
Screen Time	1	55	5.12	.028
Visual Feature × Age	2	110	0.02	.984
Visual Feature × Screen Time	2	110	0.82	.443
Age × Screen Time	1	55	0.33	.570
Visual Feature × Age × Screen Time	2	110	0.25	.775

Supplementary Table S5.

Descriptive statistics for contrast sensitivity performance across screen time, visual feature, and age

Panel A. By screen time and visual feature

Screen Time (h/day)	Luminance <i>M (SD)</i>	Red-Green <i>M (SD)</i>	Blue-Yellow <i>M (SD)</i>	<i>N</i>
0.5	42.7 (9.7)	10.9 (4.9)	6.7 (2.3)	13
1.5	41.1 (14.3)	8.7 (4.3)	6.2 (2.6)	27
2.5	44.1 (15.1)	7.6 (2.3)	6.8 (2.0)	12
3.5	42.8 (6.7)	9.4 (3.3)	5.7 (1.8)	5
4.5	56.2 (33.1)	6.3 (0.4)	5.7 (3.5)	2

Note: Descriptive statistics are based on the observed data. Age and screen time were modeled as continuous variables in the primary analyses; screen time categories are presented for descriptive purposes only. Contrast sensitivity values were derived by converting contrast thresholds (dB) to Michelson contrast and calculating contrast sensitivity as the inverse of the threshold; higher values indicate greater contrast sensitivity.

Panel B. By age and visual feature

Age (years)	Luminance <i>M (SD)</i>	Red-Green <i>M (SD)</i>	Blue-Yellow <i>M (SD)</i>	<i>N</i>
4–5	36.0 (10.8)	7.95 (3.87)	5.17 (2.26)	18
6–7	39.8 (12.1)	8.33 (3.30)	6.54 (2.19)	24
8–9	54.0 (11.5)	10.8 (4.77)	7.41 (2.13)	17

Note: Descriptive statistics are based on the observed data. Age and screen time were modeled as continuous variables in the primary analyses; age categories are presented for descriptive purposes only. Contrast sensitivity values were derived by converting contrast thresholds (dB) to Michelson contrast and calculating contrast sensitivity as the inverse of the threshold; higher values indicate greater contrast sensitivity.

Supplementary Table S6.*Type III analysis of variance for the feature search linear mixed-effects model*

Effect	df1	df2	<i>F</i>	<i>p</i>
Visual Feature	1	1207	2.34	.126
Motion	1	1207	1.49	.223
Set Size	1	1207	0.96	.328
Age	1	61	42.01	< .001
Screen Time	1	61	0.50	.480
Visual Feature × Motion	1	1207	2.05	.153
Visual Feature × Set Size	1	1207	0.02	.876
Motion × Set Size	1	1207	0.01	.934
Visual Feature × Age	1	1207	9.51	.002
Motion × Age	1	1207	0.91	.341
Set Size × Age	1	1207	0.11	.743
Visual Feature × Screen Time	1	1207	0.14	.713
Motion × Screen Time	1	1207	0.21	.648
Set Size × Screen Time	1	1207	0.10	.753
Age × Screen Time	1	61	0.45	.505
Visual Feature × Motion × Set Size	1	1207	0.01	.908
Visual Feature × Motion × Age	1	1207	6.10	.014
Visual Feature × Set Size × Age	1	1207	0.60	.440
Motion × Set Size × Age	1	1207	0.53	.469
Visual Feature × Motion × Screen Time	1	1207	0.20	.653
Visual Feature × Set Size × Screen Time	1	1207	0.01	.918
Motion × Set Size × Screen Time	1	1207	1.43	.233
Visual Feature × Age × Screen Time	1	1207	5.21	.023
Motion × Age × Screen Time	1	1207	0.97	.324
Set Size × Age × Screen Time	1	1207	0.88	.347
Visual Feature × Motion × Set Size × Age	1	1207	0.07	.793
Visual Feature × Motion × Set Size × Screen Time	1	1207	0.09	.766
Visual Feature × Motion × Age × Screen Time	1	1207	0.15	.698
Visual Feature × Set Size × Age × Screen Time	1	1207	0.28	.596
Motion × Set Size × Age × Screen Time	1	1207	0.10	.756
Visual Feature × Motion × Set Size × Age × Screen Time	1	1207	3.45	.063

Supplementary Table S7.*Descriptive statistics for feature search performance across screen time, visual feature, and age**Panel A. By screen time and visual feature*

Screen Time (h/day)	Visual Feature	<i>M</i>	<i>SD</i>	<i>Mdn</i>	<i>N</i>
0.5	Luminance	995	287	945	16
0.5	Color	1003	258	961	16
1.5	Luminance	895	239	864	29
1.5	Color	910	248	858	29
2.5	Luminance	853	239	809	13
2.5	Color	874	254	800	13
3.5	Luminance	835	251	764	5
3.5	Color	764	208	682	5
4.5	Luminance	829	183	834	2
4.5	Color	730	143	712	2

Note: Descriptive statistics are based on the observed data. Age and screen time were modeled as continuous variables in the primary analyses; screen time categories are presented for descriptive purposes only. Performance is reported as a P score, calculated as $P = RT(1 + 2ER)$, where RT is the mean reaction time for correct trials with valid responses ($RT > 0$) and ER is the error rate; lower P scores indicate better performance.

Panel B. By age and visual feature

Age (years)	Luminance <i>M (SD)</i>	Color <i>M (SD)</i>	<i>N</i>
4–5	1054 (181)	1080 (159)	23
6–7	843 (171)	873 (167)	24
8–9	796 (152)	738 (122)	18

Note: Descriptive statistics are based on the observed data. Age and screen time were modeled as continuous variables in the primary analyses; age categories are presented for descriptive purposes only. Performance is reported as a P score, calculated as $P = RT(1 + 2ER)$, where RT is the mean reaction time for correct trials with valid responses ($RT > 0$) and ER is the error rate; lower P scores indicate better performance.

Panel C. Age distribution by screen time

Screen Time (h/day)	<i>N</i>	Age <i>M (SD)</i>
<1	16	5.80 (1.19)
1–2	29	6.79 (1.21)
2–3	13	7.03 (1.98)
3–4	5	7.52 (1.03)
4–5	2	8.42 (0.27)

Note: Age and screen time were retained as continuous variables in the primary analysis.

Supplementary Table S8.

Type III analysis of variance for the conjunction search linear mixed-effects model

Effect	df1	df2	<i>F</i>	<i>p</i>
Visual Feature	1	532.15	0.46	.497
Set Size	1	65.13	90.20	< .001
Age	1	67.44	53.90	< .001
Screen Time	1	67.06	0.23	.632
Visual Feature × Set Size	1	532.44	0.98	.324
Visual Feature × Age	1	532.82	4.69	.031
Set Size × Age	1	66.48	8.11	.006
Visual Feature × Screen Time	1	532.17	0.00	.956
Set Size × Screen Time	1	65.68	0.89	.348
Age × Screen Time	1	67.98	0.09	.767
Visual Feature × Set Size × Age	1	533.18	0.26	.611
Visual Feature × Set Size × Screen Time	1	532.51	0.20	.658
Visual Feature × Age × Screen Time	1	533.68	7.30	.007
Set Size × Age × Screen Time	1	68.26	4.59	.036
Visual Feature × Set Size × Age × Screen Time	1	534.64	0.01	.936

Supplementary Table S9.

Descriptive statistics for conjunction search performance across screen time, visual feature, age, and set size

Panel A. By screen time and visual feature

Screen Time (h/day)	Visual Feature	<i>M</i>	<i>SD</i>	<i>Mdn</i>	<i>N</i>
0.5	Luminance	3057	801	2949	18
0.5	Color	3082	1021	3084	18
1.5	Luminance	2814	919	2803	32
1.5	Color	2909	1087	2832	32
2.5	Luminance	2824	955	2654	14
2.5	Color	2726	1131	2627	14
3.5	Luminance	2613	630	2652	5
3.5	Color	2728	733	2752	5
4.5	Luminance	2138	756	2000	2
4.5	Color	2300	1220	1957	2

Note: Descriptive statistics are based on the observed data. Age and screen time were modeled as continuous variables in the primary analyses; screen time categories are presented for descriptive purposes only. Performance is reported as a P score, calculated as $P = RT(1 + 2ER)$, where RT is the mean reaction time for correct trials with valid responses ($RT > 0$) and ER is the error rate; lower P scores indicate better performance.

Panel B. By age and visual feature

Age (years)	Luminance <i>M (SD)</i>	Color <i>M (SD)</i>	<i>N</i>
4–5	3273 (559)	3391 (635)	28
6–7	2944 (504)	2974 (739)	25
8–9	2140 (551)	2147 (719)	18

Note: Descriptive statistics are based on the observed data. Age and screen time were modeled as continuous variables in the primary analyses; age categories are presented for descriptive purposes only. Performance is reported as a P score, calculated as $P = RT(1 + 2ER)$, where RT is the mean reaction time for correct trials with valid responses ($RT > 0$) and ER is the error rate; lower P scores indicate better performance.

Panel C. Age distribution by screen time

Screen Time (h/day)	<i>N</i>	Age <i>M (SD)</i>
<1	18	5.70 (1.17)
1–2	32	6.73 (1.18)
2–3	14	6.85 (2.02)
3–4	5	7.52 (1.03)
4–5	2	8.42 (0.27)

Note: Age and screen time were retained as continuous variables in the primary analysis.

Panel D. By screen time, age, and set size

Screen Time	Age	Set Size	<i>M</i>	<i>SD</i>	<i>Mdn</i>	<i>N</i>
High	Older	3	1855	530	1821	14
High	Older	5	2290	691	2176	14
High	Older	7	2391	862	2217	14
High	Older	9	2600	883	2548	13
High	Older	11	2715	774	2665	14
High	Younger	3	3218	760	3016	7
High	Younger	5	3309	1408	3009	7
High	Younger	7	3302	926	3146	7
High	Younger	9	3419	562	3305	7
High	Younger	11	3622	909	3714	7
Low	Older	3	2097	808	1814	20
Low	Older	5	2306	753	2021	20
Low	Older	7	2758	1072	2755	20
Low	Older	9	2893	1063	2631	20
Low	Older	11	2863	858	2775	20
Low	Younger	3	2779	818	2608	29
Low	Younger	5	3130	900	3054	29

Screen Time	Age	Set Size	<i>M</i>	<i>SD</i>	<i>Mdn</i>	<i>N</i>
Low	Younger	7	3287	888	3263	30
Low	Younger	9	3422	857	3471	29
Low	Younger	11	3377	934	3289	29

Note. Descriptive statistics are based on the observed data. Age and screen time were modeled as continuous variables in the linear mixed-effects analyses. “Low” and “High” screen time groups and “Younger” and “Older” age groups were created solely to facilitate presentation of the observed data corresponding to the simple-slopes analyses. Performance is reported as a P score, calculated as $P = RT(1 + 2ER)$, where RT is the mean reaction time for correct trials with valid responses ($RT > 0$) and ER is the error rate; lower P scores indicate better performance.

Appendix S1

Screen Use Questionnaire

Technology Use Questionnaire

Please think about the types of technology in your home, and the technology that your child has access to outside of the home when answering the following questions.

Technology in the Home

Please check the boxes next to the devices that your household owns:

- | | |
|--|--|
| ☐ Smartphone (i.e. iPhone, Android) | ☐ Tablet (i.e. iPad, Kindle Fire) |
| ☐ Smartwatch (i.e. Apple watch) | ☐ Gaming system (i.e. Nintendo DS, Wii) |
| ☐ Home Assistant (i.e. Amazon Alexa) | ☐ Laptop Computer |
| ☐ Television (e.g. LCD, HD, Smart etc.) | ☐ Other: _____ |

Technology Outside the Home

Please check the boxes next to the devices that your child has access to outside the home:

Include technology they have access to at school, the library, daycare, community center etc.

- | | |
|--|--|
| ☐ Smartphone (i.e. iPhone, Android) | ☐ Tablet (i.e. iPad, Kindle Fire) |
| ☐ Smartwatch (i.e. Apple watch) | ☐ Gaming system (i.e. Nintendo DS, Wii) |
| ☐ Home Assistant (i.e. Amazon Alexa) | ☐ Laptop Computer |
| ☐ Television (e.g. LCD, HD, Smart etc.) | ☐ Other: _____ |

Technology Use

Please indicate what purposes your child uses the technology they have access to:

- | | |
|---|--|
| ☐ Playing games for entertainment | ☐ Playing games for educational purposes |
| ☐ Watching videos for entertainment | ☐ Watching videos for educational purposes |
| ☐ Searching the internet for entertainment | ☐ Searching the internet for educational purposes |
| ☐ Social media/communicating | ☐ Other: _____ |

Total Technology Time

Think about your child's daily usage of all the technology above, please indicate how many hours per day your child spends using and interacting with these items:

- | | |
|------------------------------------|--|
| ☐ <1 hour | ☐ 3-4 hours |
| ☐ 1-2 hours | ☐ 4-5hours |
| ☐ 2-3 hours | ☐ 5+ hours (Number of hours: _____) |

Television and Video Streaming

Please indicate the types of videos and television your child prefers to watch:

- ☐ Comedy (animated and/or with human actors)
☐ Adventure (e.g. Paw Patrol; Blue's Clues; My Little Pony)
☐ Educational (e.g. Sesame Street)
☐ Foreign (e.g. British, Korean etc.)
☐ Language Education (e.g. Dora the Explorer; Ni Hao, Kai-lan)
☐ Other: _____

Technology Skill Level (1-5)

Please rate your child's technology use expertise level on a scale from 1 to 5:

- ☐ (1) Needs considerable assistance (Cannot turn on devices without help)
☐ (2) Novice (Can turn on device and use select functions and games)
☐ (3) Intermediate (Can use multiple devices efficiently without help)
☐ (4) Advanced (Can conduct online searches independently)
☐ (5) Expert/Completely independent (Uses multiple devices, functions, and can help others)

Appendix S2

On the outliers in the contrast sensitivity task

We observed that many of the outlying observations reflected floor-level contrast sensitivity values (e.g., values of 1.0, corresponding to log-transformed values of 0). Such observations likely reflect difficulties understanding task instructions, maintaining engagement throughout the psychophysical threshold procedure, or successful convergence of the adaptive staircase to its minimum detectable value, rather than valid estimates of underlying contrast sensitivity. Consistent with this interpretation, excluded participants were substantially younger than the retained sample (excluded participants: $M = 5.21$ years, $SD = 0.77$), with all but one excluded participant falling within the 4- to 5-year-old range. Because these observations appeared to reflect invalid or highly unreliable task performance rather than meaningful individual differences in contrast sensitivity, we retained their exclusion from the primary analyses.