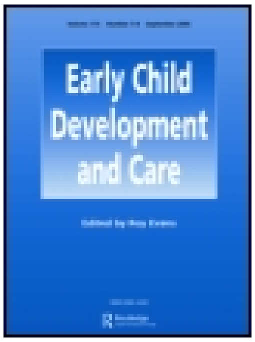

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Early Child Development and Care

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/gecd20

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To cite this article: Sebastian Paul Suggate & Philipp Martzog (2021): Preschool screen-media usage predicts mental imagery two years later, Early Child Development and Care, DOI: 10.1080/03004430.2021.1924164

To link to this article: https://doi.org/10.1080/03004430.2021.1924164

Published online: 16 May 2021.

EARLY CHILD DEVELOPMENT AND CARE
https://doi.org/10.1080/03004430.2021.1924164

Preschool screen-media usage predicts mental imagery two years later

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ABSTRACT

During typical childhood interactions with screen-media, two features are prominent. First, input is dominated by audio-visual signals and second, these predominately provide children with ready-made images, potentially negating effortful mental imagery construction. We present a two-year longitudinal study on a sample of 109 preschool children. We endeavoured to measure media usage and mental imagery development in a differentiated manner, also taking account of control variables and purpose of media use (learning vs. entertainment). Results indicated that children who viewed more media had worse mental imagery skill. Active media usage (e.g. gaming, tablets) and total screen time linked to lower mental imagery performance. Further, both mental images in the visual and haptic modalities appeared equally affected. Findings are discussed in terms of shaping early educational experiences with respect to virtual and three dimensional reality.

ARTICLE HISTORY

Received 9 March 2021
Accepted 26 April 2021

KEYWORDS

Screen-media; media usage; mental imagery; visual imagery; haptic imagery

Mental imagery is thought to be a fundamental human attribute lying at the heart of cognition, culture, problem solving and human endeavour (Kosslyn, Thompson, & Ganis, 2010; Paivio, 1975), developing over the course of childhood (Kosslyn, Margolis, Barrett, Goldknopf, & Daly, 1990). Due to their providing powerful images in the visual and auditory sensory modalities requiring little effortful image construction, the advent of screen-media pose interesting questions precisely for children's mental imagery development (Suggate & Martzog, 2020; Valkenburg & Beentjes, 1997). Specifically, the consequences of the, on average, 2–3 h per day (Feierabend, Plankenhorn, & Rathgeb, 2017; Gingold, Simon, & Schoendorf, 2014) of screen usage for mental image development has scarcely been investigated. Therefore, we present longitudinal data from 109 preschool children studying links between media usage and mental imagery ability two years later.

Mental imagery

Mental imagery refers to the ability to construct, inspect, and manipulate images in the mind's eye, in the absence of external stimuli (Kosslyn, 1994). Accordingly, mental imagery underlies a range of activities, from planning and carrying out motor actions to higher-order cognitive functioning (Kosslyn et al., 1990). Mental imagery is not confined to the visual modality, but is experienced in relation to the six or so other sensory modalities (e.g. balance, kinesthetic, hearing, touching, smelling, and tasting, Andrade, May, Deeprose, Baugh, & Ganis, 2014). Perhaps because of this broad

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imagery content, numerous theories and bodies of work posit that mental imagery relies on sensorimotor networks, neural infrastructure, and skills (Jeannerod, 2001; Kosslyn, Ganis, & Thompson, 2001; Martzog & Suggate, 2019). Sensorimotor skills and corresponding networks undergo rapid and continual development across childhood into early adulthood (Leversen, Haga, & Sigmundsson, 2012). Given links between sensorimotor networks, mental imagery and learning, a broader understanding of mental imagery is essential – however, educational and developmental psychological research has yet to really embrace this key construct (for exceptions see Zwaan & Madden, 2004).

Although not directly referring to mental imagery as defined as involving inspection of sensory representations, research on children's ability to form mental models provides insight into their developing mental imagery skills. Specifically, mental imagery plays a role in models formed during reading (Boerma, Mol, & Jolles, 2016), with mental models lying at the heart of language development (e.g. Zwaan & Radvansky, 1998). Young children can form mental models during story tellings (Fecica & O'Neill, 2010; Nyhout & O'Neill, 2017). Presumably, developing mental models and mental representations is a foundation of human cognition, emerging early in development (O'Neill & Shultis, 2007), although debate exists as to whether these exist as images or in the form of propositions (e.g. Kosslyn et al., 2010). In terms of the current study, it has been shown that learning media can stimulate the formation of mental representations (Schroeder & Kirkorian, 2016). However, as dicussed later, little is know about how the audio-vidual dominance of screen-media affects children's ability to form 'inspectable' mental images.

Screen-media usage

Screen-media usage refers to spending time viewing, interacting with, or listening to media presented on two-dimensional, (usually) LED, displays accompanied by audio signals projected via speakers (Madigan, Browne, Racine, Mori, & Tough, 2019; Webster, Martin, & Staiano, 2019). A challenge for researchers exists in trying to categorize the wide range of activities and content constituting screen-media, with this being incidental or purposeful, passive or active, for multiple purposes spanning entertainment, communication, learning and information gathering, logistic, commercial, and professional formats. However, preschool children generally use screen-media in the form of television or viewing films and gaming (Feierabend et al., 2017), primarily for entertainment and learning purposes. Research often divides media usage into active and passive media (Lin, 2019; Suggate & Martzog, 2020), with passive media requiring no direct input from the consumers, such as when viewing television, whereas active media require input (e.g. gaming, internet usage).

An established body of work has investigated potential benefits and costs of screen-media. In terms of benefits, studies demonstrate that, depending on age and content, children and adults can learn from screen-media (Barr & Linebarger, 2017). Educational software has also shown some success in school settings (Cheung & Slavin, 2012) and interactive video games can enhance cognitive control in adults (Anguera et al., 2013; Powers, Brooks, Aldrich, Palladino, & Alfieri, 2013). Specifically, prompts provided by interactive electronic books can support learning (Strouse & Ganea, 2017), especially for low SES families (Linebarger, 2005). Some work demonstrates that screen-media can improve children's vocabulary (Rice, Huston, Truglio, & Writhgt, 1990), narrative skill (Linebarger & Piotrowski, 2009), and copying (Kirkorian et al., 2020). Although very young children have difficulty acquiring new words from screen media (Krcmar, Grela, & Lin, 2007; Robb, Richert, & Wartella, 2009).

In terms of potential costs, multitasking and rapid changes inherent in media usage negatively affect executive functions in both adults (Ophir, Nass, & Wagner, 2009) and children (Lillard & Peterson, 2011; Nathanson, Aladé, Sharp, Rasmussen, & Christy, 2014), including attention-deficit hyperactivity disorder symptomatology (Nikkelen, Valkenburg, Huizinga, & Bushman, 2014) and self-regulation (Cliff, Howard, Radesky, McNeill, & Vella, 2018). Early use of passive media can also negatively influence language development (Christakis, Zimmerman, & DiGiuseppe, 2004). Generally speaking, media for entertainment purposes appears to be more detrimental than that for learning purposes, providing a further distinction worthy of study in children's media usage.

Screen-media usage and mental imagery

Given that screen-media usage in early childhood is dominated by media – media which often provide children with ready-made content – an interesting question arises as to what effect these have on mental imagery. Indeed, transfering learning from media into the real-world can be cognitively challenging for children (Kirkorian, 2018). The contrast can be made apparent by considering reading or language experiences, in which children have to form their own mental representations arising from language (Sadoski & Paivio, 2013; Zwaan & Madden, 2004). Theoretically, it would be expected that screen-media usage would provide reduced opportunities to practice forming mental images (Suggate & Martzog, 2020), yet evidence is scarce. Additionally, screen-media generally provide audio-visual experiences, giving rise to the idea that effects might be differentiated according to the modality of mental imagery in question.

In the first instance, providing indirect evidence of how media affect mental imagery, studies on links between television and day-dreaming/creative imagination have been conducted (Valkenburg & Peter, 2013; Valkenburg & van der Voort, 1994, 1995). These have found that children perform more poorly on measures of creative and divergent production after viewing a television *versus* hearing a radio programme (Valkenburg & Beentjes, 1997). In a study with a large sample of children, television viewing affected both the content of day-dreaming and reduced its occurrence (Valkenburg & van der Voort, 1995).

To our knowledge, only one study has examined the effect of screen-media on objective and direct measures of mental imagery. Suggate and Martzog (2020) studied the mental imagery development and screen-media usage of 266 children over the course of one year. To measure mental imagery, they used a mental comparisons task (Martzog & Suggate, 2019), in which participants had to call forth one image and then a second, to then compare these objects on a sensory property (e.g. 'what is pointer, a nail or a pin?'). Suggate and Martzog (2020) found that screen-media usage was associated with lower mental imagery performance one year later, for both passive and active media. However, no work has examined whether different modalities of mental imagery are differentially affected. Specifically, it would seem intuitive that mental imagery for visual in comparison to haptic imagery might be differentially affected, given that media speak strongly to the first but not to the second.

Current study

Sensorimotor development activities in early and middle childhood (Brandwein et al., 2011; Ernst, 2008), provide the foundation for later cognitive development, including mental imagery (Kiefer & Harpaintner, 2020; Martzog & Suggate, 2019; Pexman, 2019). Rapid advances in analogue and digital technologies constitute fundamentally different experiences for children compared to those available 100 years ago and earlier – experiences that might responably be expected to relate to sensorimotor and corrsponding cognitive development. Mental imagery, being a foundational skill for cognitive development, likely requires active practice to develop, such as when forming images provided by language interactions (Zwaan & Madden, 2004). Conversely, it is likely that screen-media, in particular passive screen-media, may understimulate the mental imagery system by providing ready-made mental images. Previous work, however, has seldom investigated the effect of screen media on mental imagery, with the only direct investigation covering one year of development (Suggate & Martzog, 2020).

Accordingly, we present a study of the longitudinal influence of screen-media on mental imagery development in a cohort of 109 preschool children across two years. Studying screen-media and mental imagery across two years would be a logical extension to previous work (Suggate &

Martzog, 2020) and was the maximum possible due to the duration of the current study and the corresponding Covid-19 pandemic. We included the mental imagery task used by Martzog and Suggate (2019) because this provides an objective measure of image generation and inspection. As noted, screen-media provide strong audio-visual experiences, accordingly we test the novel idea that haptic imagery is differentially affected by screen-media than visual imagery. Additionally, we also included a further measure of mental imagery investigating image transformation, to test whether an additional imagery construct was similarly affected. Finally, we also took a more differential look at media usage than previous work. Specifically, we examined whether media were used for learning or entertainment purposes, speculating that learning purposes might involve more practice at forming images for media content, with the opposite being the case for entertainment media. Second, in a novel step to provide data to validate parent-responses, we included a Media-Titles Test administered directly to the children that tested their familiarity with common media programmes and characters.

In line with the only previous study (Suggate & Martzog, 2020), we expected negative links between media usage and mental imagery to be found across two years. We further expected negative links to be greater for the haptic imagery items, particularly for passive media usage.

Method

Participants

Participants in this study comprised originally 153 children at the beginning of the study. However,44 could not be tested two years later due to the implementation of a nationwide COVID-19 lockdown and school closures. A small proportion ($n = 9$) were lost to the study due to their families moving away, or because the parents withdrew from the study ($n = 1$). Of the remaining number of children ($n = 109$), 51% were boys and 87% were right-handers. Parents indicated that 77% spoke exclusively German at home and 45% of the mothers and 35% of the fathers had obtained a University degree or equivalent, which is higher than the German average for adults holding a university degree in Germany in a similar age range 32% (Federal Bureau of Statistics, 2019). Children were aged 57.76 ($SD = 10.64$) months at the beginning of the study, and were 79.86 ($SD = 10.67$) months old by the end of the study, with 63.2% having graduated into elementary school. Given that the sample was reduced due to the Covid-19 closures, we calculated post-hoc power tests. Assuming an $R^2 = .25$ and 10 predictors (media usage variables and controls), our models could be expected to have adequate, power = .98 (Soper, 2020).

Procedure

Children were tested individually by trained researchers and the second author in their educational institutions as part of a longitudinal study that was planned to span three points in time, one year apart giving rise to two years between the first and final assessments. The first testing took place in the school year 2017/2018, and of the current data, media usage, vocabulary, and working memory were measured. In the original study that included tests of sensorimotor and fine motor skills as part of a larger study, between two and three testing sessions were required, each of approximately 20 min, so as to not overtax concentration spans. Two years later in 2019/2020 the mental imagery measures were administered (alongside sensorimotor and fine motor measures not reported here). Parents completed questionnaires, at each time point parallel to data collection, providing information on their children's screen-media usage and demographic data, however, an insufficient number were returned at the second time point to include in the current study. Ethical approval was obtained from the Ministry of Education prior to conducting the study and written consent was provided by the parents of participating children, followed by the latter's verbal assent.

Measures

We measured demographic data and media usage using parent questionnaires, and mental imagery and general vocabulary in individual testing sessions with the children, as detailed below. Demographic data entailed questions on parents' highest educational degree, country of birth, and home language were obtained from a parent questionnaire.

Screen-media usage. The parent questionnaire also measured children's media usage (see Suggate & Martzog, 2020). To estimate media usage, we used a semi-diary format to increase accuracy of reporting (Reinsch, Ennemoser, & Schneider, 1999), asking about typical usage at various times of the day (i.e. before school/preschool, in the afternoon, and in the evening, and then on the weekend), but collecting usage intervals with Likert scales. The purpose of this approach was to encourage more specific responses tied to daily routines, while collecting data on an easily quantifiable Likert scale. Additionally, we asked about the amount of time spent on various devices, including televisions, computers, tablets, play-consoles, and smartphones, which allowed us to calculate use of passive (i.e. television) vs. active media (i.e. computers, tablets, play-consoles, and smartphones). We also asked parents (a) how old children were when they first began using the various appliances to determine the effect of long-term exposure and (b) whether media were used for entertainment, learning, or communication purposes (the latter was dropped from analyses due to floor effects).

Media usage time was rated on a 6-point Likert scale for each medium (no media usage, < 30 mins, < 1 h, < 2 h, < 3 h, > 3 h, and on the weekends categories extended to 5 h per day). An equal-interval sum score across all media was estimated, with the total value indicating the number of hours across the five media formats (i.e. television, smartphone, computer, tablet, game-console). Internal consistency in usage across the times of day and media was $\alpha_{cr} = .51$. Age of first screen-exposure 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 5 to 40.

Media-Titles Test. To include an additional behavioural measure of screen-exposure we directly captured children's knowledge of characters from typical movies and series using a Media-Titles Test. To do this, we adapted a procedure that had been used earlier (McIlwraith & Schallow, 1983; Rimal, Figueroa, & Storey, 2013) and presented the children with pictures of movie charters across 23 trials. For each picture the child was asked about the movie (do you know the movie______?). The selection of the movies was based on a review of channels known to be most preferred by German preschool children, including items such as Kika, Super RTL, RTL, Disney Channel, and Nickeldeon. Internal consistency was excellent, $\alpha_{cr} = .89$.

Mental imagery. We used two measures of mental imagery, focusing on generation and inspection (mental comparisons task) and manipulation (mental transformation).

Mental comparisons. We employed a mental comparisons task (Martzog & Suggate, 2019) based on previously developed mental size comparisons tasks (Moyer, 1973; Paivio, 1975). 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?'). 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 41 items, 14 of which pertained to the visual modality (i.e. shinier) and 24 to the haptic modality (i.e. scratchy, and something best translating as 'needlier'), with three being visual-haptic (i.e. pointier). The task was administered using a computer with children hearing the stimuli through headphones and responding by pressing large buzzers connected to a laptop. Internal consistency was adequate for accuracy, $\alpha_{cr} = .85$, and reaction time, $\alpha_{cr} = .92$.

Mental transformation. To assess a form of mental imagery that is more reliant on processes of manipulation than the mental comparisons task, we used a procedure first introduced by Finke and Slayton (1988). Children inspect a number of different object components distributed across a sheet of paper (e.g. triangle + square) and are then asked to integrate them into a complete object (e.g. house). The test comprised 19 items which were developed according to the criteria that: (a) preschool children should be familiar with the objects, (b) provide a clear, distinct solution, (c) represent different degrees of difficulties by including more components as the test progressed, and (d) items should not be solvable by characteristic object features (e.g. chimney emitting smoke on a triangle in a house task). If a child did not provide an answer within 10 s, then three possible answers were shown and children were to choose one that was correct. Imagery performance was captured by measuring accuracy and reaction time across each of the 19 items. A second score was calculated based on the number correct using the response alternatives, which, given that this could only occur if the first was not responded to correctly, negatively correlated with the main score. Internal consistency were good for accuracy, $\alpha_{cr} = .61$, and excellent for reaction time $\alpha_{cr} = .87$. The test was only administered at time 2.

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 $\alpha = .89$.

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 $\alpha = .78$.

Data analyses

Data were analysed using multi-level linear models because, in comparison to classic regression, these allow item-level intercepts (for each imagery item), which we reasoned would prove more sensitive to detecting subtle effects of media-usage on mental imagery. Additionally, this allowed us to overcome the difficulty present in reaction time research of including all data, even incorrect responses, by including these as item-level predictors (Ranger, Wolgast, & Kuhn, 2019). Accordingly, we conducted models with two levels, an item level random intercepts and modelled with mental comparisons accuracy as a fixed effect, and a subject level containing total media usage (hours), home language, working memory, and vocabulary control variables. Working memory was included as a control variable because of the role that this plays in mental imagery, along with vocabulary, as a proxies for general cognitive functioning. Further, we included learning and entertainment media in the analyses, and their interactions with total media usage to represent that children who spent, for example, all of their 10 min a day on entertainment media were treated differently to those who spent half of three hours a day on entertainment media.

Results

For some children, parent questionnaires were not returned at time 1, but these had been completed one year later. Given the strong correlation between total media usage across one year, $r(88) = .55$, $p < .001$, these data ($n = 6$) were imputed from data collected via a parent questionnaire administered 10 months later. Depending on the specific analysis, the sample size is lower than 109 due to missing data, because it was possible that specific parts of the parent questionnaire were not completed, whereas other parts were. Descriptive statistics for the media and control variables are presented

Table 1. Descriptive statistics for the screen-media variables, working memory, and vocabulary.

Dependent variable	*N*	Min	Max	*M*	*SD*	Skew.	Kurt.
Total media usage (hours)	109	.00	9.14	1.58	1.29	2.24	10.01
Passive media (hours)	109	.00	4.71	.95	.83	1.90	5.77
Active media (hours)	109	.00	4.57	.63	.81	1.93	5.00
Learn media (rating)	109	.00	7.00	1.74	1.58	.85	.42
Entertainment media (rating)	109	.00	12.00	3.42	2.07	1.40	3.98
Age began using media	108	12.00	32.00	22.17	4.21	-.12	-.61
Media-Titles Test	103	1.00	21.00	12.21	5.46	-.28	-.97
Vocabulary	103	4.00	35.00	16.494	5.41	.23	.50
Working Memory	95	0	4	1.62	1.29	-.26	−1.56

Note. Kurt. = kurtosis, Skew. = Skewness.

in Table 1 and correlations between the variables in Table 2. As can be seen, there is minimal evidence of marked deviations from normality in the data.

Turning to the mental comparisons data, we first sought to exclude random guessing, marked by a quick response time and a low response accuracy. Thus, all responses faster than 420 msec were capped at 420 msec. The threshold of 420 msec was determined by finding the point at which responses across all participants were less than 75% correct, which applied to responses quicker than 420 msec. Additionally, because these data are part of natural response variation, we capped, as opposed to excluding, these. Applying the same procedure to the upper end, found that responses slower than 5800 msec were only 75% accurate, so these were also capped at 5800 msec. Descriptive statistics for the mental imagery tasks are presented in Table 3.

In Table 4 we present the models on relations between media usage and mental imagery as a function of learning and entertainment media and total screen time. As can be seen in Table 4, total media usage was associated with a slower response latency on the mental comparisons task, although this was offset somewhat via an interaction with entertainment media usage. Models using the Media Titles Test did not find that this contributed uniquely, no did it correlate with media usage (see Table 2), hence to preserve power this was not included in the multilevel modelling. Additionally, relations were similar for haptic and visual imagery. In Table 5, models testing for links between active versus passive media are presented. Active media usage predicted less mental imagery performance two year later. Finally, in Table 6, we tested whether media usage related to mental imagery accuracy (without time components) on both the mental comparisons and the imagery transformations task. In these analyses, media usage was not a significant predictor.

Discussion

In the current study, we investigated whether screen-media differentially influenced mental imagery, using a two-year longitudinal design. One feature of the current design is that we measured media usage in a differentiated manner, accounting for both the daily exposure, the age at which this began, whether media were used for learning or entertainment, and passive versus active media use. Consistent with previous work (Suggate & Martzog, 2020), we found that children who used more media had worse mental imagery, as measured by the mental comparisons task, but not on the mental transformation task. This provides further support for the idea that screens appear to take over some of the work of active image generation, perhaps leading this to be suppressed (Valkenburg & Beentjes, 1997).

Contrary to the hypothesis, we did not find that media usage related differentially to haptic and visual mental imagery. Both tasks showed similar links to screen-media, being similarly affected by active media and total media usage. One likely reason for this is that haptic and visual mental imagery correlated highly ($r = .82$). Additionally, in contrast to Suggate and Martzog (2020), response latency instead of accuracy related to media usage. This difference may be due to the broader age group in their study, which perhaps generated more heterogeneity on the imagery measure.

Table 2. Correlation coefficients between media usage (Time 1) and mental imagery measures (Time 2).

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Mental comparisons (msec)	1	.29**	.96**	.01	.04	-.04	.04	.07	-.01	-.05	-.09	-.02	.02	-.17	.07
2	Mental comparisons visual (msec)		1	.81**	.02	-.01	.04	-.01	.02	-.03	-.06	-.02	.010	.02	-.13	.09
3	Mental comparisons haptic (msec)			1	.02	.08	-.09	.07	.13	-.02	-.04	-.14	.00	.05	-.16	.03
4	Mental comparisons (acc)				1	.16	.14	.04	.08	-.02	-.09	-.03	.13	.25*	.29**	.33**
5	Imagery Transformation (acc)					1	-.20*	.02	.05	-.02	.14	.02	.16	.25*	.37**	.11
6	Imagery Transformation (msec)						1	-.06	-.07	-.02	-.10	.19	-.01	.04	-.18	.12
7	Total media usage (hours)							1	.79**	.78**	.21*	.18	.00	.12	.00	-.04
8	Passive media (hours)								1	.23*	.05	.01	.12	.14	.09	-.02
9	Active media (hours)									1	.29**	.27**	-.12	.05	-.10	-.05
10	Learning										1	.28**	.10	.05	.09	.09
11	Entertainment											1	.11	.01	.18	.13
12	Media Titles Test												1	.45**	.51**	.39**
13	Age													1	.51**	.50**
14	Vocabulary														1	.62**
15	Working memory															1

* = $p < .05$.
** = $p < .01$.

Table 3. Descriptive statistics for the mental imagery variables, working memory, and vocabulary.

Dependent variable	*Observations*	Min	Max	*M*	*SD*	Skew.	Kurtosis
Subject level							
Mental comparisons total (msec)	109	739.51	8269.90	2615.03	1364.13	1.57	4.03
Visual comparisons (msec)	109	620.71	7248.50	2482.99	1339.98	1.29	2.05
Haptic comparisons (msec)	109	945.56	11585.69	3075.10	1829.65	2.16	7.22
Mental comparisons total (acc)	109	5.00	40.00	31.90	6.43	−1.93	4.80
Mental transformation (%)	108	.00	12.00	4.31	2.59	.77	.41
Mental transformation (msec)	108	2.74	18.55	8.31	2.53	.62	2.06
Item level							
Mental comparisons (msec)	4797	420	5800	2329	1650	.92	-.30
Mental comparisons (acc)	4797	0	1	.78	.42	−1.34	-.21

Note. Kurt. = kurtosis, Skew. = Skewness.

Table 4. Multilevel linear models predicting mental imagery performance (mental comparisons) from screen-media.

	Mental imagery (all)			Mental imagery (visual)			Mental imagery (haptic)		
Predictors	Estimates	CI	*p*	Estimates	CI	*p*	Estimates	CI	*p*
Constant	1906.81	540.76–3272.86	0.006	1490.70	120.76–2860.64	0.033	2198.39	728.33–3668.45	0.003
Mental comparisons (acc)	−274.99	−383.83 – −166.14	<0.001	−106.81	−295.22–81.60	0.267	−350.19	−493.81 – −206.56	<0.001
Home language	13.97	1.97–25.97	0.023	13.46	1.54–25.37	0.027	14.19	1.32–27.07	0.031
Vocabulary	−50.55	−89.32 – −11.79	0.011	−44.03	−82.53 – −5.53	0.025	−53.04	−94.61 – −11.46	0.012
Working memory	181.94	17.30–346.57	0.030	174.59	11.09–338.09	0.036	188.77	12.16–365.37	0.036
Media usage (hours)	332.03	87.91–576.15	0.008	342.72	100.20–585.23	0.006	296.16	34.35–557.98	0.027
Age of first exposure	27.43	−17.85–72.72	0.235	28.18	−16.78–73.14	0.219	27.27	−21.30–75.83	0.271
Learning media	−77.57	−350.08–194.93	0.577	−101.66	−372.25–168.92	0.461	−89.70	−381.98–202.59	0.548
Entertainment	152.56	−5.16–310.28	0.058	182.43	25.80–339.05	0.022	126.49	−42.67–295.65	0.143
Media usage X Learning	39.20	−83.57–161.96	0.531	49.34	−72.55–171.23	0.428	44.13	−87.54–175.80	0.511
Media usage X Entertainment	−100.18	−181.44 – −18.92	0.016	−105.06	−185.75 – −24.37	0.011	−94.59	−181.74 – −7.44	0.033
σ^2	1732552.76			1653403.84			1780428.36		
τ_{00}	588812.46 $_{id}$ 187410.75 $_{MC\_Item}$			504034.64 $_{id}$ 169237.74 $_{MC\_Item}$			651724.99 $_{id}$ 192905.13 $_{MC\_Item}$		
ICC	0.31			0.29			0.32		
N	41 $_{MC\_Item}$ 96 $_{id}$			14 $_{MC\_Item}$ 96 $_{id}$			24 $_{MC\_Item}$ 96 $_{id}$		
σ^2	1732552.76			1653403.84			1780428.36		
τ_{00}	588812.46 $_{id}$			504034.64 $_{id}$			651724.99 $_{id}$		

Alternatively, we also allowed inaccurate responses (>75%) and controlled for accuracy in the models, indicating that accuracy was not unimportant here too.

We theorized that screen-media provide, by virtue of their comparatively rapid presentation of audio-visual images, the mental imagery system with reduced opportunities to generate its own mental images (see Suggate & Martzog, 2020). The current data are consistent with this idea, with media generally being associated with reduced mental imagery performance. A second idea is that media present images that dominate images from the three-dimensional environment. For example, research has found that the content of television shows can dominate day-dreaming (Valkenburg & van der Voort, 1994). Perhaps, this property of media is the cause of reduced mental imagery as this replaces children's image generation beyond immediate screen exposure. In support of this idea, active media showed the strongest link to reduced mental imagery, over and

Table 5. Multilevel linear models predicting mental imagery performance from active and passive screen-media.

	Mental imagery (all)			Mental imagery (visual)			Mental imagery (haptic)		
Predictors	Estimates	CI	*p*	Estimates	CI	*p*	Estimates	CI	*p*
Constant	1939.37	540.24–3338.50	0.007	1530.22	122.88–2937.57	0.033	2174.95	674.77–3675.13	0.004
Mental comparisons (acc)	−275.70	−384.56 – −166.85	<0.001	−108.81	−297.35–79.74	0.258	−351.23	−494.86 – −207.59	<0.001
Home language	12.01	−0.32–24.35	0.056	11.71	−0.58–24.00	0.062	12.04	−1.14–25.23	0.073
Vocabulary	−55.38	−94.80 – −15.96	0.006	−48.68	−87.97 – −9.39	0.015	−57.88	−100.02 – −15.75	0.007
Working memory	157.62	−8.24–323.48	0.063	150.11	−15.20–315.43	0.075	160.31	−17.00–337.61	0.076
Passive media (hours)	75.85	−123.86–275.57	0.457	82.76	−116.31–281.83	0.415	53.54	−159.94–267.01	0.623
Active media (hours)	562.12	76.28–1047.96	0.023	567.03	82.66–1051.40	0.022	546.46	27.16–1065.76	0.039
Age of first exposure	34.60	−13.63–82.84	0.160	35.35	−12.72–83.42	0.150	35.83	−15.72–87.39	0.173
Learning media	30.06	−156.27–216.40	0.752	6.94	−178.76–192.64	0.942	38.79	−160.38–237.96	0.703
Entertainment	80.43	−52.14–213.01	0.234	106.97	−25.17–239.11	0.113	57.98	−83.72–199.69	0.423
Active X learning media	−40.45	−189.71–108.82	0.595	−22.04	−170.79–126.71	0.772	−50.36	−209.90–109.18	0.536
Active X entertainment media	−119.22	−251.42–12.98	0.077	−125.27	−257.03–6.50	0.062	−110.54	−251.84–30.77	0.125
Random Effects									
σ^2	1732554.48			1653390.41			1780430.29		
τ_{00}	597914.51 $_{id}$ 187419.17 $_{MC\_Item}$			517654.92 $_{id}$ 169285.08 $_{MC\_Item}$			657206.36 $_{id}$ 192882.61 $_{MC\_Item}$		
ICC	0.31			0.29			0.32		
N	41 $_{MC\_Item}$ 96 $_{id}$			14 $_{MC\_Item}$ 96 $_{id}$			24 $_{MC\_Item}$ 96 $_{id}$		
Observations	3936			1344			2304		
Marginal R^2 / Conditional R^2	0.060 / 0.353			0.055 / 0.332			0.061 / 0.365		

Table 6. Multilevel linear models predicting mental imagery accuracy from screen-media.

	Mental imagery (acc)			Image transformation I		
Predictors	Estimates	CI	*p*	Estimates	CI	*p*
Constant	0.66	0.41–0.91	<0.001	0.22	0.01–0.43	0.039
Home language	0.00	−0.00–0.00	0.234	−0.00	−0.00–0.00	0.693
Vocabulary	0.01	−0.00–0.01	0.097	0.01	0.00–0.01	0.009
Working memory	0.03	0.00–0.06	0.038	−0.00	−0.03–0.02	0.700
Media usage (hours)	0.02	−0.02–0.06	0.385	0.00	−0.03–0.04	0.955
Age of first exposure	−0.00	−0.01–0.01	0.808	0.00	−0.00–0.01	0.579
Learning media	−0.03	−0.08–0.02	0.300	0.02	−0.02–0.06	0.242
Entertainment	0.00	−0.03–0.03	0.897	−0.01	−0.04–0.01	0.244
Media usage X Learning	0.01	−0.02–0.03	0.618	−0.01	−0.03–0.01	0.353
Media usage X Entertainment	−0.00	−0.02–0.01	0.548	0.01	−0.01–0.02	0.313
Image transformation II	-	-	-	−0.36	−0.39 – −0.32	<0.001
σ^2	0.15			0.09		
τ_{00}	0.02 $_{id}$ 0.01 $_{MC\_Item}$			0.01 $_{id}$ 0.03 $_{ImageTransItem}$		
ICC	0.14			0.28		
N	41 $_{MC\_Item}$ 96 $_{id}$			19 $_{ImageTransItem}$ 95 $_{id}$		
Observations	3936			1804		
Marginal R^2 / Conditional R^2	0.025 / 0.160			0.204 / 0.427		

beyond passive media. On the one hand, this could indicate a sub-group of children with a higher media usage because they actively engage with active media. In support of this idea, the current sample report little active media usage, but this correlated with both entertainment and learning media (see Table 2). On the other hand this might indicate that active media, perhaps via a more intense experience with the presented images, suppress mental imagery. However, such an account would need to argue that mental images generated on the basis of experiences from non-virtual reality are somehow more beneficial than those generated from screen media – which has yet to be demonstrated.

Limitations

A key limitation of this study is the loss of data due to the Covid-19 pandemic, which reduced the sample size, preventing us from constructing more complex models such as structural equation modelling or mediation tests. Additionally, our findings are correlational and hence do not prove that media usage causally relates to sensorimotor and mental imagery development. As such, although the findings of this study replicate those of Suggate and Martzog (2020), they are explorative with regard to the types of screen media.

Interestingly, we found effects from media usage for the mental comparisons task but not for the mental transformations task. One explanation for this finding could be that transformation of visual images is stimulated via media, for example in playing games (e.g. tetras). Additionally, our analyses did not indicate that the Media-Titles Test was predictive, indicating that this measure needs further development. Specifically, the Media Titles Test correlated with age, vocabulary, and working memory, but not parent-report media usage, indicating that children with higher scores were more able to remember film titles – perhaps tapping cognitive development as much as screen usage. Finally, the amount of media usage was fairly modest in comparison to levels reported elsewhere (Gingold et al., 2014), which, due to attenuated variance, may have led to reduced associations with sensorimotor development and mental imagery.

Future research and implications

Given links between media usage and mental imagery (see also Suggate & Martzog, 2020), we suggest that future research needs to examine links experimentally. Possible studies could include exposing participants to various forms of media and then testing for suppression effects on mental imagery. The current mental imagery task would lend itself to this methodology because multiple measurements in a short period of time are possible, giving rise to modelling of any suppression and recovery trajectory. With such research, the type of media exposure could be systematically varied (e.g. active, passive, learning media). Further, research should look at developing new mental imagery measures to gage the content and experience of mental imagery as well as performance. Finally, such research as the current study takes research from the principles of cognitive psychology (i.e. embodied cognition, sensory effects on thought, mental imagery) and tests these in real world settings. Continuing this approach has the potential to expand our understanding of the relation between sensorimotor experiences and cognitive development.

Although the correlational nature of this research leads to hesitancy in drawing strong implications for practice, we urge that care is taken to ensure that children's mental imagery development is not undermined by excessive screen-media usage. Specifically, cognitive skill and therewith mental imagery is dependent on experiences garned from a multitude of sensory experiences in three-dimensional reality (Barsalou, 1999; Suggate, Stoeger, & Pufke, 2016). It would follow that such experiences cannot be supplanted exclusively with virtual two-dimensional experiences. Accordingly, early childhood education settings should ensure that a variety of real-world experiences are available (e.g. outdoor play, art, crafts, Suggate & Suggate, 2019). Furthermore, although we are unaware of research directly testing this, free play would intuitively appear to be an activity in which children's mental imagery development is particularly fostered (Golinkoff, Hirsh-Pasek, & Singer, 2006), alongside active listening to stories (Lenhart, Lenhard, Vaahtoranta, & Suggate, 2020; Suggate, Lenhard, Neudecker, & Schneider, 2013). Finally, media designers to consider integrating educational features into apps that encourage sensorimotor movement and active image generation (Hirsh-Pasek et al., 2015)

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This research was supported by a grant from the Software AG Stiftung awarded to the first author [grant number ER-P 11657].

Data statement

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

Ethics

Ethical approval was obtained from the Ministry of Education's ethical review department for research in schools (Influences of Screen-Media on developing sensorimotor skills and cognition in children, No. X.7-BO7106/108/15).

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