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Screen media are associated with fine motor skill development in preschool children

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ABSTRACT

Media form an integral part of children's environments and represent, amongst other domains, altered sensorimotor experiences. Fine motor skills (FMS) represent a fundamental prerequisite for learning and cognition and initial work has begun to show links with screen media usage – although work is scarce and the directionality is uncertain. Therefore, using a cross-lagged-panel design with 2 waves 1 year apart, we examined longitudinal links between media usage and FMS in 141 preschool children. Results show a negative cross-lagged path from media usage to FMS, which was also statistically significant when only newer media were examined, after controlling for parental educational attainment, immigrant status, device ownership, age of first use, working memory, and vocabulary. The study contributes to our understanding of links between media usage and FMS development.

1. Introduction

For many children growing up in today's world, the use of digital screen devices permeates their lives (Feierabend, Rathgeb, & Reutter, 2018; Rideout, 2017). Accordingly, interest in the benefits and costs of this development has led to numerous reports on the effects of screen-time and digital media usage in early development, for example on language (Wright et al., 2001; Zimmerman, Christakis, & Meltzoff, 2007), cognition (Lillard, Drell, Richey, Boguszewski, & Smith, 2015; Zimmerman & Christakis, 2005), and later academic achievement (Kostyrka-Allchorne, Cooper, & Simpson, 2017). One key feature of media usage appears to have been largely neglected, namely, that during media usage sensorimotor experience is fundamentally altered. Specifically, dominant sensory input in the visual and auditory modalities can be expected (Suggate & Martzog, 2021b), whereas purposeful motor activity involving complex actions and manipulations of objects in 3-dimensional space can be reduced to a minimum —perhaps depending on media type (Hinkley, Salmon, Okely, Crawford, & Hesketh, 2012).

Although research indicates that gross motor skill is negatively associated with high screen media use (McArthur, Browne, Tough, & Madigan, 2020; True et al., 2017), it has been argued that newer media tend to encourage fine manual actions stimulating Fine motor skills (FMS) (Bedford, Saez de Urabain, Cheung, Karmiloff-Smith, & Smith, 2016). Conversely, it may be that movements such as button pressing are insufficiently varied, lacking differentiated proprioceptive and haptic feedback, and 3-dimensionality (Latash, Turvey, & Bernshteĭn, 1996; Pesce et al., 2016) to support motor development (Hadders-Algra, 2010). Given the importance of FMS for child development (Grissmer et al., 2010; Martzog & Suggate, 2019b), it is surprising that only a few studies have examined links between media usage and FMS (Bedford et al., 2016; Cadoret, Bigras, Lemay, Lehrer, & Lemire, 2016; Webster, Martin, & Staiano, 2019). Therefore, we present a study to systematically investigate links between media usage and FMS in a cohort of preschool children, using a longitudinal cross-lagged panel design (CLPD), which is ideal for testing for complex developmental relations.

1.1 Media usage

Research on media usage in children is notoriously difficult due to the vast range of media formats and activities that are engaged in, spanning entertainment, learning, and professional purposes (Valkenburg, Peter, & Walther, 2016). Historically, research has focused on either single form of media, in particular television and gaming, or has defined media usage in a broad manner, as time of exposure to any kind of digital screen device, including

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television, computer, gaming consoles, smartphones, and tablets (Madigan, Browne, Racine, Mori, & Tough, 2019; Webster et al., 2019).

Much research has investigated the effects of media usage in early childhood, with a particular focus on educational outcomes and developmental influences. Beginning with educational implications, depending on age and content, children can learn from screen-media (Barr & Linebarger, 2017), however, very young children have difficulty acquiring new words from screen media (Krcmar, Grela, & Lin, 2007; Robb, Richert, & Wartella, 2009). Some work demonstrates that media can improve children's vocabulary (Rice et al., 1990), narrative skill (Linebarger & Piotrowski, 2009), and copying (Kirkorian et al., 2020). Further, educational software has also shown some success in school settings (Cheung & Slavin, 2012). Prompts provided by interactive electronic books can support learning (Strouse & Ganea, 2017), especially for low SES families (Linebarger, 2005).

However, media usage has also been associated with negative developmental outcomes in early childhood resulting in warnings against excessive use in pediatric guidelines (AAP, 2016). Media use has been associated with changes in neural structures (Hutton, Dudley, Horowitz-Kraus, DeWitt, & Holland, 2019), obesity (Ebbeling, Pawlak, & Ludwig, 2002; Schmidt et al., 2012), and visual problems (Huang et al., 2020; Yang et al., 2020). Several features of passive screen media, such as when images change rapidly of encourage multitasking (i.e., consuming 2 media at once), may negatively affect executive functions (Corkin et al., 2021; 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).

Considering the current study's focus on examining the linkage between media usage and FMS development, for the latter, the degree of purposeful and varied motor activity appears important (Hadders-Algra, 2010), as this is essential for developing motor skills (Mavilidi et al., 2018). Thereby, it would seem reasonable to suggest that altered motor practice resulting from increased screen-media usage might affect motor development (Suggate & Martzog, 2020). However, as some of the new media devices require greater FMS input than others, a definition differentiating between newer media (i.e., gaming, smartphone, tablet and PC) and television viewing would appear warranted, as a first step to understanding complex developmental relations.

1.2 FMS

Unlike gross motor skills that represent large movements of the limbs and torso (Piek, Dawson, Smith, & Gasson, 2008), FMS as defined here, pertain to the control and coordination of the distal musculature of the hands and fingers (Bruininks & Bruininks, 2005). This entails a number of specific skills, usually focused on manipulating objects in the environment (e.g., grasping, touching, placing objects, in-hand manipulation). Measures typically focus on manual dexterity, grapho-motor skill, and tapping/speed, with research showing that manual dexterity is probably the strongest predictor of learning (Martzog et al., 2019a). Performance on FMS tasks has been found to relate to children's learning and development in a number of academic and cognitive domains (Fischer, Suggate, & Stoeger, 2020; Grissmer, Grimm, Aiyer, Murrah, & Steel, 2010a; Suggate, Pufke, & Stoeger, 2019; Martzog, Stoeger, & Suggate, 2019b; Luo, Jose, Huntsinger, & Pigott, 2007a) and daily functioning (Backman, Gibson, & Parsons, 1992).

1.3 Links between media usage and FMS

1.3.1 Gross motor skills

Given the lack of research on media usage and FMS, we first review work on gross motor skills then turn to FMS. Television viewing is thought to relate to gross motor skill development via an increase in sedentary behavior (Fakhouri, Hughes, Brody, Kit, & Ogden, 2013), with extreme usage linking to weight problems (Andersen, Crespo, Bartlett, Cheskin, & Pratt, 1998; Gupta, Saini, Acharya, & Miglani, 1994; Poitras et al., 2017, cf. Burdette & Whitaker, 2005cf) and reduced leg strength (Fitzpatrick, Pagani, & Barnett, 2012). Physical activity is linked to cognitive performance and more favorable lipid profiles, which are in turn negatively linked to screen-media usage (Fakhouri et al., 2013; Walsh et al., 2018). However, the relation likely depends to some extent on the content of media usage (e.g., television vs new media), with some games encouraging physical activity (Rosa, Ridgers, & Barnett, 2013).

Regarding studies with younger children, media usage has been associated with performance in general development, although mechanisms are complicated (Kostyrka-Allchorne et al., 2017). Further, studies often use data from parent-report questionnaires, such as from parts of the Bayley Scales of Infant Development (BSID, Lin, Cherng, Chen, Chen, & Yang, 2015) or the Ages and Stages Questionnaire (ASQ, Madigan et al., 2019), which contain self-report bias (e.g., Lin et al., 2015; Madigan et al., 2019; True et al., 2017). Fine motor skills, in particular, are difficult to estimate subjectively and require direct, standardized, and normed assessments.

Turning to direct measures of motor skills, Li and Atkins (2004) examined frequency of computer usage in a sample of 122 preschoolers but found no evidence for links with gross motor skills. However, Kaiser-Jovy et al. (2017) found lower gross motor skills associated with more media usage in 10–14 years old children. Considering single types of media, a prospective longitudinal study with young children identified a negative link between hours of television exposure at age 29 months and performance in gross motor skills at age 5 (Pagani, Fitzpatrick, & Barnett, 2013). Perceived motor competence has also been found to link to media usage and BMI (Niemistö et al., 2019). Finally, Felix and colleagues (2020) found links between high media usage and lower gross motor skills in preschoolers. Generally, it appears that media usage is associated with lower gross motor skills and lower levels of physical activity in preschool age children (Hinkley et al., 2012).

1.3.2 FMS

Reports of general reductions in the FMS of children (Gaul & Issartel, 2016) and adolescents (O' Brien, Belton, & Issartel, 2015) have been attributed, in part, to an increase in the use of screen media devices. At a theoretical level, screen-devices provide an environment that potentially alters FMS development in a nuanced and differentiated manner. Thus, tablets, smartphones and gaming consoles require some form of fine motor control (e.g., swiping or controlling input-devices) which might stimulate FMS, particularly for FM movements specific to the given media (Bedford et al., 2016; Gozli, Bavelier, & Pratt, 2014). Conversely, the specific FMS used during media usage can be characterized as being somewhat repetitive (e.g., button pressing, swiping), probably lacking varied motor programs inherent in many play experiences (e.g., block play, writing, playing in a sandpit). A further idea is that media usage might displace other activities involved in fine motor learning in 3 dimensional settings (Schmidt, Pempek, Kirkorian, Lund, & Anderson, 2008; Vandewater et al., 2006). However, research on these points is lacking and it would seem that a first important step would be to determine whether television and newer media are even associated with lower FMS development.

However, only a couple of studies have examined FMS specifically and, in total, 3 out of 4 studies found negative associations between FMS and media usage. Winterstein and Jungwirth (2006) analyzed data from 1894 preschool children collected in general practitioners' practices prior to school enrolment and found lower grapho-motor skills (figure-drawing task) among preschoolers with more television exposure compared to children with less exposure. However, the authors did not take covariates into account, which is problematic given that screen-media usage is linked with socio-economic status (Feierabend et al., 2018) and that the figure drawing test taps cognitive abilities too. Webster et al. (2019) also report a negative link between media usage (i.e., television, computer games, smartphone, and tablet use) and FMS in a sample of 126 preschool children, even after controlling for covariates (e.g., household income).

Evidence from longitudinal research is crucial for establishing directionality and stability of links, but is scarce and inconsistent. Bedford et al. (2016), found a positive association between retrospectively reported age of first touch screen usage and parent-reported acquisition of FMS (i.e., stacking blocks). However, considering the retrospective study design and the exclusive reliance on parent data, it is possible that parents' estimates of their children's FMS performance and first screen usage are confounded.

Cadoret, Bigras, Lemay, Lehrer, and Lemire (2016) examined a composite measure of general motor skills, including both gross motor and a range of FMS, and observed a negative relationship between media usage at age 4 and motor proficiency at age 7 years. Unfortunately, separate analyses for FMS were not reported, making it impossible to determine whether specifically FMS were affected. Although being longitudinal in nature, the study did not control for covariates or prior motor performance at age 4. Finally, in a recent paper investigating FMS amongst other sensorimotor skills, it was found that media usage negatively linked to FMS in a sample of 117 preschoolers 2 years later (Suggate & Martzog, 2021a). However, this study did not contain a CLPD testing for differential links between newer media and television with FMS.

In summary, a few exceptions aside (Bedford et al., 2016; Li & Atkins, 2004), initial evidence suggests a negative link between media usage and FMS. However, for 3 reasons, previous work does not stringently link media usage to FMS. First, the quality of FMS measures that were used in some studies is questionable. Bedford et al. (2016) relied on data from retrospective parent reports instead of a researcher-administered measure and the "draw a figure measure" in the Winterstein and Jungwirth (2006) study is likely confounded with cognitive representations and drawing skill.

Second, studies have not accounted for important covariates such as parental educational attainment and immigrant background, media device ownership, vocabulary, working memory, and age of initial use of screen media (Bedford et al., 2016; Cadoret et al., 2016; Webster et al., 2019; Winterstein & Jungwirth, 2006). Controlling for device ownership, educational attainment and immigrant status provides a better estimate of true effects (Feierabend et al., 2018). Specifically, parental educational attainment likely relates to the number and type of media devices in complex ways, from purchasing power, via app selection (e.g., educational vs entertainment, with commercials vs advertisement-free subscriptions) to device interactiveness (e.g., smartphones, tablets, televisions). In a similar vein, controlling for vocabulary and working memory provides important proxies for general cognitive development (Hodapp & Gerken, 1999) and executive functioning skills (Chan, Shum, Toulopoulou, & Chen, 2008), which link to media usage (Nathanson et al., 2014) and FMS (MacDonald et al., 2016).

Finally, previous research employed cross-sectional designs (Webster et al., 2019), or longitudinal designs without controlling for interindividual differences in prior FMS performance (Cadoret et al., 2016; Pagani et al., 2013). The only experimental study demonstrating a negative effect of screen-exposure on general FMS examined only 1 type of media, namely tablet use (Lin, Cherng, & Chen, 2017). Thus, it is unclear whether media usage generally has a negative impact on FMS or if parents of children with underdeveloped FMS allow for more media usage. Finally, television viewing and newer media may show differential links.

1.4 Current study

Research has recently begun to look at the link between media usage and FMS (Bedford et al., 2016; Cadoret et al., 2016; Webster et al., 2019) for good reasons, given the importance of FMS for development (Backman et al., 1992; Grissmer et al., 2010a; Martzog et al., 2019a; Martzog and Suggate, 2019b; Suggate et al., 2019). Screen devices provide children with experiences that potentially influence FMS development, likely in complex and nuanced ways. Regarding screen-media, 2 possibilities exist. First, these may stimulate FMS development through active and rapid key pressing or swiping movements with the hand and fingers (Bedford et al., 2016; Price, Jewitt, & Crescenzi, 2015). Alternatively, the kinds of FMS experiences possible with media devices might be insufficiently complex and varied to stimulate FMS performance on standardized tests, such that FMS development might either plateau (i.e., no effect), or comparatively decline, if children would otherwise be involved in activities supporting FMS (i.e., displacement). Specifically, Hadders-Algra (2010) argues that FMS are optimally stimulated when motor programs are varied and non-repetitive. However, empirical work on screen media usage and FMS is scarce and methodologically problematic because it lacks longitudinal studies, direct measures of FMS, and needs to treat media in a more differentiated manner.

To shed light on this key issue, we therefore conducted a CLPD study in which both media usage and FMS were measured concurrently at 2 points in time, nearly 1 year apart. A CLPD enabled testing directionality of associations in an ecological yet controlled manner (Kearney, 2017). By using a CLPD, depicted in Fig. 1, we are able to analyze individual change in FMS and media usage across time while controlling for interindividual differences in prior FMS performance and media usage.

Moreover, the design allowed us to test for a possible converse path from FMS performance at the first measurement occasion on media usage at the second occasion. This latter path might, for example, appear if children with lower FMS ask their parents for more media usage to compensate their inability to engage in FMS-based playing activities. Testing both paths also allowed for a more comprehensive picture regarding previous findings from cross-sectional studies. Considering the non-experimental nature of CLPDs, we included a number of potential covariates mentioned in both FMS (Luo et al., 2007a; Roebers et al., 2014) and screen-media research (Feierabend et al., 2018; Kostyrka-Allchorne et al., 2017). In particular, we accounted for: (a) chronological age due to rapid changes in FMS and screen media across development, (b) parental educational attainment and immigrant status, given the role that these play in type and quantity of media usage, (c) working memory and vocabulary as standard cognitive controls in developmental research, and (d) device ownership and initial use of screen-media as important media variables relating to media exposure prior to recruitment in this study.

To illustrate hypotheses, we refer the reader to the CLPD in Fig. 1. Consistent with indications from previous work (Cadoret et al., 2016; Lin et al., 2017; Webster et al., 2019), we expected that media usage would result in lower FMS, as manifested in a significant negative (diagonal) path from media usage at time 1 to FMS at time 2, after taking account of the control variables.

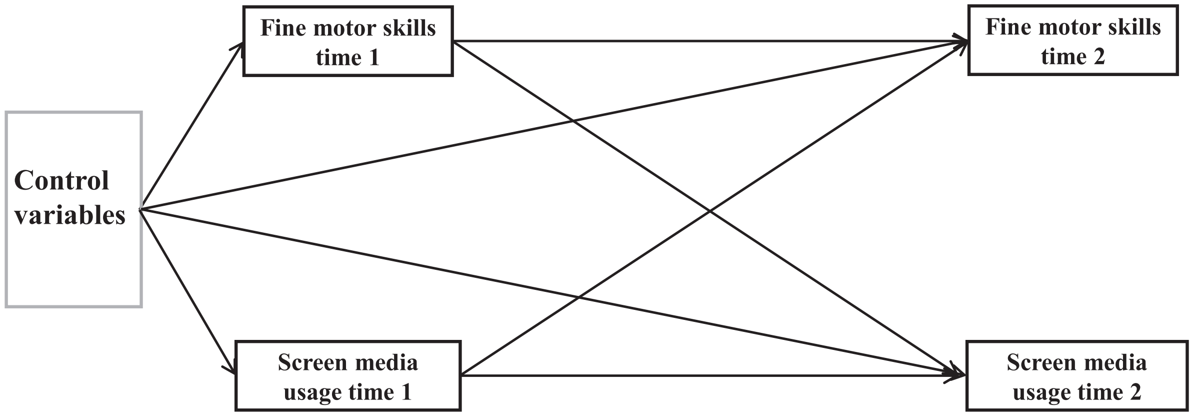

Fig. 1. Hypothesized model for testing links between FMS and media usage.

In terms of television viewing and newer media, due to an anticipated lack of FMS activity, we expected negative cross-lagged links between television viewing and FMS. In a similar vein, given that newer media are less likely to afford varied 3-dimensional motor actions thought necessary to stimulate FMS (Hadders-Algra, 2010), we also expected negative links to FMS.

2. Methods

2.1 Participants

The sample comprised 141 German preschool children at time 1. A post-hoc power analysis (Model 1 in Table 4, β = .24) indicated a power level of .90 (Faul et al., 2009). The sample had an age range between 35 and 82 months (M = 4 years and 10 months; SD = 11 months) with 50% boys (note that children can remain in preschool until they are 6 in Germany). Children attended preschools in a small city in Germany at time 1, with 34 children moving into elementary schools at time 2. So as to avoid floor effects and unnecessary stress for the children, preschool teachers did not hand out consent and information forms to children with severe disabilities that would prevent them from being able to complete the tasks. Nineteen percent of all participating children had at least 1 parent born in a foreign country (mostly Eastern Europe) but all children spoke German. Forty-one percent of the children's parents held a university degree or equivalent. The national average percentage for individual adults holding a university degree in Germany in a similar age range currently is 32% (Federal Bureau of, 2019). Hence, the current sample was more highly educated. Some data were missing at time 2 (i.e., 7.8%, absent or families moved away), with children whose data were missing showing no statistically different performance on measures of vocabulary, working memory, FMS, or media usage at time 1.

2.2 Design and procedure

The study was designed as a longitudinal CLPD. Accordingly, data were collected on media usage and FMS variables at time 1 and time 2, with the control variables only at time 1. The mean interval between both time points was 10.37 (SD = 1.54) months. Children were tested in single sessions by the first author and trained research assistants in a quiet room at their educational institutions. Parents completed questionnaires, at 2 time points parallel to data collection, providing information on their children's media usage and demographic data. Between 2 and 3 testing sessions were required, each of approximately 20 minutes, so as to not overtax attention spans.

As required by policy, the appropriate ethics procedure involved approval from the Ministry of Education for a large longitudinal study (Bayerisches Staatsministerium für Wissenschaft und Kunst; protocol number: X.7- BO7106/108/15). This comprised a rigorous process examining all aspects of the ethics procedure (e.g., informed and voluntary consent, procedures, economy and confidentiality of data collection, potential benefit to society). Prior to conducting the assessments, written consent was provided by the parents of participating children, followed by the latter's verbal assent.

2.3 Measures

2.3.1 FMS

FMS were measured using the German Version of the Movement-Assessment-Battery for Children (Movement ABC; Petermann, Bös, & Kastner, 2011). The Movement ABC is a widely used test of gross and FMS with normed versions published in multiple languages. The Movement ABC comprises tasks tailored to children's developing general FMS (e.g., reaching, grasping, manipulating, transporting, releasing) in 3 different task (coin posting, bead threading, tracing). Children completed the 3 tasks with their dominant hand. Tasks comprised (a) posting coins through a slot, (b) threading beads, and (c) tracing through a maze by drawing in between 2 parallel lines. To avoid ceiling effects in Grade 1, as per test instructions, for those children who shifted from preschool the following year, children were presented with more challenging tasks, namely (a) inserting pegs into a pegboard, (b) weaving a thread through holes, and (c) tracing through a maze. According to the test manual, the FMS measures demonstrate good to excellent interrater reliability, test-retest reliability, and construct validity (Petermann et al., 2011).

To create comparable, robust norms that account for age and test version in a differentiated manner, continuous norming procedures were used (Lenhard, W [Wolfgang], Suggate, & Segerer, 2018). In a first step, raw values for each task were transformed into age adjusted norm values (T-scaled, M = 50 and SD = 10) using continuous norms generated from hundreds of research data (depending on test, n = 212–632, mostly from ages 3 to 7, with some children as old as 11 years) collected in our research lab over different studies (Lenhard et al., 2018). We preferred these continuous norms to the published norms because of the comparatively small sample sizes in the published norms and the categorical approach to norming adopted, which likely misestimates performance at the extremes (Lenhard et al., 2018). This allowed us to calculate a FMS composite score represented by the arithmetic mean across the individual subtests. Furthermore, with this procedure we accounted for differences between FMS tasks in the preschool sample at time 1 and at time 2 because some children who had entered school at time 2 received different FMS tasks, as per test instructions. T-values were negatively coded due to the type of tasks (i.e., lower scores = faster response) with lower values indicating better performance. Therefore, to facilitate interpretation these were reverse coded for the remainder of the paper.

2.3.2 Media usage

A parent questionnaire was used to measure children's media usage (see Suggate & Martzog, 2020). To estimate media usage, we adopted a semi-diary format to increase accuracy of reporting (Reinsch, Ennemoser, & Schneider, 1999). This measured usage at 3 time periods in a typical day (i.e., before school/preschool, in the afternoon, and in the evening) and on the weekend. In doing so, we wanted to encourage more specific responses by using daily routines as a cue, while at the same time collecting data on a Likert scale as opposed to diary recordings or intrusive time sampling.

Media usage time was rated on a 6-point Likert scale for each medium (no media usage, < 30 minutes, < 1 hour, < 2 hours, < 3 hours, > 3 hours, and on the weekends, categories extended to 5 hours per day). An equal-interval sum score across all media was estimated, with the total value indicating the number of hours across the 5 media formats (i.e., television, smartphone, computer, tablet, game-console). Given the low frequency of media usage in the sample, especially for newer media, a composite scale was created to represent newer media usage while avoiding floor effects. Thus, an equal-interval sum score across all media, weighted according to days to create a representative average (such that week days counted one fifth and weekend days 1 seventh), was estimated, with the total value indicating the number of hours across the 5 media formats (i.e., television, smartphone, computer, tablet, game console). Given that newer media and television viewing might have different influences on FMS development, we additionally created newer media usage and television viewing scales by separating those media that required a direct FMS input into newer media usage (i.e., smartphone, computer, tablet, game-console) from television viewing.

2.3.3 Covariates

To control for key covariates within the children's home environments we assessed parental education, immigrant status, device ownership, and initial use of screen media, on the one hand, and indicators of general and cognitive development on the other, including age, vocabulary and working memory.

2.3.4 Device ownership. Device ownership was measured with the parent questionnaire. Device ownership was the sum score of whether any of 7 given devices were present in the household (i.e., television, computer, internet access, laptop, smartphone, tablet, game console). Thus, 3 smart-phones would only count once because the rating captured device type, not the absolute number. Accordingly, scores ranged between 0 and 7.

2.3.5 Age of first use. The parent questionnaire was further used to assess age at which regular media use began (age of first use) to control for a potential role of the age of initial use of media on FMS and current media usage. Age of first use 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.

2.3.6 Parental education and immigrant status. To capture parental educational attainment and immigrant status, data were also drawn from the parent questionnaire. Regarding parent education we used educational attainment as reported by parents and computed a dummy variable indicating whether parents attained a university degree (1 = yes, at least 1 parent, 0 = no). Similarly, a dummy variable was used to represent immigrant status, with no immigrant background being represented by 0 and 1 indicating that at least 1 parent was not born in Germany.

2.3.7 Vocabulary. Children's vocabulary was assessed using the vocabulary test at time 1 from the Kaufmann ABC (Kaufman & Kaufman, 2015), administered in paper and pencil format. The Kaufmann ABC is a well-established measure of intelligence used in many different countries. 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 3 correct responses. The maximum number of points possible was 39 and the internal consistency of the vocabulary test was estimated at $\alpha = 0.89$.

2.3.8 Working memory. A backwards digit span task was used to assess children's working memory (Endlich et al., 2017), administered in paper and pencil format and taken from a widely used German test. In total, there are 9 items of 3 different lengths (i.e., 2, 3, and 4 numbers), ordered according to difficulty with a ceiling criterion of 2 consecutive errors. The maximum number of points obtainable was 9. The internal consistency of the working memory test was estimated at $\alpha = 0.86$ at time 1.

2.4 Data analysis

CLPD were used to test for links between media usage and FMS, in both directions, across time, and while accounting for key control variables. The model was developed a priori and is depicted in Fig. 1. The key feature is that the link between FMS at time 1 and time 2 is modelled along with the corresponding link between media usage at time 1 and 2. Thereby, by including cross-lagged paths, a change in time 2 variables as a function of the opposing construct at time 1 can be estimated. Specifically, we can test whether greater media usage is associated with reduced FMS at time 2, controlling for changes in media usage and FMS across both points in time. Further the model contains paths from each of the control variables to both time 1 and time 2 FMS and media usage variables (i.e., with individual paths from each predictor, but simplified for graphic representation in Fig. 1).

All models were specified and run with AMOS v. 23 (Arbuckle, 2019) including missing values through full maximum likelihood estimation. All subsequent analyses are based on 2-tailed tests with alpha level set at .05. Maximum likelihood estimation was used because it has been shown to perform well in the absence of extremely large samples (Schermelleh-Engel, Moosbrugger, & Müller, 2003). Model fit was evaluated against global and local fit indices, whereby good global fit is usually indicted by a CFI around or above 0.95, RMSEA should not exceed 0.05, and the ratio of χ^2 /df should not be significant against a chi-square distribution (Byrne, 2010).

To test the hypothesis of a negative influence from overall media usage to FMS development, a cross-lagged path was specified from media usage at time 1 to FMS at time 2. To test a possible inverse influence, a cross-lagged path from FMS at time 1 to media usage at time 2 was specified. To facilitate interpretation of any temporal relation between media usage and FMS, we implemented 2 additional specifications within the path model. First, initial performance levels in both FMS and media usage at time 1 were controlled through autoregressive paths and the influence of the covariates were controlled by predicting their influence on both time 1 and time 2 media usage and FMS. Control variables included parent education, whether parents and children were born

Table 1
Descriptive statistics for fine motor skills (FMS), daily screen time and control variables.

	Time 1				Time 2			
	M	*SD*	Min	Max	*M*	*SD*	Min	Max
FMS	51.03	8.29	29.67	74.00	49.38	5.39	33.33	66.00
Media usage (h)	1.51	1.06	0.00	4.71	1.28	.89	0.00	4.93
Daily television (h)	.92	.78	0.00	4.71	.76	.59	0.00	2.57
Daily use of newer media (h)	.59	.70	0.00	3.07	.53	.75	0.00	3.93
Age (mo.)	58.68	11.25	35	82	-	-	-	-
Vocabulary	16.59	5.23	4	35	-	-	-	-
Working memory	1.59	1.24	0	3	-	-	-	-
Device ownership	5.24	1.36	1	7	-	-	-	-
Age of initial media use	22.02	4.13	11	32	-	-	-	-

Table 2
Correlations between FMS, media usage, and control variables at Time 1 and at Time 2.

	1	2	3	4	5	6	7	8	9	10
FMS time 1	-	.20	-.04	-.03	-.02	-.05	.15	.06	.12	.03
FMS time 2	.21	-	-.16	-.11	-.01	-.02	.01	.03	.05	-.12
Media usage time 1	-.05	-.18	-	.54***	.08	-.32**	-.02	-.10	.05	-.07
Media usage time 2	-.04	-.13	.55**	-	.12	-.19	-.02	-.18	.24	.07
Device ownership	.00	.02	.06	.10	-	-.23	.00	.28	-.15	.05
Age of initial media use	-.08	-.07	-.28*	-.14	-.26*	-	-.08	-.08	-.02	-.06
Working memory	.08	-.10	.03	.05	-.08	.07	-	.46***	-.10	.16
Vocabulary	.01	-.06	-.05	-.11	.18	.05	.58**	-	-.48***	.18
Immigrant status	.12	.04	.05	.24*	-.15	-.01	-.07	-.42**	-	-.07
Educational attainment	.03	-.12	-.07	.07	.04	-.06	.14	.17	-.07	-
Age	-.10	-.21	.10	.13	-.16	.27*	.52**	.44**	.03	01

Note. Age-adjusted correlations are above the diagonal.
*$P < 0.05$.
**$P < 0.01$. *** = $P < .001$

in Germany (i.e., immigrant status), device ownership, age of initial screen-media usage, vocabulary, working memory and chronological age. First, we ran a model to test links between media usage and FMS, check model plausibility and the influence of the control variables. Second, we tested whether newer media and television viewing showed different links to FMS by running 2 separate models for each type of screen time.

3. Results

3.1 Descriptive statistics

In Table 1 descriptive statistics are presented. Skew and kurtosis statistics (not presented in Table 1) indicate that FMS and media usage were approximately normally distributed. Anderson-Darling tests of univariate normality for the overall media usage variables and FMS indicated normality (all ps > 0.10) and a Henze-Zirkler test indicated multivariate normality, HZ = 0.75, $P = 0.09$. In total, 3 children at time 1 and 2 children at time 2 had no media usage. Furthermore, prior to running path analyses, bivariate and age-controlled correlations were computed between FMS, control variables and media usage variables for both measurement points (Table 2).

Regarding FMS, mean scores show a performance increase from time 1 to time 2, t (125) = 2.17, P = 0.03, but media usage did not significantly change, t (92) = 1.67, P = 0.10.

Correlations in Table 2 show the expected relation between FMS at time 1 and FMS at time 2 and an even stronger relation between media usage at both measurement points. Media usage negatively related to FMS. Furthermore, both media usage and FMS were correlated with covariates, although FMS to a lesser degree and mostly not statistically significant. Recall that FMS represent norm scores with age partialled out, hence these do not correlate with age in Table 2.

3.2 Path analyses

3.2.1 Influence of media usage

We ran path analyses to test the hypothesis that media usage has a negative influence on FMS (Model 1). In Table 3, estimates for the influence of covariates on FMS and media usage at time 1 and time 2 are shown. As can be seen in Table 4, the model showed a good global fit (Kline, 2011; Byrne, 2010).

Turning to the autoregressive paths, media usage showed moderate stability across development, $\beta = 0.53$, $P < 0.001$. FMS significantly predicted FMS over time, although stability was lower, $\beta = 0.26$, $P < 0.001$. Cross-sectional correlations between FMS and media usage at time 1 and time 2 beyond the influence of covariates did not exist, thereby facilitating interpretation of cross-lagged paths. An analysis of the cross-lagged paths was more in line with the expected negative association between media usage and FMS development than with the inverse effect. In particular, a positive cross-lagged path from media usage at time 1 to FMS at time 2 indicated a negative influence of media usage that was statistically significant, $\beta = -.24$, $P < 0.01$, and there was no support for a significant inverse influence. The model is depicted in Fig. 2.

3.2.2 Role of television vs newer media

Next, we tested whether newer media (Model 2) vs television viewing (Model 3) related differently to FMS. This was done by adopting the same model as in Fig. 3, with the exception that either television viewing or newer media usage was used to predict time 2 FMS and media use. Model fit indices are presented in Table 4 and the models in Fig. 3. As can be seen in Fig. 3, there was a significant path from newer media at time 1 to FMS at time 2 indicating that newer media were associated with worse performance on FMS measures. Also, for newer media, FMS predicted reduced media usage 1 year later.

Table 3
Estimates for the influence of control variables on media usage and FMS.

	Time 1						Time 2					
	Screen time			FMS			Screen time			FMS		
	B	*SE*	*β*	*B*	*SE*	*β*	*B*	*SE*	*β*	*B*	*SE*	*β*
Age (months)	.03	.01	.30**	-.04	.08	-.05	.01	.01	.16	-.04	.05	-.08
Working memory	-.05	.10	-.06	.48	.82	.07	.03	.09	.04	-.18	.52	-.04
Vocabulary	-.02	.03	-.08	.19	.21	.12	-.03	.02	-.18	.01	.13	.01
Immigrant status	.09	.22	.04	.60	1.83	.03	.21	.18	.10	1.47	1.14	.12
Parental education	-.26	.18	-.12	.56	1.50	.03	.23	.15	.13	-1.22	.94	-.11
Device ownership	.10	.07	.13	.19	.59	.03	.08	.06	.13	.15	.37	.04
Age of initial media use	-.09	.02	-.33***	.12	.19	.06	-.001	.02	-.00	-.01	.13	.00

*$P < .05$.
**$P < 0.01$.
***$P < 0.001$.

Table 4
Global fit indices for path models as a function of media type, showing the cross-lagged paths from media to fine motor skills (β)

Model	Media	β	χ^2	df	p	χ^2/df	CFI	RMSEA
1	Combined	.24*	2.54	4	.64	.63	1.0	.00
2	Newer media	.22*	7.41	4	.12	1.85	.99	.06
3	Television viewing	.12	5.13	4	.27	1.28	1.0	.03

Note. FMS are negatively coded, with lower scores representing better performance.
* $P < 0.05$.
**$P < .01$.

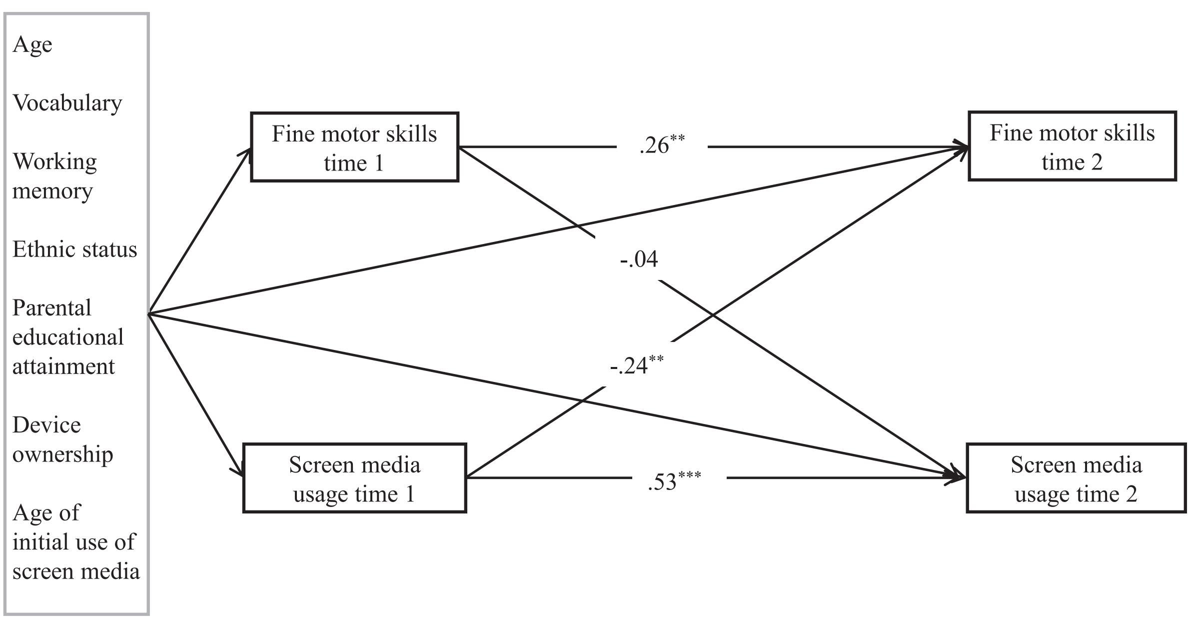

Fig. 2. Path diagram showing cross-lagged links between FMS and media usage. Values represent standardized path coefficients. R^2 for FMS = 0.15 and for media $R^2$0.38. *P< 0.05; **P < 0.01; ***P < 0.001.

4. Discussion

Using longitudinal CLPD data we investigated longitudinal and directional links between screen media usage and the development of general FMS, while accounting for inter-individual differences and key covariates in a sample of preschool children. Results indicated that screen media usage is negatively associated with FMS development across time. Considering that screen media constitute an important factor in children's environments (Biddle, Pearson, Ross, & Braithwaite, 2010), effects on child development are to be expected. Accordingly, it was important to also consider the type of media usage, which we did by dividing media usage into newer vs television media, according to whether fine motor input was likely required. Interestingly, we found that, overall, newer media were associated with lesser FMS development across time, a finding which we return to later. Further, the diagonal path in Fig. 3 from FMS to media usage were significant, indicating also that those who have greater FMS used less media 1 year later.

Results correspond to Gaul and Issartels (2016) findings of a slowed growth rate of FMS in older 4th and 6th grade children in conjunction with media usage and to the general pattern of negative links between media usage and FMS in children (Cadoret et al., 2016; Lin et al., 2017; Webster et al., 2019; Winterstein & Jungwirth, 2006). However, by using a CLPD and considering a host of control variables our results extend previous correlational and quasi-experimental work (Lin et al., 2017), providing a clearer indication of directionality for television vs newer media, controlling for device ownership and age of initial usage.

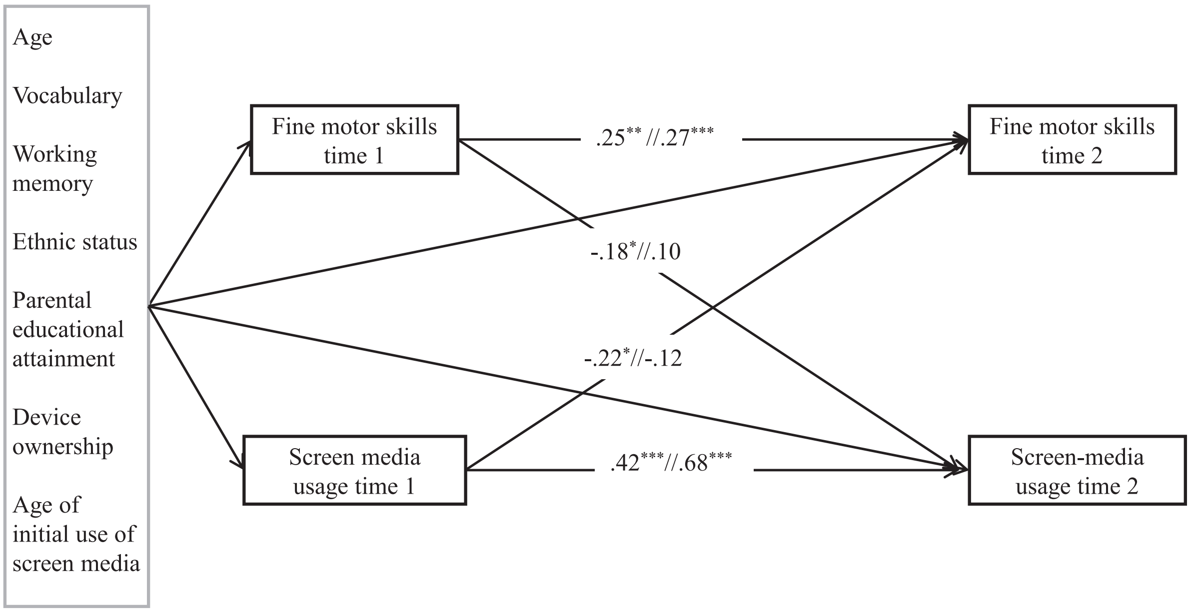

Fig. 3. Path diagram showing cross-lagged links between FMS and media usage. Values represent standardized path coefficients. Path coefficients for newer media precede coefficients for television media separated by //. For the active media model, R^2 for FMS = 0.13 and for active media $R^2$0.35. For the television model, R^2 for FMS = 0.12 and for active media $R^2$0.51. $^*P< 0.05$; $^{**}P < 0.01$; $^{***}P < 0.001$.

The current findings seem initially inconsistent with Bedford et al. (2016), who report a positive association between the emergence of the pincer grip and touch screen scrolling in infancy. However, there are several factors to consider. Methodologically, Bedford et al. (2016) used a retrospective design and data on children's FMS and screen usage from parent-reports on performance on a single FMS task (i.e., stacking blocks). Conceptually, Bedford and colleagues looked at specific aspects of FMS and media, whereas the focus here was on broader media usage and was hence more coarsely grained. Generally, findings from the current study are likely more generalizable to other FMS than Bedford's because proficiency on a more general FMS battery was examined.

4.1 Theoretical implications

The main objective of the current study was to examine directionality between media usage and FMS by using a CLPD and controlling a number of covariates missing from previous analyses. Further, the study provides additional information on at least 3 current issues. First, it adds evidence to the current debate on whether media usage stimulates or suppresses FMS development, which appears particularly pressing considering the high relevance of FMS for the foundations of learning and development (Grissmer et al., 2010a), including cognitive functioning (Martzog et al., 2019a; Martzog and Suggate, 2019b).

Second, the finding that media usage may influence FMS in preschool development is consistent with the idea of FMS being particularly sensitive to environmental influences in preschool (Venetsanou & Kambas, 2010). Younger children have difficulty transferring learning generally (Strouse & Samson, 2021), and in terms of actions linked to FMS, the difficulty in transferring these from 2-dimensional to 3-dimensional media has been demonstrated (Zack, Barr, Gerhardstein, Dickerson, & Meltzoff, 2009). Perhaps this explains why FMS development was associated with media usage. Additionally, the finding that greater FMS was associated with decreased media usage 1 year later is consistent with a functionist perspective (e.g., Suggate & Stoeger, 2017), whereby having greater FMS frees up resources for engaging in other activities than media. Perhaps, taken together with the link between media usage and later FMS, this finding suggests that media displace the opportunities to develop FMS.

Third, although it is conceivable that newer media (e.g., gaming consoles, interactive apps) might train specific FMS (Bedford et al., 2016), the current study suggests the opposite regarding general FMS development. The current finding that the path from newer media to FMS tended to be stronger than from television media appears counter-intuitive and hence worthy of closer consideration. At a functional level, although newer media require fine motor actions (joystick, mouse, etc.) it remains questionable as to whether this support FMS development, beyond task specific skills (e.g., tapping, gaming control operation). As outlined, fine motor actions during gaming or other new media use may lack the variation and complexity found in manual childhood activities (e.g., block-play, crafting, drawing, playing in a sandpit). Alternately, media usage might displace other important learning activities (Schmidt & Vandewater, 2008; Suggate, Pufke, & Stoeger, 2016; Vandewater et al., 2006). Support for this idea derives from the study from Lin et al. (2017) who found a negative effect from a tablet based fine-motor intervention on general FMS while a traditional FMS intervention resulted in positive effects.

However, if newer media are associated with decreased FMS, this intuitively seems inadequate in explaining why television viewing did not result in significant negative links to FMS. Television mostly provides audio-visual sensory experience and other modalities (haptic, proprioceptive, motor) are not directly stimulated. Although research has looked at play behavior during television viewing (Schmidt et al., 2008), we are not aware of direct data on FMS activity during screen viewing. Further, newer screen media might conceivably distort and confuse 3-dimensional spatial mapping during development. Thus, in virtual reality, a small mouse movement rockets the cursor from 1 side of the screen to the other to a level disproportionate to the effort generally required in non-virtual reality. If integration refers to combining information across sensory channels to form coherent mental representations, sensory disintegration might refer to the opposite process (e.g., Suggate & Martzog, 2021a). However, no research has examined whether such a sensory disintegration exists and arises from newer media usage during development.

Finally, although the study provides no general indications of an inverse path from FMS to media usage, children with lower FMS tended to spend more time with newer media. Accordingly, it is likely that younger children's FMS determine media usage with newer media, thereby explaining part of the negative link between FMS and newer screen media in previous research (Webster et al., 2019). Children with lower FMS might feel hesitant to engage in more challenging non-digital FMS tasks such as construction play or painting and instead, if accessible these children might turn to digital gaming. Such a displacement hypothesis could be tested by comparing two groups of children who both viewing media, but 1 group engages in FMS activities and the other does not.

4.2 Limitations and future work

The nature of the current CLPD provides evidence for directionality (Kearney, 2017), but still falls short of demonstrating a causal link between media usage and FMS. In this sense, the low amount of variance explained in FMS at time 2, as reflected in $R^2 = 0.11$ in the overall model (Model 1), indicate that certain variables were likely not measured. Among these variables might be aspects of children's fine motor home learning environment such as types of toys or parent supported participation of children in fine motor activities within the household. Controlled randomized experiments pose logistical and ethical problems because this would require assigning high media usage to non- or low-media users. However, 1 viable option might be quasi-experimental designs that try to reduce media usage, possibly supplementing this with FMS activities.

We found little evidence of newer media usage in our sample, which severely hampered our efforts to examine media type in a more differentiated manner. Additionally, our measure of media usage did not directly capture activities, but instead the time spent on the screen-devices generally. This will doubtlessly prove to be too undifferentiated to take our understanding to the next level in ascertaining how FMS are affected by different screen-media and activities. Further, we measured media usage on an interval scale which may be too coarsely grained and our measure relied on parent-report, which is susceptible to forgetting and social desirability effects. Accordingly, future research should use more differentiated information on different types of screen media activities actually performed on the devices and whether these activities involved FMS (e.g., fine motor activities on smartphones, streaming episodes on newer devices, co-use with peers, or family members).

Finally, results are based on a sample with greater formal educational qualifications than average. Conversely, the proportion of families with an immigrant background other than German was comparatively less pronounced. Conceivably, effect sizes might differ in future studies with different socioeconomic characteristics (Comstock & Scharrer, 1999). In all likelihood, education and socio-economic status relate in differentiated and nuanced ways with media usage, affecting content, purpose, frequency, and device usage. For instance, more recent work on the digital divide, whereby classically more prosperous homes have more media devices and access, suggests that this has shifted from differences arising due to access to media and the internet (e.g., Judge et al., 2006) to how the internet and media are actually used (e.g., Wei & Hindman, 2011).

5. Conclusions

Overall, the current study yields evidence that more media usage relates negatively to FMS development in early childhood. Acknowledging the ubiquitous role of children's FMS in several fields of daily functioning, and the now broad range of possible activities and uses for newer media, future research with more differentiated media measures is required to progress the field.

Disclosures

Credit author statement: Philipp Martzog: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Project administration; Writing - original draft.

Sebastian Suggate: Conceptualization; Data curation; Formal analysis; Funding acquisition; Investigation; Methodology; Project administration; Resources; Writing - second draft; Writing - review & editing

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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