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Screen-time influences children's mental imagery performance

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Abstract

Mental imagery is a foundational human faculty that depends on active image construction and sensorimotor experiences. However, children now spend a significant proportion of their day engaged with screen-media, which (a) provide them with ready-made mental images, and (b) constitute a sensory narrowing whereby input is typically focused on the visual and auditory modalities. Accordingly, we test the idea that screen-time influences the development of children's mental imagery with a focus on mental image generation and inspection from the visual and haptic domains. In a longitudinal cross-lagged panel design, children (n = 266) aged between 3 and 9 years were tested at two points in time, 10 months apart. Measures of screen-time and mental imagery were employed, alongside a host of control variables including working memory, vocabulary, demographics, device ownership, and age of exposure to screen-media. Findings indicate a statistically significant path from screen-time at time 1 to mental imagery at time 2, above and beyond the influence of the control variables. These unique findings are discussed in terms of the influence of screen-time on mental imagery.

KEYWORDS

cognitive development, electronic media, mental imagery, mental simulation, screen-media, screen-time

1 | INTRODUCTION

> TV provides the viewer with ready-made visual images and thus does not provide viewers with practice in generating their own visual images.
>
> (Valkenburg & van der Voort, 1994, p. 317)

Children spend a significant proportion of their time operating, viewing, and engaging with screen devices such as televisions, computers, game consoles, tablets and smartphones—sometimes in excess of 4 hr/day (Gingold, Simon, & Schoendorf, 2014; Hinkley, Salmon, Okely, Crawford, & Hesketh, 2012; Rideout, 2017). Two hallmark features of screen-time—almost regardless of whether the device is a television, smartphone, or computer—are, firstly, its degree of passivity regarding its provision of mental images and, secondly, its sensory narrowing. Beginning with passivity, the images provided by screens can generally be described as "ready-made" in that they are provided directly via the screen media. Accordingly, it could be surmised that they may not require active image construction, otherwise typical in mental life such as when reading text (i.e. the reduction hypothesis, see Valkenburg & van der Voort, 1994). Second, during screen-time sensory input is typically dominated by two modalities, namely the visual and auditory, presumably somewhat to the detriment of others (e.g. tactile, proprioceptive, visceroceptive, and even olfactive and gustative).

It is now indisputable that sensory experience provides human cognition with not only input, but impetus for its development (Lewkowicz, 2000), with mental imagery and thought depending on activation of sensory areas extending beyond the visual and auditory modalities (Connell & Lynott, 2012; James, 2010; Martzog & Suggate, 2019; Wellsby & Pexman, 2014). Although previous work has considered passivity during screen-time (Valkenburg & van der Voort, 1994), research has neglected the question of whether screen-time's narrower sensory input affects an important aspect of cognitive development, namely, mental imagery. However, it is an open question as to whether screen-time suppresses mental imagery (i.e. reduction hypothesis) or potentially stimulates imagery by training rapid processing of images (i.e. the stimulation hypothesis). To address this tantalizing question, we use a longitudinal cross-lagged design to examine the effect of screen-time on children's mental imagery.

Research Highlights

- Mental imagery lies at the heart of mental life and requires both active image generation and a broad range of sensorimotor experiences.
- Screen media provide children with ready-made and visually dominated mental images, hence may reduce multimodal mental imagery.
- Using a longitudinal cross-lagged design with 266 children we tested the effect of screen-time on mental imagery, controlling for a host of variables.
- Greater screen-time linked to reduced mental imagery in children.

1.1 | Active and passive screen-media

A number of studies have investigated links between screen-time and aspects of cognitive, academic, and child development (Allchorne, Cooper, & Simpson, 2017). Screen-time here is defined as time spent viewing content displayed and projected from active and passive screen-media, namely, those media that present visual information on two dimensional displays. This encompasses traditional media (e.g. television and Personal Computers) and new media, such as smartphones and game-consoles. The defining feature of these media is that they convey sensory experiences primarily via the visual, but also auditory senses, with only minor stimulation of other sensory modalities.

Importantly for the current paper, the advent of active screen-media, such as touch-screens and media requiring direct interaction in shaping the course of subsequent media content (e.g. game-consoles), requires careful consideration in comparison with more passive media (i.e. television viewing). First, these active screen-media generally require the input of participants in shaping the course of the images provided by the screens. For example, the course taken in role-play computer games depends on active input, as does word-processing, taking photos, chatting, and so forth. Second, the haptic and fine-motor system is also active in delivering this input (e.g. pressing buttons), although in a comparatively impoverished form due to the sensory homogeneity of touch screens or keys (e.g. Hipp et al., 2017). As discussed below, such active screen-media may activate mental imagery in a different way to passive screen-media (i.e. television). For the purpose of the current paper, we exclude new media, such as 3D interactive technologies, because these are not in widespread use and little research exists on these.

1.2 | Screen-time and cognitive development

At a general level, research on the effect of screen-time on cognitive development includes two sets of studies. The first group concerns broad effects of screen-time, usually for entertainment purposes in the home environment, on features of cognitive development. The second research direction relates to work seeking to enhance children's learning and development by using media.

1.2.1 | General cognitive development

Despite attention-grabbing headlines such as “screentime is making kids, moody, crazy and lazy” (Dunckley, 2015), research actually often lacks consistency of findings and often concrete theoretical mechanisms linking screen-time to specific outcomes, particularly in the case of mental imagery. Turning to findings, some have linked screen-time and eye-problems (Rosenfield, 2011), obesity through impoverished physical movement (Fitzpatrick, Pagani, & Barnett, 2012; Walsh et al., 2018), blue light exposure and sleep deficiencies (Dworak, Schierl, Bruns, & Strüder, 2007), and academic achievement through reduced time for formal learning (Beentjes & van der Voort, 1988; Hancox, Milne, & Poulton, 2005; Weis & Cerankosky, 2010).

Turning specifically to cognitive development, findings are mixed. Beginning with general developmental indicators, some research indicates a small detrimental effect of excessive screen-time on achieving developmental milestones (Madigan, Browne, Racine, Mori, & Tough, 2019). Some studies also find that language development in infancy is negatively affected by screen-time (Chonchaiya & Pruksananonda, 2008; Zimmerman, Christakis, & Meltzoff, 2007), others that young children do not acquire new words from screen media (Krcmar, Grela, & Lin, 2007; Robb, Richert, & Wartella, 2009), while others still demonstrate that educational content can impart vocabulary (Rice, Huston, Truglio, & Writhgt, 1990) and narrative skill (Linebarger & Piotrowski, 2009; Linebarger & Vaala, 2010; Linebarger, 2005). However, an understanding as to why screen-time might differentially affect language development is incomplete, although studies suggest that transferring from virtual to real worlds can be difficult for infants (Hipp et al., 2017).

Executive functions have been examined more extensively. One set of findings suggests that screen-time, particularly in the form of interactive video games, can enhance cognitive control in adults (Anguera et al., 2013; Powers, Brooks, Aldrich, Palladino, & Alfieri, 2013). Other studies find that the multitasking and rapid changes inherent in screen-time negatively affect executive functions in both adults (Ophir, Nass, & Wagner, 2009) and children (Lillard & Peterson, 2011; Nathanson, Aladé, Sharp, Rasmussen, & Christy, 2014). Furthermore, screen-time has been linked to increased symptomology associated with attention-deficit hyperactivity disorder (Nikkelen, Valkenburg, Huizinga, & Bushman, 2014). However, further confusing the picture, a cross-sectional study from China found that screen-time positively linked to preschool children's executive functions (Yang, Chen, Wang, & Zhu, 2017). Another study using a large Australian sample found that media exposure at age 2 years, but not age 4, negatively related to later self-regulation (Cliff, Howard, Radesky, McNeill, & Vella, 2018).

1.2.2 | Enhancing learning through screen-time

On the other hand, a raft of approaches and studies demonstrate that, depending on age and content, children and adults can successfully learn from screen-media (Barr & Linebarger, 2017). Generally, these approaches seek to capitalize on and enhance learning processes via a number of techniques, sources, and strategies (Troseth, Strouse, Flores, Stuckelman, & Russo Johnson, 2020). When the goals are clear and the program is well-designed, even passive media (i.e. television) can enhance school readiness, problem solving, and learning (see Kirkorian, Wartella, & Anderson, 2008). At a theoretical level, well-designed programs could invoke established learning principles, such as social learning, capturing and sustaining attention, encouraging mental model development, reinforcing, facilitating explorative learning and knowledge elaboration (Barr & Linebarger, 2017; Hattie, 2012; Kirkorian et al., 2008).

Specifically, prompts provided by interactive electronic books can support learning (Strouse & Ganea, 2016, 2017), especially for low SES families (Troseth et al., 2020) and including a social model (e.g. a parent) as a co-viewer can further enhance gains (Strouse, Troseth, O'Doherty, & Saylor, 2018). Pertinent for the current line of inquiry, children can experience difficulty deriving three-dimensional information from two-dimensional media, which implicates both children's sensorimotor systems and, as discussed next, mental imagery in learning and cognitive development (Troseth, 2010).

1.2.3 | Summary

Indeed, taking research on screen-time and cognitive development as a whole, we, along with others (e.g., Troseth, 2010), note that clear and plausible theoretical mechanisms need to be carefully tested with ecologically valid designs amenable to causal interpretation, namely longitudinal cross-lagged panel designs (Kearney, 2017). Effects appear to be context (Hirsh-Pasek et al., 2015) and developmentally dependent (e.g., Barr & Linebarger, 2017). However, as we argue in the next section, research has perhaps overlooked one key feature of screen-media: such media present children with rapidly changing pre-made sensory images that are typically specific to the visual and auditory modalities alone. This might in turn influence the mental simulation of external events (i.e. mental imagery).

1.3 | Mental imagery

Visual imagery has been described as seeing with the mind's eye (Kosslyn, 1994) and the close cousin thereof, namely mental imagery, can be understood as simulation or internal re-creation of perceptual experience (Barsalou, 1999). Mental imagery can be conceived of as containing four stages, image generation, maintenance, scanning, and transformation (Kosslyn, Margolis, Barrett, Goldknopf, & Daly, 1990). Developmental effects also exist, with children being relatively poorer at generating, scanning, manipulating, or transforming images (Kosslyn et al., 1990). In addition, studies have shown that sensory and motor systems underlie mental imagery (e.g., Martzog & Suggate, 2019), as has been found in other domains such as memory, language, and thought (Barsalou, 2008).

Indeed, various theoretical approaches argue that sensory and sensorimotor experiences form the basis of mental imagery and cognition. For instance, in embodied cognition theories, cognitive processes have been described as resulting from an internal simulation of underlying actions and perceptions (Barsalou, 2008; Glenberg & Gallese, 2012; Glenberg et al., 2008). According to perceptual symbols theory, Barsalou (1999) characterizes simulations as "the top-down activation of sensory-motor areas" (p. 641). Re-enacted perceptual experiences appear to bear close similarities to the experiences behind mental imagery (Kosslyn, 1994). Both simulation theory (Jeannerod, 2001), and emulation theory of representation (Grush, 2004), make the claim that motor and visual images are analogous to real-world physical and visual experiences because they make use of similar neural infrastructure as indicated by motor and visual cortex activation during imagery (see Jeannerod, 2001 for a review and Kosslyn, Ganis, & Thompson, 2001; Tomasino, Werner, Weiss, & Fink, 2007).

1.4 | Links between screen-time and mental imagery

Although not directly investigating links between screen-time and mental imagery, as here defined, there have been studies on links between television and day-dreaming/creative imagination (Valkenburg & Peter, 2013; Valkenburg & van der Voort, 1994, 1995). Consistent with the reduction hypothesis, studies have found that children perform more poorly on measures of creative and divergent production after viewing a television versus hearing a radio program (Valkenburg & Beentjes, 1997). Furthermore, in a study with a large sample of children and using a cross-lagged design, television viewing affected both the content of day-dreaming and reduced its occurrence (Valkenburg & van der Voort, 1995). On the other hand, consistent with the stimulation hypothesis, rapid processing of screen-images might stimulate the perceptual system (Dye, Green, & Bavelier, 2009), perhaps explaining why some work has found indications that video-gaming can support information processing (Dye et al., 2009; Powers et al., 2013).

1.5 | The current study

As outlined and defined here, two features define mental imagery. First, mental imagery constitutes activity in the form of image generation, maintenance, scanning, and transformation (Kosslyn et al., 1990). Second, mental imagery depends on broader sensorimotor simulations and experiences (Barsalou, 1999; Kosslyn, 1994). Two functional properties of screen media bear close examination.

First, screen-media provide images that presumably somewhat circumvent the effortful construction processes required during mental imagery, which has been called the reduction hypothesis (Valkenburg & van der Voort, 1994). Conceivably, various screen-media might differentially result in a reduction in mental imagery, for instance if during screen-time children anticipate, or reflect on, content, then some mental imagery might be employed. Furthermore, if actions are to be planned and executed via screen-media, it is likely that mental imagery of subsequent actions would be stimulated more so with active than passive media. Accordingly, it might be expected that screen-media generally would reduce the active generation of mental images, but that active screen-media might have less of a detrimental effect on imagery compared to passive media.

Second, as mentioned, screen-time represents a sensory narrowing, in that two modalities (i.e. the visual and auditory) are likely stimulated while other broader sensorimotor experiences (e.g. motor, haptic, proprioceptive) are suppressed. Again, it may be important to distinguish between passive and active screen-media, in that the latter involve some direct motor action (Galetzka, 2017). However, given the homogeneity of motor action when interacting with flat screens or analogous buttons—which by nature vary little in terms of haptic or proprioceptive feedback—screen time likely results in comparatively impoverished sensorimotor experiences otherwise to be expected in childhood (e.g. outdoor play, block games). Indeed, mental imagery, which is itself a fundamental building block of thought and cognition (Barsalou, 1999; Kosslyn, Ganis, & Thompson, 2003), depends on both broader sensorimotor experience and active image generation. Thus, it would appear pressing to investigate the effect that children's screen-time experiences have on their mental imagery performance. However, to date, no study has directly investigated this.

Accordingly, we conducted a longitudinal cross-lagged panel study measuring 266 preschool and primary school children's mental imagery and screen-time use at two points in time, 10 months apart. Crucially, our use of a cross-lagged panel design has the key advantage that mental imagery at time 2 can be predicted from screen time at time 1, and screen time at time 2 from mental imagery at time 1, while accounting for control variables. A pattern consistent with the unidirectional causal operation of screen-time on mental imagery would be found if the diagonal pathway from screen-time (t1) to mental imagery (t2) were significant, but the converse pathway were not, indicating unidirectional influences as opposed to bidirectional association (Kearney, 2017).

Furthermore, the design permitted us to control for a host of theoretically important control variables beyond parental demographic data and including working memory and vocabulary. The latter two are key covariates because working memory is intimately related to executive functions, which, along with vocabulary, have been found to relate to screen-time usage. Additionally, we used a novel mental imagery measure, namely a mental comparison task, designed to specifically target the sensorimotor foundations of mental imagery (Martzog & Suggate, 2019), that generates response accuracy and response latency.

In accordance with the reduction hypothesis, we expected that mental imagery performance (accuracy) would be lower in children exposed to more screen-time because they have less experience with the active creation of their own mental images. Theoretically, it is conceivable that screen-media train rapid processing of mental images that have been provided by screens, perhaps leading to greater mental imagery processing speeds for familiar images. Additionally, previous work has found that screen-time increases children's impulsivity (Lillard & Peterson, 2011; Nikkelen et al., 2014) and processing speed (Dye et al., 2009). Accordingly, we tentatively expected screen-time to result in faster response latencies, consistent with the stimulation hypothesis (Valkenburg & van der Voort, 1994). Finally, we tested whether passive and active screen-media differentially relate to mental imagery, reasoning that the added activity (i.e. planning and executing actions) inherent in active screen-media means that active screen-time may not relate negatively to mental imagery.

2 | METHOD

2.1 | Participants

Participants in this study were 266 children (51.1% girls) aged between 35 and 120 months ($M = 75.26$, $SD = 20.05$) at the first time point, attending either preschools ($n = 141$) or primary schools ($n = 125$) in a small city in Germany. Thirty-two percent of children had at least one parent born in a foreign country and 26.3% spoke a language other than German at home. Aside from German, there was no clear majority amongst the home languages spoken, with these being a mixture of Eastern European and Asiatic languages. Additionally, 56.4% of the families had at least one parent with a University degree or equivalent. The national average for individual adults (and hence not directly comparable) in a similar age range to the parents is 29% for this generation (Federal Bureau of Statistics, 2017), indicating that the sample was likely more highly educated.

2.2 | Measures

Demographic data were collected via a parent questionnaire. Parents were asked about languages spoken at home, educational background, home country, screen-time usage, device ownership, and first contact with media.

2.2.1 | Screen-media questionnaire

A parent questionnaire was used to measure children's screen-time and media usage. Given notorious difficulties in measuring screen-time, in part due to information bias and social desirability, we optimized our method over the course of several pilot studies. At a theoretical level, measures involving diaries have been recommended in preference to questionnaires because these are thought to provide more accurate estimates (Reinsch, Ennemoser, & Schneider, 1999). However, one key disadvantage with diaries is low-compliance. To address these issues, we opted for a diary-questionnaire format in which parents were asked about their children's screen time activities at different points in the day. Thus, during the working week, we asked about usage before school/preschool, in the afternoon, and in the evening, and then on the weekend. Additionally, we asked about the amount of time spent on various devices, including televisions, computers, tablets, play-consoles, and smartphones. Thereby, we responded to previous work calling for a focus on more modern media in addition to television (Valkenburg & Peter, 2013). Because of our hypotheses that screen-time affects imagery via sensory-narrowing, we also asked parents how old children were when they first began using the various appliances to determine the effect of long-term exposure. Finally, we also included questions asking about the ownership of electronic media appliances.

Accordingly, our data provided three scores: (a) device ownership, (b) daily exposure time, and (c) age at which exposure began. Screen-time was rated on a 6-point Likert scale for each medium (no screen-time, <30 min, <1 hr, <2 hr, <3 hr, >3 hr, and on the weekends categories extended to 5 hr/day). An equal-interval sum score across all media, weighted according to days (such that week days counted for five sevenths and weekend days two sevenths of the total time), was estimated, with the total value indicating the number of hours across the five media formats (i.e. television, smartphone, computer, tablet, game-console). Additionally, we created active and passive media usage scales by separating those media that required a direct sensorimotor input (i.e. smartphone, computer, tablet, game-console) from those that do not (i.e. television).

Total media ownership was simply a sum score of the number of appliances and media available in the household (i.e. television, computer, internet access, laptop, smartphone, tablet, game-console) and hence ranged between 0 and 7. Age at which media use began was scored on an 8-point Likert scale (1 = <age 2 years, 2 = age 2–3 years, 3 = 3–4, 4 = 4–5, 5 = 5–6, 6 = 6–7, 7 = 7–8, 8 = not at all) and summed across all media (i.e. television, computer, tablet, smartphone, game-console), giving a theoretically possible score range from 4 to 32.

2.2.2 | Mental imagery

We employed a mental imagery task based on previously used mental size comparisons tasks (Moyer, 1973; Paivio, 1975), that has been recently utilized and further developed (Martzog & Suggate, 2019). Pertinent to the task was that children needed to rely on information derived *from* the mental images themselves, not declarative knowledge *about* the images. Children were asked to imagine two specific objects, and then asked to make a judgment as to which from the target and distractor item was better encapsulated by a sensory feature (i.e. “which is shinier, [a] trumpet or [a] violin?”). Note that the question was thus phrased, such that the stimuli appear at the end so that processing can only begin after presentation. Also, in German, the indefinite article “a” was not grammatically necessary in the question sentence, thus reducing memory load between presentation of the two target stimuli. The invoked modalities were determined by two conditions, firstly the question contained an adjective pertaining to the modality (e.g. “shiny”) and secondly, the target words had a sensory feature that was prominent in the corresponding modality (e.g. “trumpet”). Although the original task contained stimuli pertaining to the haptic, visual, and visual-haptic modalities, analyses found that the task was best conceptualized as a general imagery measure (Martzog & Suggate, 2019). During task development, Martzog and Suggate (2019) accounted for diverse lexical features (e.g. length, syllabic structure, frequency, imageability, manipulability, sensory ratings).

Response accuracy and latency were both recorded by the experimenter using response keys on a laptop. In total there were 34 items, each containing a distractor and a target and children were asked to respond as soon as they knew the answer without, however, emphasizing speed in order to avoid hectic and erratic responses. Response accuracy and response time was recorded and the internal consistency was estimated at $\alpha = 0.85$ at time 1 and $\alpha = 0.79$ at time 2. At time 1, the experimenters were stringently trained by the second author in the timing procedure, with a feasibility check on interrater reliability indicating excellent consistency, $\alpha = 0.96$, $r(34) = 0.93$, $p < .001$. At time 2, we computerized the task and children heard the stimuli through headphones and responded by pressing large buzzers connected to a laptop.

2.2.3 | Working memory

A backwards digit span task was used to assess children's working memory (Endlich et al., 2017). In total, there are nine items of three different lengths (i.e. 2, 3, and 4 numbers), ordered according to difficulty with a ceiling criterion of two consecutive errors. The maximum number of points obtainable was nine. The internal consistency of the working memory test was estimated at $\alpha = 0.86$ at time 1.

2.2.4 | Vocabulary

Children's vocabulary was assessed using the vocabulary test at time 1 from the Kaufmann ABC (Kaufman & Kaufman, 2015). In this task, children are shown pictures and are required to name the object in the pictures. One point was awarded for each correct item and there was a discontinue rule after 4 consecutive errors, and a basal item was established after three correct responses. The maximum number of points possible was 39 and the internal consistency of the vocabulary test was estimated at $\alpha = 0.89$.

2.3 | Procedure

Children were tested twice on the screen-time, imagery, and some of the control variables, on average 9.81 (*SD* = 1.33) months apart, once in the academic year of 2017–2018 and again in 2018–2019, in their educational institutions. Data were drawn from a larger longitudinal study in progress. All tasks were administered individually by trained research assistants and the second author according to test instructions. Parents completed questionnaires, at two time points parallel to data collection, providing information on their children's screen-time and demographic data. For preschool children, between two and three testing sessions were required, each of approximately 20 min, so as to not overtax concentration spans. Approval from the Ministry of Education was obtained prior to conducting the study and written consent was provided by the parents of participating children, followed by the latter's verbal assent.

2.4 | Data analyses

Data analyses consisted of first screening the data for anomalies (skew and kurtosis) and calculating descriptive statistics. We winsorized the data by capping outliers on mental imagery reaction time to the three standard deviations above the item level mean. Next, we conducted correlation analyses to explore relations between the exogenous and endogenous variables central to the cross-lagged panel design and path modeling. Path models allowed us to conduct regression analysis (Kline, 2011) testing for cross-lagged effects consistent with the causal operation of screen-time on mental imagery (Reinders, 2006), controlling for the influences of a host of variables (Byrne, 2010; Kline, 2011). Path models were calculated using AMOS v. 23 (Arbuckle, 2014) with missing values being given full consideration through full maximum likelihood estimation. Screen-time and mental imagery were modeled as manifest variables to facilitate model convergence and the control variables (presented in Table 2) were added as predictors with paths onto both time 1 and time 2 screen-time and mental imagery. Control variables included parent education, ethnic status, device ownership, age of exposure to screen-media, vocabulary, working memory, chronological age, and, to control for variations in testing procedure, the number of months between time 1 and time 2.

TABLE 1 Descriptive statistics for control variables, screen-time, and mental imagery

	Descriptive statistics				
Variables	*M*	*SD*	*N*	Min	Max
Control variables					
Age (months)	75.26	20.05	259	35	120
Vocabulary	19.02	5.28	255	4.00	37.00
Working memory	2.44	1.28	248	0	4.00
Screen exposure (age)	23.18	3.90	255	11.00	32.00
Device ownership	5.68	1.173	255	1.00	7.00
Time 1 variables					
Mental imagery (acc)	26.86	5.36	254	2.00	34.00
Mental imagery speed (ms)	2,589	1,068	254	745	10,023
Screen-time	1.87	1.43	237	0.00	9.14
Time 2 variables					
Screen-time	1.52	1.11	197	0.00	5.93
Mental imagery (acc)	25.62	4.97	250	2.00	32.00
Mental imagery speed (ms)	2,327	1,494	250	487	13,105

Finally, although in our mental imagery task we did not directly ask children to respond as quickly and accurately as possible, the data represent a double challenge in that response time is not independent of response accuracy. Accordingly, we treated these two variables separately, reasoning that response speed—regardless of accuracy—provided one source of information about how participants approached the task (i.e. the stimulation hypothesis) and that response accuracy to another (i.e. the reduction hypothesis).

3 | RESULTS

3.1 | Descriptive statistics

In Table 1 the descriptive statistics for scores on the screen-time, mental imagery, and control variables are presented. Inspection of skew and kurtosis statistics suggested that data were normally distributed, however, response latency to the imagery items appeared to be right skewed (skewedness in the vicinity of 2.50). Of the imagery data, 4.5% was missing at time 1 and 6.0% at time 2, with the corresponding percentages for the screen-time data being 10.9% and 25.94%. Next correlation coefficients were calculated for the variables in Table 1, which are presented in Table 2. Trends indicate that screen-time correlated negatively with accuracy, as did response speed on the imagery task. Vocabulary and working memory positively predicted mental imagery and were generally negatively

TABLE 2 Product-moment and partial correlation coefficients between screen-time, control, and mental imagery variables

		1	2	3	4	5	6	7	8	9	10
1	Vocabulary	–	0.38*	0.08	0.28*	−0.12	0.55*	−0.25*	−0.21*	0.36*	−0.19*
2	Working memory	0.61*	–	0.08	0.19*	−0.14*	0.34*	−0.15*	−0.02	0.23*	−0.02
3	Screen exposure (age)	0.05	0.04	–	−0.13*	−0.36*	0.13*	0.01	−0.27*	0.14*	−0.05
4	Device ownership	0.30*	0.22*	−0.13*	–	0.06	0.17*	0.01	−0.06	0.22*	−0.04
5	Screen-time t1	0.02	0.05	−0.35*	0.08	–	−0.05	0.01	0.64*	−0.21*	−0.02
6	Mental imagery t1 (acc)	0.71*	0.63*	0.08	0.20*	0.10	–	−0.26*	−0.12	0.35*	−0.20*
7	Mental imagery speed t1 (ms)	−0.34*	−0.29*	0.01	−0.02	−0.04	−0.36*	–	−0.01	−0.12	0.27*
8	Screen-time t2	−0.04	0.15*	−0.27*	−0.03	0.66*	0.07	−0.07	–	−0.17*	−0.04
9	Mental imagery t2 (acc)	0.54*	0.51*	0.10	0.25*	−0.06	0.58*	−0.24*	−0.01	–	−0.03
10	Mental imagery speed t2 (ms)	−0.34*	−0.26*	−0.04	−0.08	−0.09	−0.37*	0.33*	−0.13	−0.21*	–
11	Age t1	0.55*	0.69*	−0.03	0.12	0.21*	0.65*	−0.26*	0.24*	0.53*	−0.35*

Note: Correlations above the diagonal have age partialled out, t1 = time 1, t2 = time 2.

**p* < .05.

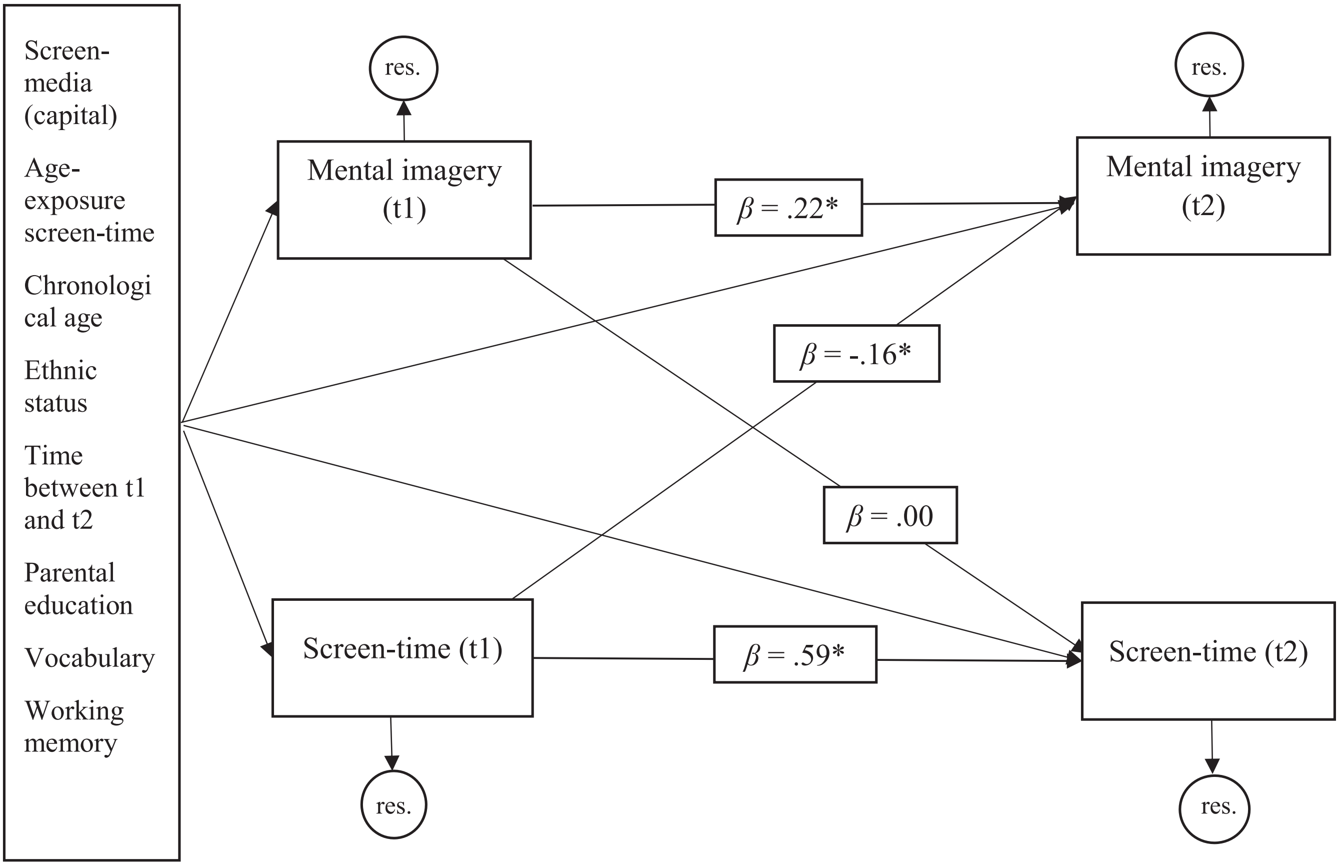

FIGURE 1 Structural equation model depicting cross-lagged panel design testing links between screen-time and mental imagery

TABLE 3 Estimates for influence of control variables on screen-time and mental imagery from structural equation model in Figure 1

	Screen-time t1			Mental imagery t1			Screen time t2			Mental imagery t2		
Variable	*B*	*SE*	*β*	*B*	*SE*	*β*	*B*	*SE*	*β*	*B*	*SE*	*B*
Age (months)	0.02	0.01	0.24*	0.09	0.02	0.34*	0.01	0.01	0.14	0.06	0.02	0.23*
Vocabulary	−0.01	0.02	−0.08	0.40	0.06	0.39*	−0.04	0.02	−0.20*	0.15	0.07	0.17*
Working memory	0.00	0.10	−0.00	0.64	0.26	0.15*	0.11	0.08	0.12	0.36	0.30	0.09
Screen exposure (age)	−0.11	0.02	−0.31*	0.07	0.06	0.05	−0.03	0.02	−0.11	0.00	0.07	0.00
Device ownership	0.06	0.07	0.05	0.17	0.20	0.04	−0.03	0.05	−0.03	0.48	0.22	0.11*
Ethnic status	0.22	0.19	0.07	−0.45	0.50	−0.04	0.15	0.14	0.06	0.68	0.58	0.07
Parental education	−0.43	0.18	−0.15*	0.54	0.46	0.05	−0.01	0.13	−0.01	−0.01	0.53	0.00

*$p < .05$.

associated with screen-time. Age of media exposure was correlated with screen-time and device ownership.

3.2 | Cross-lagged effect between screen-time and mental imagery

We estimated two models to test links between screen-time and mental imagery, one each for mental imagery accuracy and mental imagery speed. In both instances, the control variables were specified to predict the screen-time and mental imagery variables, which contained cross-lagged paths. Beginning with accuracy, the model converged on the 9th iteration. A chi-square value estimating goodness of fit was not significant, $\chi^2(2) = 1.34$, $p = .51$, indicating good model fit. In addition to the chi-square statistic, other fit indices are recommended, namely, that the CFI should be around or above CFI = 0.95, RMSEA around or below 0.05, and that χ^2/df should not be significant against a chi-square distribution (Byrne, 2010). The current estimates indicated excellent model fit, $\chi^2/df = 0.67$, CFI = 1.00, and RMSEA = 0.000 (Byrne, 2010; Kline, 2011). As can be seen in Figure 1, accounting for the host of control variables screen-time at time 1 negatively predicted mental imagery at time 2, whereas the converse was not true. In Table 3, working memory, vocabulary, and chronological age were significant predictors of mental imagery. Both chronological age and age of exposure to screen media also predicted screen-time. To estimate the correlation between screen-time and mental imagery accuracy at time 1, their residuals were covaried. The corresponding correlation was not statistically significant, $r = 0.08$, $p = .23$.

In a second path model, the same model was used with the exception that response latency replaced response accuracy in the imagery task. The model again showed good global fit, $\chi^2/df = 0.64$, CFI = 1.00, and RMSEA = 0.000, but the path of interest, between screen-time at time 1 and mental imagery response latency at time 2, was not statistically significant, $\beta = -0.06$, $p = .35$, nor was the converse path from imagery to screen-time, $\beta = -0.01$, $p = .93$. Additionally, we attempted to partial out the influence of accuracy from the mental imagery reaction time measurements by using these as predictors in the model, and covarying the imagery residuals. The model again showed good global fit, $\chi^2/df = 1.54$, CFI = 1.00, and RMSEA = 0.05, but the path of interest between screen-time and mental imagery response latency—although in the direction predicted by the stimulation hypothesis—was not statistically significant, $\beta = -0.05$, $p = .46$, nor was the converse path from imagery to screen-time, $\beta = -0.01$, $p = .91$. In an alternative procedure, we (natural) log transformed the response latencies, which transformed the skew and kurtosis statistics to near zero for these data; however, the cross-lagged path from screen-time at time 1 to imagery response latency at time 2 was not significant, $\beta = -0.06$, $p = .37$, despite good model fit.

Finally, we examined the possibility of a speed accuracy trade-off operating, whereby participants' response latencies were shorter at the expense of greater accuracy (Heitz, 2014). Product moment correlation coefficients indicated that accuracy correlated negatively with speed, $r = -0.40$ at time 1 and $r = -0.21$ at time 2, $ps < .002$, thus suggesting the opposite of a speed-accuracy trade-off because faster responders were more accurate. To control for developmental influences, the partial correlation coefficients controlling for age between response latency and accuracy were calculated. At time 1, this was negative and significant, $r(248) = -0.28$, $p < .001$), indicating that greater accuracy was linked to greater speed, however, this correlation was not significant at time 2, $r(240) = 0.00$, $p = .95$. Thus, although the data do not indicate a speed-accuracy trade-off, the previous model was re-run, this time including accuracy as a control variable, however, this did not alter the magnitude of the small, negative, but nonsignificant path between screen-time and mental imagery response latency.

3.3 | Passive versus active screen-media and mental imagery

To investigate links between active versus passive screen-media and mental imagery we first examined descriptive statistics pertaining to the daily engagement with the various media. These are presented in Table 4. As can be seen in Table 4, television constituted the most heavily used screen-medium in this sample. The remaining media were scarcely used and, given that they can all be classified as active screen-media, were aggregated into a single measure (i.e. active screen-media) for subsequent analysis. Next two structural path models were calculated, replicating those presented in Figure 1, with the exception that one was calculated for active and the other for passive screen-time. As shown in Table 5, both models fitted the data well and, although the models are not depicted in full due to space constraints, they were highly similar to those in Figure 1. Importantly, both types of screen-media at time 1 showed a similar, statistically significant, cross-lagged link to mental imagery accuracy at time 2.

4 | DISCUSSION

We tested, for the first time, whether children's mental imagery abilities were affected by screen-time, the latter of which now constitutes a significant proportion of the mental activities that children engage in Gingold et al. (2014), Hinkley et al. (2012) and Rideout (2017). Two features of screen-time that have scarcely been investigated are, first, its sensory narrowing (i.e. dominance of the auditory-visual modalities) and, second, its providing ready-made and often rapidly changing images which potentially suppress the active mental life (Valkenburg & van der Voort, 1994). We reasoned that these two features of screen-time might lead to negative associations with mental imagery accuracy via the reduction hypothesis and, conversely, a decrease in response latencies as predicted by the stimulation hypothesis. Furthermore, we reasoned that different (i.e. active vs. passive) screen-media might differentially affect mental imagery. Finally, we tested these hypotheses using a longitudinal cross-lagged panel design, which has the advantage of testing causal pathways without sacrificing ecological validity as in laboratory experiments (Kline, 2011).

TABLE 4 Estimated daily (hours) time spent with various media devices

	Descriptive statistics				
Variables	***M***	***SD***	***N***	**Min**	**Max**
Time 1					
Television	1.01	0.84	237	0.00	4.71
Active media	0.17	0.20	237	0.00	1.14
PC	0.06	0.20	237	0.00	1.64
Smartphone	0.18	0.45	237	0.00	4.57
Tablet	0.33	0.50	237	0.00	3.07
Gaming console	0.10	0.32	237	0.00	2.14
Time 2					
Television	0.76	0.67	197	0.00	3.93
Active media	0.20	0.25	195	0.00	1.30
PC	0.09	0.29	192	0.00	2.14
Smartphone	0.21	0.41	192	0.00	2.36
Tablet	0.32	0.48	194	0.00	3.29
Gaming console	0.16	0.39	193	0.00	2.29

Findings were clear in three regards. First, children who spent greater amounts of time using screen media showed statistically significantly lower performances on mental imagery accuracy, consistent with the reduction hypothesis (Valkenburg & van der Voort, 1994). Thus, our hypothesis that viewing screen-media, by virtue of their providing ready-made mental images that suppress active image generation, receives initial support.

Second, we found virtually no difference in the negative cross lagged-link between screen-time and mental imagery for media classified as active versus passive. On the one hand, this finding is surprising because we expected that more active media would involve mental imagery abilities to a greater extent. However, our supposition has not been verified by empirical evidence, such that it is plausible that even many more so-called active media types might still not involve much active imagery generation, perhaps especially in comparison to other typical childhood experiences (e.g. reading, imaginative play).

Third, contrary with the stimulation hypothesis, screen-time did not relate to children's response latencies on the mental imagery task, as we had posited based on previous work (Dye et al., 2009; Lillard & Peterson, 2011; Nikkelen et al., 2014). Perhaps the dosage of screen media here, which was less than in previous work, may not have been sufficient to induce the greater impulsivity necessary to affect response latencies. In terms of our suggestion that screen-media might train the perceptual system (Dye et al., 2009), with hindsight, it could instead be argued that this likely only applies for certain kinds of games unlikely to have been systematically employed here—especially given that the dominant form of screen-time in this sample was television viewing. Accordingly, we tentatively conclude that screen-time does not stimulate mental imagery performance when this requires mental comparisons of visual/haptic images.

Alongside screen-time, vocabulary, working memory, and chronological age were also significant predictors of mental imagery. At a conceptual level, our mental comparisons task required working memory because the participants were required to compare mental images to solve the task. Accordingly, we controlled in advance for working memory. Although it might be tempting to apply a similar line of reasoning to vocabulary's influence on mental imagery, we consider it unlikely that children's vocabulary knowledge directly constrained task performance. Specifically, although it is true that children would have to know the words in the mental comparisons task in order to be able to image them, stimuli were simple and hence could be expected to be familiar to the children (see Martzog & Suggate, 2019 for stimuli and a discussion of this task). Instead, we suggest that children with larger vocabularies likely have richer perceptual representations in general (Connell & Lynott, 2016; Hargreaves, Pexman, Johnson, & Zdrazilova, 2012; Suggate & Stoeger, 2017), which leads to greater imagery performance. Support for this idea also comes from the contribution of age to mental imagery performance found here, which suggests that a more mature cognitive system relates to performance,

TABLE 5 Model parameters comparing cross-lagged path for active versus passive screen-time (time 1) on mental imagery (time 2)

Model	*df*	X^2	*p*	χ^2/df	CFI	RMSEA	Screen-time to mental imagery (β)
Active screen-media	2	0.10	0.95	0.05	1.00	0.00	−0.12*
Passive screen-media	2	2.66	0.26	1.33	0.99	0.04	−0.11*

*$p < .05$.

extending beyond specific lexical level knowledge directly derived from the imagery items.

4.1 | Theoretical and practical implications

The current study adds to the rapidly growing body of research looking at children's learning and development in relation to screen-media (e.g., Herodotou, 2018). In terms of developmental work, the study's findings contribute to work suggesting that screen-time affects child development in a complex manner, with mental imagery now seemingly a factor to consider amongst others (see Barr & Linebarger, 2017).

According to the current data, the, on average, 1 hr of television viewing per day (ranging up to a maximum of 4 hr and 42 min) across the course of nearly 10 months was enough to negatively affect mental imagery accuracy at time 2. More surprisingly, the corresponding time 1 engagement with active screen-media of up to a maximum of 68 min/day—with a sample average of just 10 min/day—was enough to negatively predict time 2 mental imagery. Turning these figures into total exposure across the course of the study, across 10 months, it is likely that children spent, on average, over 300 hr watching television—with the heavy viewers spending around 1,410 hr. In terms of the reduction hypothesis, perhaps then it is not surprising that links between screen-time and mental imagery were found. Accordingly, mental imagery seems to undergo continual development in the age of samples studied here and seems sensitive to reduced practice at the active generation of mental images. As such, the current work is consistent with studies showing that mental processes and concepts are dependent on a rich array of sensorimotor information and processes (Connell & Lynott, 2016; Hargreaves et al., 2012; Suggate & Stoeger, 2017).

The current study also extends previous work on media learning. Research has examined the conditions under which screen-media contribute to learning, among other factors, focusing on media content presentation, and children's developmental readiness (e.g., Barr & Linebarger, 2017). Although some work has examined the medium itself, for example by comparing reading from e-readers versus books (Chang, Aeschbach, Duffy, & Czeisler, 2015), this study adds mental imagery to this already complicated picture (Barr & Linebarger, 2017). Conceivably, media might be tailored to also encourage mental imagery, or in educational settings to be embedded in other activities that stimulate the sensorimotor system, such as activities that involve outdoor experiences.

4.2 | Limitations and future work

In the current study, we found that children spent, on average, nearly 2 hr/day engaged in screen-media usage. This figure is consistent with previous work for this age group in Germany (Feierabend, Plankenhorn, & Rathgeb, 2017), but is still somewhat lower than that found in the United States, for example (Gingold et al., 2014), although more recent data from the United States also found a mean daily screen-media usage of 2 hr and 19 min. Reasons for this difference are speculative, but might be due to the region in which the study was conducted, which has rural surroundings, low levels of crime, and a culture in which unsupervised outdoor play is still encouraged. Presumably, conducting the study in samples with greater levels of screen-time would result in greater associations with mental imagery due to reduced opportunities to engage in compensatory activities for the effects of screen-time. In a similar vein, in terms of statistical variance, such work might be especially fruitful in the United States where children spend about twice as much time interacting with smart-phones (Rideout, 2017).

Children's daily experiences appear to increasingly include screen-time experiences, which may come at the expense of time engaged in activities that require greater levels of mental imagery (Ennemoser & Schneider, 2007; Weis & Cerankosky, 2010), such as reading (Glenberg, Brown, & Levin, 2007) or imaginative play (Wallace & Russ, 2015). Accordingly, future work could expand on the current findings and test whether home reading activities, for example, offset effects of screen-time and support mental imagery development. In a similar vein, future work needs to examine the sensorimotor consequences of screen-time. In the current paper, we allude to a sensory narrowing during screen-time, in that the visual and auditory senses are stimulated whereas other sensorimotor modalities may be neglected (i.e. proprioception, active motor control, olfaction, gustation, haptics). Accordingly, future work should test sensorimotor development as a function of screen-time and time engaged in sensorimotor activities, also studying neuroanatomical changes underlying these skills (see Hutton, Dudley, Horowitz-Kraus, DeWitt, & Holland, 2019).

In the current study, although we examined a host of control variables, recent work has discovered further factors that link to screen-time, such as self-regulation skills (Cliff et al., 2018) and factors lying behind familial and socioeconomic factors, such as stress. Although, to our knowledge, work has not yet investigated whether these factors link to mental imagery, the current findings need to be tempered by the fact that third variables may explain links found with screen-time. Additionally, we utilized a single mental imagery measure including items targeting visual and haptic modalities. Subsequent work should examine a broader repertoire of mental imagery, including imagery pertaining to other sensory modalities and motor imagery (Borst, 2014). Given links between screen-time and executive functions (Lillard & Peterson, 2011), a more comprehensive battery extending beyond working memory might serve as an additional control. Experimental work in which screen-time is manipulated, controlling for media content and different levels of experience with screen media, could be used to compliment the more ecologically valid longitudinal cross-lagged panel design employed here.

Finally, our findings supported the reduction, but not the stimulation, hypothesis. Concerning the latter, one might speculate that a general increase in processing speed in the visual system from increased screen-time, with its often rapidly changing visual images, might cause a general processing advantage (e.g., Dye et al., 2009), perhaps leading also to a tendency to respond rapidly due to greater impulsivity (e.g., Lillard & Peterson, 2011). However, our analyses at best only resulted in a small, albeit expectedly negative, pathway between screen-time and reaction time on the imagery task.

5 | CONCLUSION

The ability to draw forth mental images, inspecting and comparing these, would appear to be a foundational human faculty lying at the heart of cognitive functioning (Kosslyn et al., 2003). On the one hand, society is becoming increasingly technical and specialized, on the other hand, more dynamic and instable. Accordingly, education will need to ensure that children are creative and innovative, alongside acquiring specialized skills. Mental imagery is precisely an ability that can contribute to novel problem solving and adaptive thinking as well as specialized skills, hence it would seem wise to avoid compromising children's development in this regard. In this sense, the current findings that screen-time negatively affect mental imagery need to be actively replicated and pursued, with a focus on better understanding underlying mechanisms, potentially leading to interventions to reduce screen-media usage (Schmidt et al., 2012), and participation in educational activities to foster mental imagery.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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