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# Relation between executive functions and screen time exposure in under 6 year-olds: A meta-analysis

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ABSTRACT

Some previous research works have reported potential benefits of screen media use in children aged under 6 years, and others have evidenced that screen media use might be particularly detrimental. To our knowledge, this is the first study to provide the first meta-analytic synthesis of existing research on the relation between overall screen time use and EFs. To address this issue, the current meta-analysis aimed to review the relations between overall screen time and EF in infants, toddlers and preschoolers. A systematic search was done on Web of Science and EBSCO to identify the eligible studies published until January 2023. Fifteen manuscripts with 6922 participants aged 0–6 years were included, and yielded 44 effect sizes. Three-level models were carried out, and the following study characteristics were tested as potential moderators: mean age, percentage of females, EF type, and whether exposure was active or passive. There was no statistically significant association in the relation between overall time use and EF or in the chosen moderators. Nevertheless, the study highlights the need to consider other contextual-related and development-related factors to determine the overall screen time use effect on EF in children.

## 1. Introduction

As an integrated part of children's lives, in the digital era screen media use, which includes activities like Internet surfing, computer use, mobile phone use, television viewing and video game playing (Marshall et al., 2006), is children and adolescents' most popular leisure-time activity (Adelantado-Renau et al., 2019), and an increasingly used learning tool at school (Li et al., 2020). This growing screen device use has alerted medical experts, researchers and educators about the time and the consequences of screen use. This has led some organizations, such as the World Health Organization (WHO), to recommend parents to carefully monitor older children's screen time for no more than 2 h per day and no screen time for infants aged under 1 year (Madigan et al., 2019; WHO, 2019).

Screen time may be either passive, which refers to viewing screen content that requires no interaction or no input from the user, as in television viewing, or active, which refers to interactive, intentional and cognitive engagement with a device that provides screen content (Hu et al., 2020; Sweetser et al., 2012), such as a computer or internet-enabled touchscreen devices that allow interactivity and feedback based on user input (Hu et al., 2020). According to recent results, the average age of using electronic screen devices has decreased (Chang et al., 2018) and more than 80% of preschool children spend an average of 2–3 h per day looking at various screens (McNeill et al., 2019; Rideout et al., 2003; Shah et al., 2019), and television and smartphones are major contributors (Shah et al., 2019), which exceed WHO recommendations. Moreover, more than 4 in 5 children own at least one screen-based device and, on average, they own three different digital devices at home (Graham & Sahlberg, 2021). Along with screen media's advantages (i.e., access to a wide variety of resources and communication), a growing number of researchers have proposed that children who engaged in more screen time spent less time playing with peers (identified as the displacement hypothesis theory), which ultimately may affect healthy child development (Putnick et al., 2022; Roberts et al., 1993). Thus, this maladaptive excessive screen time behavior in children has been recently associated, among others, with adverse physical (e.g., overweight/obesity), psychological (e.g., language delay) and social health consequences (de Rezende et al., 2014; Li et al., 2020; Lissak, 2018), as well as with impaired executive functions (Zeng et al., 2021).

Executive function (EF) refers to an interrelated set of higher-order cognitive skills that support goal-oriented behavior and adaptive responses to novel situations (Altun, 2022; Diamond, 2012; Zelazo, 2020).

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The first and most extended conceptualizsupportsation of EF supports the notion that cognitive inhibitory control (i.e., the ability to suppress dominant information in favor of subdominant information), working memory (i.e., the ability to hold numerous pieces of information in one's mind and to manipulate it) and attentional focusing/flexibility (i.e., the ability to focus and shift attention in response to change) are generally regarded as EFs' core components in adolescents, adults, and also children (Blankson et al., 2015; Carlson et al., 2004; Diamond, 2012; Diamond et al., 2007). Nevertheless, recent research has pointed out the overlapping of these components (Wiebe et al., 2011), which has led to the reconceptualization of the EF construct.

Specifically in children, recent research has proposed two new definitions of EF. First, the most widely-used formulation in developmental contexts differentiates between 'Hot' and 'Cool' EF (Zelazo & Carlson, 2012; Zelazo et al., 2005). Hot EF is a top-down processing of socio-emotional or incentive signals that has been associated with the development of social competence in preschool years (Di Norcia et al., 2015). Cool EF is a top-down processing of salient information signals that presumably have minimal incentive and/or emotional intensity (Nigg, 2017). As Zelazo and colleagues suggest (2005; 2012), these are not two different systems, but ends of a continuum spectrum and, in most situations, both are partially involved. This Hot/Cool distinction faces difficulties like confounding of tasks with construct, and failure of efforts upon psychometric validation (Welsh & Peterson, 2014). Nonetheless, the Hot/Cool constructs have been established as well-accepted theoretical formulations (Nigg, 2017). This is why these two dimensions (Hot and Cool) are taken into account for the present meta-analysis.

The second most recent EF reformulation comes from authors like Mungas or Wiebe and collaborators (Mungas et al., 2013; Wiebe et al., 2011). As they propose, before the age of 6, EF cognitive skills can be interpreted as a homogeneous unitary factor that is not completely developed in children. According to this interpretation, despite researchers being able to use specific tasks to assess working memory, inhibitory control and/or attentional focusing/flexibility, the results can be always interpreted as a general index of EF.

In order to consider these three different conceptualizations of EF in children and to include research from different fields, we should take into account these three approaches: 1. EFs operationalized as the combinations of the three classic EF subcomponents (i.e., cognitive inhibitory control, working memory, attentional focusing/flexibility); 2. EFs operationalized as two dimensions: Hot and Cool; 3. EFs operationalized as a unitary component.

The first years of life (0–6 years) are a period of increased neural plasticity (Conway & Stifter, 2012; Zelazo & Carlson, 2012) in which EFs, including executive attention, rapidly develop (Best et al., 2009; Horowitz-Kraus et al., 2016). This is why this crucial early childhood development period is arguably the best time to start investigating whether exposure to screen media affects these essential functions (Best et al., 2009; Conway & Stifter, 2012). In fact over the last three decades, numerous studies have found concurrent and longitudinal relations between measures of children's EFs and measures of diverse skills and outcomes, such as academic achievement (Cortés-Pascual et al., 2019; Spiegel et al., 2021), social-emotional skills (Huang et al., 2020) and reasoning in biology (Zaitchik et al., 2014). On the contrary, deficits in EFs in this first life stage have been proposed as transdiagnostic indicators of atypical development (Harden et al., 2020; Zelazo, 2020) linked with a range of clinical outcomes, including attention-deficit/hyperactivity disorder (Bathelt et al., 2018), autism (Vaidya et al., 2020) and internalizing symptoms like anxiety and depression (Gardiner & Iarocci, 2018; Wagner et al., 2015). This means that ages from 0 to 6 years have been recently considered a period of greater sensitivity during executive development (Garon et al., 2008; Wiebe et al., 2011), which is associated with the maturation of cortical brain regions and is critical for integrative mental health in adulthood (Brock et al., 2009).

During this specific life span period, it has been evidenced that electronic screen-based media might be particularly detrimental to EF development. Recent literature has shown negative effects of screen time use on executive functioning (Zeng et al., 2021). For example, in longitudinal studies, Christakis et al. (2004) show that television exposure in children aged between 1 and 3 years might be associated with attentional problems, while McHarg et al. (2020) demonstrate that regular exposure to screens at the age of 4 months predicts poorer inhibitory control performance at 14 months, but is not related to other EF components, such as cognitive flexibility or working memory. Similar results have been found in cross-sectional studies. By way of example, McMath et al., 2023 evidence that toddlers meeting the WHO guideline (no more than 1 h per day) display better inhibitory self-control and overall EF. These negative effects on EFs can be present from early childhood, and might predict multiple indicators of health, wealth, social adaptation and school achievement (Cortés-Pascual et al., 2019; Moffitt et al., 2011). However, not only negative relations have been reported. A few scientific cross-sectional reports also highlight the potential benefits of screen-based media when used by children. Huber et al. (2018) show better EF skills and delayed gratification in 2- to 3-year-old children after viewing an educational app rather than a cartoon. Similarly, Lui et al. (2021) reveal a positive association between touchscreen exposure and both parent-reported composite EF score and cognitive flexibility in 10-month-old children.

Interestingly, the screen time use effect on children's cognitive functioning and development has also been studied in relation to passive/active screen time uses (Hu et al., 2020). Huber et al. (2018) report that 2-3 year-old children's use of an interactive educational app (active screen time) had a positive effect on children's EF compared to passive observational screen time (i.e. watching cartoons or an educational TV show). Similarly, an Australian study with over 5000 infants, has compared television viewing (passive) and computer use at home (active screen time) with cognitive skill. It concludes that active, but not passive, screen time haa a positive effect on children's cognitive development, and the impact is valid even 2 years after testing (Fiorini, 2010). Therefore, initially the results might indicate that only active screen time can be associated with young children's improved cognitive outcomes.

These mixed and partially opposite results evidence that a deeper and global analysis is necessary to clarify the relation between screen time use and EFs during the initial development period from 0 to 6 years. To this end, a meta-analytic approach is undoubtedly useful as an effective approach to synthesize the findings from all existing studies on one specific topic. Nevertheless, it is also necessary to consider whether the association between screen time use and EFs can be moderated by study characteristics, such as the sample's mean age, the percentage of females in the sample, EF type and exposure type (passive or active).

In relation to age, 0–6 years old is the period during which the brain undergoes major development (Andersen, 2003) and, consequently, when performance for EF measures dramatically improves (Diamond, 2015; Hodel, 2018). For example, in the Day-Night task, a typically inhibition task, response accuracy and latency have been shown to improve between 3 and 5 years (Carlson et al., 2004). Similarly, the Dimensional Change Card Sort (DCCS) task, a widely used tool for assessing cognitive shifting and EF in general (Garon et al., 2008), has repeatedly shown that most 3-year-olds correctly perform the pre-switch phase, in which children are asked to sort cards according to one dimension (e.g., color), but have difficulty with the post-switch phase (Moriguchi & Hiraki, 2013). It is noteworthy that 4- and 5-year-old children correctly sort cards according to the second dimension (post--switch phase) (Moriguchi & Hiraki, 2013). Because older children's cognitive capacities are further developed, they may already possess the basic and necessary executive functioning abilities to avoid the possible screen time-related problem, or to even improve their cognitive abilities through screen use.

On the sex differences matter, the literature well documents that school boys display more problem behaviors and are involved in longer screen times compared to school girls (Hu et al., 2020; Shan et al., 2010). On the contrary, only a few studies address these differences in children under the age of 6 years. For example, Downing et al., 2017 indicate that child sex is not associated with screen time. Nevertheless, more studies are needed to clarify this question. We consider the sex differences (also referred to in the text as the sample female percentage) as a moderator because of the EF-related task performance differences reported between girls and boys. Some recent studies have reported sex differences in EF tasks and their correlated brain areas. For example, Wiebe, Espy, & Charak (2008) report significant sex differences in four out of ten cognitive tasks which evidence that girls display a higher latent executive control level than boys. Additionally, recent neuroimaging studies that employ functional near-infrared spectroscopy (fNIRS) also confirm small sex differences in EF tasks and brain-related areas, such as the prefrontal cortex (Shinohara & Moriguchi, 2021). Thus it is relevant to assess whether girls or boys can be more affected by the time they spend using a screen device.

As previously indicated, although the most extended model proposes that EFs are composed of three main subcomponents, defined as inhibitory control, working memory and attentional focusing and flexibility (Diamond, 2012; Diamond et al., 2007), there is no comprehensive theory of EFs for the first years of life (0–6 years). Therefore, EFs have also been compiled as Hot/Cool EFs (Zelazo et al., 2005) or as a unitary component that is not developed enough to dissociate between subcomponents (Mungas et al., 2013; Wiebe et al., 2011). Among the numerous studies that evaluate EF in children a considerable variation appears in which EF can be understood from these different theoretical positions. To consider all these proposed frameworks from the selected studies, we analyzed the type of EF (inhibitory control, working memory, flexibility, Hot EFs, Cool EFs and a general EF) as a moderator to assess whether one of these perspectives may prevail over the rest in relation to the possible screen time use effect.

The last moderator that we took into account was the way in which children interact with screen devices (passive *vs.* active). As recently shown (Hu et al., 2020; Tomopoulos et al., 2010), while television viewing (the prototypical passive screen) is negatively associated with EF in preschoolers, active screen times are not associated with children's declining EF skills (Hu et al., 2020). It is noteworthy that when most of the literature on the field has assessed screen time with any screen-based device (both active and passive), almost none of the works have already interpreted their results in relation to active *versus* passive screen use. The meta-analytic approach allowed us to reconsider the published data to evaluate this dissociation between active and passive screen time.

Taking into account the above-mentioned moderators, the aim of this meta-analysis is to estimate the association between overall screen time exposure (both passive and active) and EFs in 0–6 year-old infants. This methodological approach will shed light on how screen time use can affect EFs in children, specifically during a critical development period.

## 2. Method

The preregistration of this meta-analysis can be found at https://osf.io/kwnu3. We followed the Preferred Reporting Items for Systematic Reviews and Meta-analyses "PRISMA" Checklist (Page et al., 2021) to report all the information from the meta-analysis (available in Table 5 in the Supplementary Material).

### 2.1. Study search

The search of studies was carried out in July 2022. Articles were identified with extensive literature searches using the following online electronic databases: Web of Science, PsycArticles, APA PsycInfo, Psychology and Behavioral Sciences Collection, PSICODOC, MEDLINE, EBSCOhost, ERIC, and OpenDissertations. Only English-written articles were considered. The search was carried out on article titles and the used search string was: ("executive AND functions'' OR "executive AND control" OR "working AND memory" OR "inhibitory AND control" OR "cognitive AND flexibility" OR "attentional AND shifting" OR "executive AND attention" OR "cognitive AND skills") AND ("screen AND time" OR screen OR "digital AND media" OR television OR TV OR "electronic AND screen AND behaviour" OR tablet OR smartphone OR "media AND exposure" OR "Screen AND media" OR Touchscreens OR "internet AND gaming" OR "screen AND addiction" OR "screen AND related-risk AND behaviours'' OR media OR mobile OR "electronic AND devices" OR computers OR video OR phones). No specific terms for different EF conceptualizations were included (i.e., Hot/Cool). The reference lists from all the studies included in this meta-analysis and from published reviews on screen time use and EFs (Radesky & Christakis, 2016) were also examined. When the statistical results were insufficient to include them in the current analysis, additional information was requested from the authors.

The same search strategy was conducted again in January 2023 to retrieve any studies published after our first search (in July 2022). For this search, we imposed time limits: only the manuscript published from July 2022 to January 2023.

### 2.2. Study selection

No time restriction was imposed in our main search. A study was included in the present meta-analysis if the following inclusion criteria were met: (1) participants were children aged from 0 to 6 years (infants or toddlers); (2) the independent variable was exposure time with any screen-based device (i.e., TV, computer or laptop, smartphone, tablet, etc.); (3) the study provided an outcome of the relation between screen time use and EFs; (4) the study had a cross-sectional or longitudinal design; (5) the assessment of neuropsychological executive functioning was based on a valid and reliable test that is commonly used in research or clinical practice; (6) the study was published in English. A study was excluded if: (1) the children sample was diagnosed with a disease or disorder; (2) the search was not limited to the established temporal development period; (3) studies used computerized tasks or video games for computer-based training with no information about general screen time use. As shown in Fig. 1, the initial search strategy (July 2022) yielded 1401 studies, which rose to 1467 after adding the 66 studies from the second search (January 2023). Of those, 434 were excluded because they were duplicates. Of the remaining 1033, the Abstract and

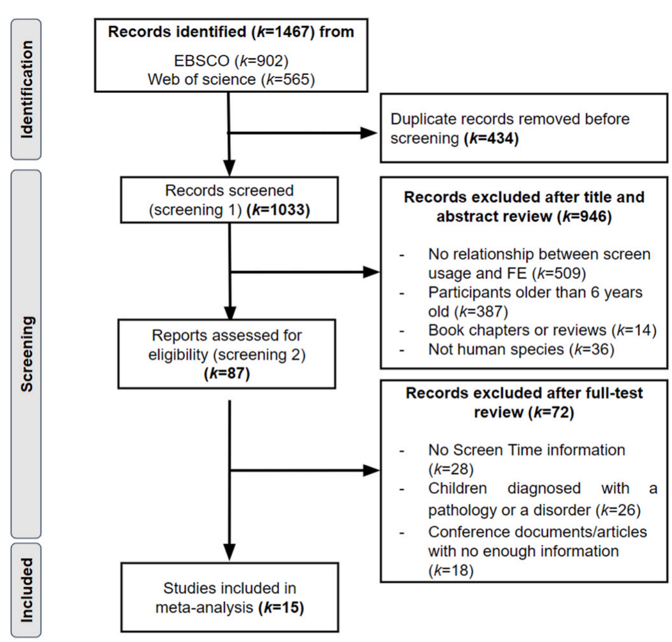


**Fig. 1.** PRISMA flow diagram for the include studies in the meta-analysis.

Method sections were thoroughly read by the first author (first screening), and 87 of them were selected for a second screening. Further examination of the full texts of these 87 studies allowed 15 studies (14 from the first search and 1 from the second search) to be finally included in the present meta-analysis (second screening), with 16 independent samples and 44 effect sizes. The studies included in the meta-analysis involved 6922 participants from nine different countries. A summary of the studies included in this review is provided in Table 1 in the Supplementary Material. The references of the studies excluded from the second round of screening can be found in Table 2 in the Supplementary Material.

### 2.3. Data extraction

The relevant data from the selected studies were extracted and coded on a spreadsheet. First, authors' names, manuscript titles and year of publication were coded. Second, data about the sample of participants were extracted: mean age, standard deviation of age, and the percentage of females in the sample. Third, information about the study characteristics was coded, such as study design (cross-sectional or longitudinal), frequency of exposure to screens (minutes a day), exposure type (active or passive) and device type (television, computer, tablet, PC, touchscreens, smartphones, etc.). Finally, the characteristics related to the outcome variable "EFs" were coded, such as EF type measured: general EFs, Hot EFs, cool EFs, Working Memory, Inhibitory Control and Flexibility. The data from 50% of the studies were also coded independently by one of the co-authors. Interrater agreement was calculated by dividing the number of items where both authors agreed on the sum of items, where the authors disagreed and agreed. If any disagreement took place, the authors solved it by discussion.

Finally, the quality of primary studies was coded with an instrument originally developed by Estabrooks et al. (2003) known as *'Quality Assessment and Validity Tool for Correlational Studies'***.** This instrument has been adapted in some other reviews (e.g., Cowden et al., 2011), and the version used by Cicolini et al. (2014) was applied. This instrument (available in Table 3 in the Supplementary Material) consists of 13 items. One item assesses the quality of the design, five items evaluate sample-related aspects, five other items aim to measure the quality of the measurement of the variables of interest, and two other variables measure the quality of the statistical analysis. These items are labeled with 1 (if the measured aspect is met) or 0 (if the aspect measured by the item is not met). The total quality score is the sum of the scores of these 13 items. A total score between 0 and 4 denotes low quality, a total score between 5 and 9 indicates medium quality, and a total score between 10 and 13 represents high quality.

### 2.4. Statistical analysis

Interrater agreement was 100%. The units of analysis for this meta-analysis were Pearson correlation coefficients, which were extracted from each study. Some studies included Spearman *rho* correlations, and they were transformed into correlation coefficients using this formula, r $= 2 \times$ sen (rho*(Π/6), proposed by Rupinski and Dunlap (1996). One problem with using these correlations as the unit of analysis is that the sampling variance of a correlation coefficient correlates with the magnitude of the correlation. This is why correlations were transformed into Fisher's Z for the analyses (Cooper et al., 2020). One study (Li et al., 2021) included the mean difference in the EFs between a group of heavy screen users and a group of non heavy screen users. For this study, a standardized mean difference was first computed, and then this Cohen *d* was transformed into a Pearson correlation (see formula 11.82 on page 234 in Cooper et al., 2020). Almost all the studies included more than one effect size, mainly because the authors studied several EFs (e.g., Jusiene et al., 2020; Lui et al., 2021). The effect sizes reported in the same study tended to be similar to one another because they were obtained from the same sample or by a similar procedure (similar study characteristics). This dependence among the effect sizes extracted from the same study has to be statistically modeled to avoid inflated type I errors (Becker, 2000). One approach to statistically model dependent effect sizes is to apply three-level models (Cheung, 2014; Van den Noortgate et al., 2013, 2015). This three-level model acknowledges the hierarchical structure of this data type: observed effect sizes (Level 1) are nested in the different types of outcomes (Level 2) that are, at the same time, nested in studies (Level 3). Therefore, this three-level model estimates and differentiates between two sources of heterogeneity: variability among effect sizes reported in the same study (Level 2 - within-study variance); variability between study-effects around the overall effect (Level 3 - between-study variance). The Level 1 variance, sampling variance, is estimated in advance and assumed to be known. If the observed pooled effect is not statistically different from zero, an equivalence test is applied (Lakens, 2017; Schuirmann, 1987), in which the null hypothesis is that the overall effect is smaller than −0.2 or larger than 0.2. These bounds correspond to small-to-moderate correlation coefficients.

To check whether between-study and within-study variances were statistically different from zero, likelihood ratio tests were applied by comparing the correct three-level model to a model that ignored Level 3 - study and a model that ignored Level 2 - outcome. If significant heterogeneity is found, categorical and continuous study characteristics are introduced into the three-level model (meta-regression) to see whether they explain the variability observed among effects. Continuous moderator variables were centered before the analyses to facilitate interpretation. To make doubly sure that the type I error was under control, robust standard error correction was applied to the results of the three-level model meta-regressions (Tipton et al., 2019). This *posterior* correction corrects for potentially shrunk standard errors.

Sensitivity analyses were performed to detect potential outliers (Viechtbauer & Cheung, 2010). Specifically, studentized residuals were obtained by means of the *rstudent* function of the *metafor* package. The effect sizes with studentized residuals larger than 1.96 or smaller than −1.96 are labeled as outlying effects. Publication bias analyses were also carried out to check whether the big effect sizes based on the smaller sample sizes were more likely to be published than the big effect sizes based on the larger sample sizes. To do so, the funnel plot was visually inspected (Light & Pillemer, 1984) and a three-level Egger regression test was run (Fernández-Castilla et al., 2021). If any evidence for publication bias is detected, selection models (Vevea & Woods, 2005) are applied to obtain an adjusted estimate of the overall effect.

All these analyses were performed with the *metafor* package (Viechtbauer, 2010). The robust variance error correction was applied using the *clubSandwhich* package (Pustejovsky, 2021). The full dataset with all the included studies, and the R code used to conduct the analysis, can be found at https://osf.io/k732v/?view_only=cf7d1b4a6ae44349a499eb134ed2ef3d.

The moderator variables included in the "Type of executive function" were based on how authors of included articles defined tasks from different conceptualizations (EF composed by subcomponents, Hot/Cool EF and a general EF index).

## 3. Results

Fifteen studies, including 44 correlations, were synthesized (Fig. 1). The overall correlation between screen exposure and EFs was 0.05 (SE = 0.05, 95% CI = [-0.04, 0.15], $t = 1.26$, $p = .242$), which is not statistically different from 0. The equivalence test was statistically significant (Z = −3.571, $p = < .001$), which means that the overall effect was statistically different from any value above 0.2 or below −0.2. This reinforces the idea that it could not be considered to statistically differ from 0. The between-study variance was 0 and not significant (LRT = 0.000, $p = 1$), but the within-study variance, which equaled 0.100, was statistically different from zero (LRT = 680.81, $p < .001$), which meant that effect sizes varied considerably within studies. No outlying effect sizes were detected, and all the studentized residuals fell within the established cutoffs (i.e., −1.96, 1.96). As shown in Table 1, none of the moderator variables explained the variability observed among effect sizes.

The total quality score of each study can be found in Table 4 in the Supplementary Material. Twelve of the 15 studies obtained a total quality score of 8, two studies had a total score of 7, and only one study obtained a total score of 9. By way of conclusion, all the included studies were categorized as moderate quality. As there was no variability among the total quality scores, we could not introduce this variable as a moderator variable.

The funnel plot (Fig. 2) did not show any evident asymmetries and the three-level Egger regression test was not significant (B = 2.25, SE = 1.40, $p$ = .100). As the overall effect size was not significant and there was no evidence for publication bias, no selection methods to obtain an adjusted estimate of the overall effect size were carried out.

**Table 1**
Moderator effect of selected variables on screen time use and executive functioning.

| Continuous moderator variables | m (k) | Effect | SE | 95% CI | $\sigma_b^2$ | $\sigma_w^2$ |
|---|---|---|---|---|---|---|
| **Age** | 44 (15) | | | | | |
| Incercept | | 0.053 | 0.043 | [-0.05, 0.15] | 0.000 | 0.103 |
| Mean age | | 0.0002 | 0.001 | [-0.01, 0.003] | | |
| **Percentage of women** | 39 (12) | | | | 0.000 | 0.111 |
| Intercept | | 0.054 | 0.044 | [-0.06, 0.16] | | |
| % women | | 0.010 | 0.005 | [-0.01, 0.03] | | |
| **Frequency** | 31 (12) | | | | 0.000 | 0.103 |
| Intercept | | 0.076 | 0.018 | [0.03, 0.12] | | |
| Frequency | | −0.001 | 0.001 | [-0.002, 0.001] | | |
| **Categorical moderator variables** | m (k) | Effect | SE | 95% CI | $\sigma_b^2$ | $\sigma_w^2$ |
| **Design** | 44 (15) | | | | 0.000 | 0.098 |
| Cross-sectional | 30 | 0.098 | 0.023 | [0.04, 0.16] | There are no statistical differences between categories | |
| Longitudinal | 14 | −0.039 | 0.106 | [−0.33, 0.26] | | |
| **Type of executive function** | 44 (15) | | | | 0.000 | 0.085 |
| Cool | 2 | −0.377 | 0.374 | [-5.14, 4.35] | There are not statistical differences between categories | |
| Flexibility | 6 | 0.050 | 0.034 | [-0.07, 0.17] | | |
| General EF | 15 | 0.089 | 0.030 | [0.02, 0.16] | | |
| Hot | 3 | −0.195 | 0.192 | [-2.63, 2.23] | | |
| Inhibitory Control | 10 | −0.016 | 0.139 | [-0.39, 0.36] | | |
| Working memory | 8 | 0.278 | 0.148 | [-0.23, 0.80] | | |
| **Passive/Active** | 35 (11) | | | | 0.031 | 0.030 |
| Passive | 20 | −0.033 | 0.097 | [-0.13, 0.36] | There are not statistical differences between categories | |
| Active | 15 | 0.114 | 0.114 | [-0.30, 0.23] | | |

Notes. $\sigma_b^2$ = Between-studies variance, $\sigma_w^2$ = Within-studies variance.

Fig. 3 shows all the study effects included in the present meta-analysis. This forest plot was adapted to the presence of multiple effect sizes within studies (Fernández-Castilla et al., 2020). The black line is a study level confidence interval that indicates study precision, which was inversely proportional to the square size. The gray line is the traditional confidence interval that only considers information about the study's sample size: the larger the sample size, the narrower the gray confidence interval. We can see that the most precise study (and that with more weight on the final estimate) was the work by Linebarger et al. (2014), whereas the study with the least precision and, therefore, with less weight on the pooled effect, was that by Jusiene et al.(2020).

## 4. Discussion

To our knowledge, the present study provides the first meta-analytic synthesis of the existing research on the relation between overall screen time use and EFs for infants, toddlers and preschoolers (0–6 years old). In fact, given our objective and inclusion criteria, only 15 articles were selected in our study. The analyses in previous research have focused on specific screen time use types without considering children's overall interaction with screen devices in the daytime. Our meta-analysis results indicate lack of statistical association between the amount of time spent on screen media use and executive functioning. Moreover, we did not obtain any statistically significant results with the other moderators, even when we considered the differentiation between cross-sectional and longitudinal studies. In any case, this study allows us to establish that if we wish to determine the effect of overall screen time use on EF in children, it is necessary to consider other contextual-related factors and development-related factors. Altogether, the meta-analysis revealed some implications that we discuss below.

The association between the overall time spent on screen-based activities and EFs during the initial development period has been previously reported. Two recent examples are: Lui et al. (2021), who reveal a positive association between touchscreen exposure and both parent-reported composite EF score and cognitive flexibility with 10-month-old children; McHarg et al. (2020), who show that regular exposure to screens at 4 months predicts poorer inhibition performance at 14 months, but is not related to other EF components, such as cognitive flexibility or working memory [1]. However, our results agree with those of Jusiene et al.(2020), who indicate no significant relations between using various screen-based media devices and EF measures. This lack of a consensus reached by studies can be partially explained by at least the following reasons (1) to date, and as shown in the flow diagram (Fig. 1), the relation between EFs and screen time use has been assessed during different development periods. However, there are not enough published articles that report overall screen media use after considering all the contexts together (i.e., at home, at school, etc.): to obtain a comprehensive picture of how much time exposure to screens (but not to other device-dependent characteristics) might affect EFs. Therefore, more studies are needed to clarify the association between these two variables (2) as Rhodes et al. (2020) recently highlight, cognitive deleterious effects (i.e., EFs); might be related to aspects of TV content itself, such as presentation pace (Lang, 2000; Lillard & Peterson, 2011; Rhodes et al., 2020), fantastical content (Huber et al., 2018; Rhodes et al., 2020) or educational content (Zimmerman & Christakis, 2005), rather than spending time using screens *per se*. Conversely to these results, Anderson and Subrahmanyam (2017) have proposed that TV content, such as "Sesame Street", might also have a positive impact on cognitive development (Anderson & Subrahmanyam, 2017); (3) one proposal is a sort of contextual factor not related to screen devices *per se* that might mediate the relation between screen time and EFs. Lauricella et al. (2015) evidence a robust interaction that links child age, parent screen time and children's screen time, and suggest that many factors influence children's screen media use. Nichols (2022) show that when toddlers are exposed to background TV exposure (BTV), they engage in

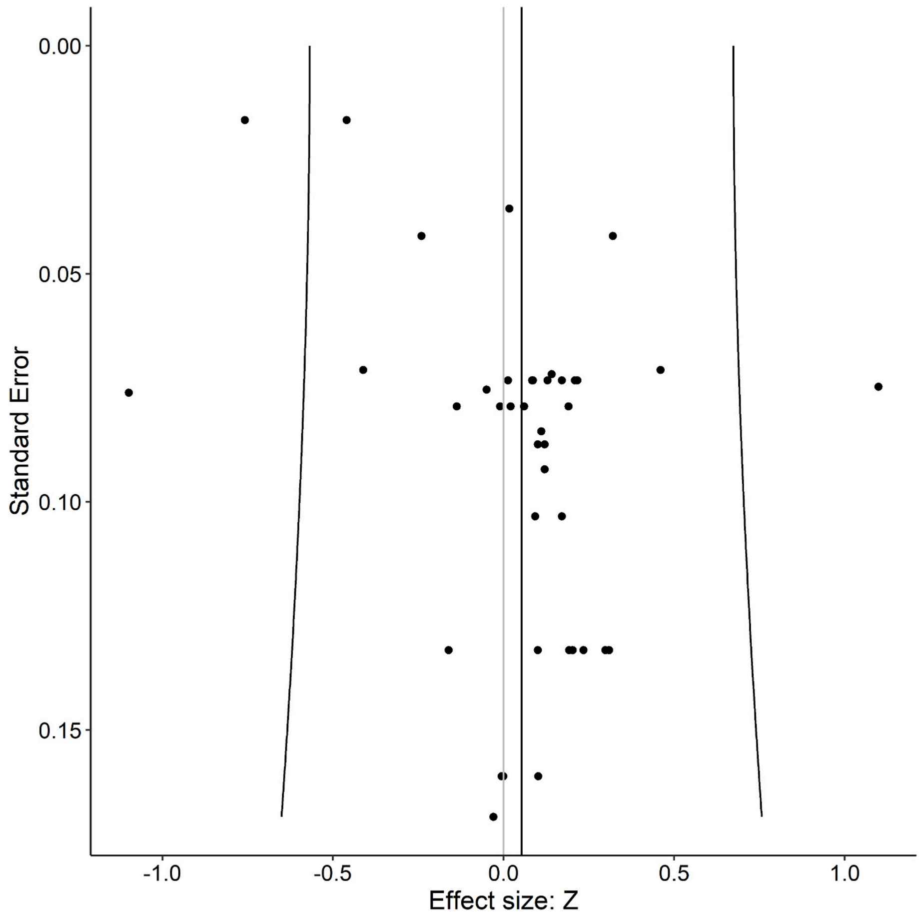


**Fig. 2.** Funnel plot for the Fisherś Z effect sizes. Effect sizes are symmetrically distributed across the figure, so there is no (visual) evidence of the presence of publication bias.

shorter and less focused play episodes, and parents engage in fewer and poorer-quality interactions during that exposure. As preschoolers' time spent playing exposed to BTV increases, the EF scores worsen. Moreover, parent attitudes is another contributor to children's screen time and its effect (Cingel & Krcmar, 2013; Lauricella et al., 2015). Even with 4-6-year-old children, screen time use is also influenced by parent-related variables like mothers' education and family income (Barragan-Jason & Hopfensitz, 2021). Additionally, parental engagement with media device use may reduce the quantity and quality of parent-child interactions, which are determinants for the development of cognitive skills like language and EFs (Anderson & Subrahmanyam, 2017). Therefore, this lack of association that we found between the overall time spent on screen-based activities and EFs might be related to the fact that the screen time use effect on EFs may depend on additional variables, such as programming type, contextual factors (Anderson & Kirkorian, 2015) and some TV content aspects, which were not analyzed in the present study.

In relation to age, a previous meta-analysis has obtained similar results to ours when measuring this variable as a moderator between EFs and lying (Sai et al., 2021) or EFs and academic performance (Cortés-Pascual et al., 2019). However, lack of significant results should not necessarily be taken as evidence to support the notion that age does not moderate the associations between screen time and EFs. This lack of results in our work may be related to the idea that the association between screen-based media use and early brain development is unknown and not extensively investigated (Hutton et al., 2020). Despite it being known that sensory brain networks mature early, but the sensory networks for higher-order skills like EF exhibit protracted development and depend on environmental factors (Stockdale et al., 2022), the study of Hutton et al. (2020) is the only one to show that longer screen use could impact brain development integrity in preschool-aged children. Zimmerman and Christakis (2005) report negative associations between television viewing before the age of 3 and adverse cognitive outcomes at the ages of 6 and 7 years. However, these authors also report that television viewing, specifically educational television, at the ages 3 to 5 may, or may not, have more positive cognitive effects (Zimmerman & Christakis, 2005). Therefore, it is necessary to take age as a variable of interest and investigate the longitudinal effects of screen time use on the development of EF brain-related areas and behavioral correlates. Otherwise as screen time use effects on EFs are possibly different in each age group, our result may be related to the fact that most studies compiled in this meta-analysis do not report effect sizes for each age or age group (Sai et al., 2021). Thus to assess the age effect for the present meta-analysis, we have to compute each sample's average age without considering our sample's age distribution. According to our data, only one study has worked with participants aged under 1 year, and most of the participants in the sample are children over the age of 3 years ($\bar{x} = 3.81$). Therefore, to appropriately address whether age moderates the associations between screen time and EFs in children, it is indispensable for future studies to specify the effect size of the results per equally distributed age groups. Another possible explanation is that the age range used to consider the meta-analysis to be a wide one is to take into account that sizable growth and EF maturation occur in this initial developmental stage. Therefore, the studies herein compiled make the interpretation of the obtained results difficult because not all ages (1, 2, 3, 4, 5 and 6 years) are sufficiently represented. Finally, it is likely that the statistical power to detect if an effect might be due to the few studies included in this review is lacking.

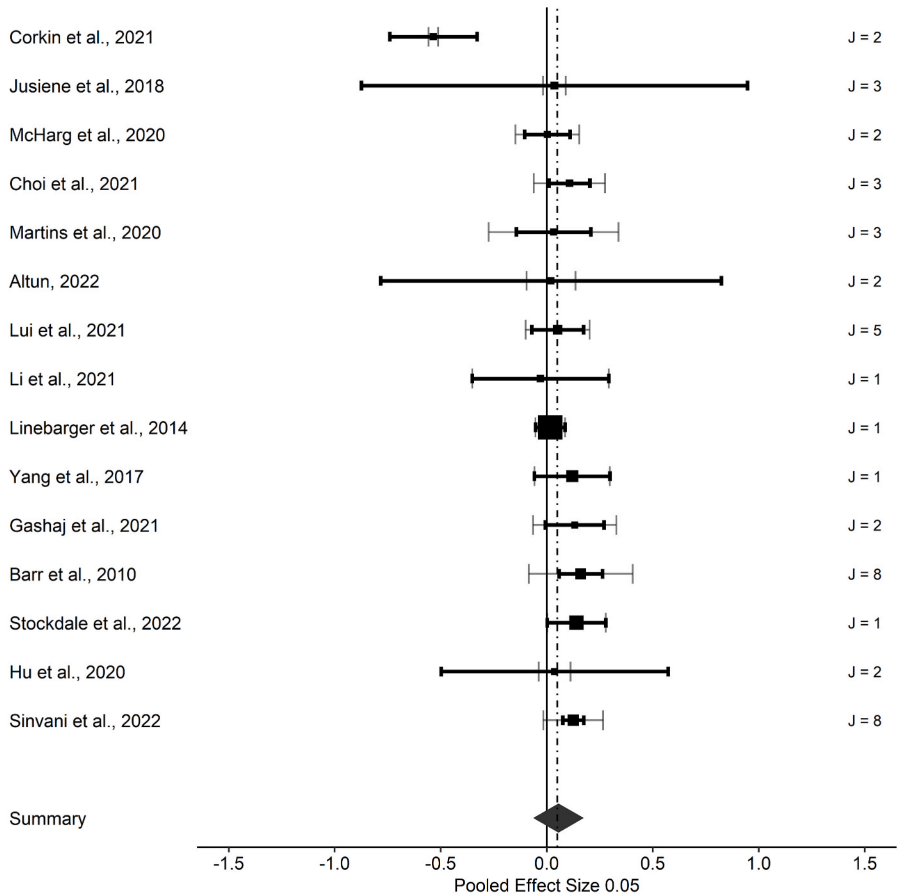


**Fig. 3.** Forest plot of the study-effects included in the meta-analysis. The black line is a study-level confidence interval that indicates the study-precision, which is inversely proportional to the square size. The gray line is the traditional confidence interval that only considers information about the sample size of the study. On the left, we indicate the number of effect sizes included in each study.

Nor is sex as a moderator variable between screen time and EFs statistically significant. This result should be interpreted cautiously because open discussion continues about possible sex differences in EFs in children. Indeed Grissom and Reyes (2019) recently propose that these dissimilarities may suggest differences in the strategy to cope with EF-demanding tasks rather than a difference in ability between sexes. Shinohara and Moriguchi (2021) evidence that sex differences in EFs are generally small and inconsistent, perhaps because questionnaires and cognitive tasks are not sensitive enough to detect them. Interestingly, these authors have also investigated EF-related brain measures to examine sex differences. They reveal that girls generally display superior performance in cognitive shift tasks and more marked prefrontal activations than boys (Shinohara & Moriguchi, 2021). Perhaps potential EF differences between sexes in this early stage may influence the screen time effect, but more studies are needed to clarify these results. Future studies may also clarify whether EFs, or some of their components, can develop sooner in girls than boys at this time point and, additionally, whether this differential skill maturation might be distinctly influenced by an excessive time effect on screens.

On the EF type, the present study does not find any statistical outcome for the chosen categories (Cool EFs and Hot EFs, flexibility, inhibitory control and working memory) as a moderator variable between screen time and EFs. Once again, we should bear in mind that there are a few effect sizes for some categories (e.g., only two effect sizes in the Cool category). This clearly implies lack of statistical power to detect any effect. Other possible explanations might be related to the fact that in early childhood, changes in EFs are unitary and hierarchical in nature (Munakata, 2001; Schoemaker et al., 2012). In fact it seems that EF components develop hierarchically during the preschool period. Garon et al. (2008) suggest that the skills underlying EF develop hierarchically, with two main development stages. Before the age of 3 and basic skills needed for component EFs to emerge; development after age 3 appears to be an integrative period during which basic skills become coordinated. Indeed findings in early EF development indicate that maturation of attentional capacity forms a foundation for the development of EF abilities during the preschool period and may, in fact, be the source of the common variance that underlies several EF skills (Rueda et al., 2004). Thus it would be interesting to specifically analyze the moderation effects that could outstand for their critical role in EF development in these age groups.

Finally, active vs. passive screen time shows an opposite trend between screen time use and EFs (see Table 1). Passive screen time (e.g., TV viewing) tends to be negatively associated with children's executive functioning, while children's active screen time (e.g., video gaming) tends to be positively related to EFs. It is important to note that this trend is not statistically significant. Yet this finding is supported by the literature. For example, Huber et al. (2018) report that an interactive app (active screen time) has a positive effect on children's executive functioning compared to an educational TV show (passive screen time) or a cartoon program (passive screen time) (Huber et al., 2018). Similarly, Hu et al., (2020) partially confirm these previous findings by showing that Chinese preschool children's passive, but not active, screen time is negatively associated with their executive functioning. Thus according to our results and previous ones, active screen-based activities might be considered possible training to improve EFs. It seems that the interventions that are most likely to improve EFs are those that train and challenge diverse EF skills, for example bring about joy, pride and self-confidence, and provide a sense of social belonging (Diamond, 2015). In fact a powerful way of strengthening EFs is done with activities for enjoyment and recreation purposes, such as play (Gibb et al., 2021; Yogman et al., 2018). In line with this, Gibb et al. (2015; 2021) state that intentional play activities that involve improvement in child-adult relationship quality can positively impact EF development. Therefore, for instance, interactive and intentional play by means of an app can improve preschoolers' EFs. However, the effects that derive from active engagement, especially if supported by co-watching or co-play with parents, or even with peers, may depend on the selection of age-appropriate media and content (Adachi & Willoughby, 2017; Yogman et al., 2018).

## 5. Limitations

In addition to the aforementioned limitations, the present meta-analysis is limited by the following points. First, the majority of the studies included in the present analysis are cross-sectional. As the preschool-age time is a period of rapid growth and wide variability, studies carried out at this time should be longitudinal in nature. Lee and collaborators (2009) evidence that a longitudinal design might be a strong predictor of later media use, and predictors of media use change when analyzed with cross-sectional data compared to longitudinal ones. Furthermore in cross-sectional studies, no previous information about children's EFs before the start point of screen use is available. Thus whether EFs at a precise time and in a given development state might be altered more in different children by the time they spend using screens remains unknown. Therefore, more longitudinal studies are needed to elucidate the interrelations between screen time and children's EFs and their respective development. Second, none of the studies included in this meta-analysis apply a probability sampling approach, which makes it difficult to generalize the obtained data. Third, Effortful Control, a traditional measure of temperament in children (Rothbart et al., 2000), has been recently proposed as a high-order cognitive control element of self-regulatory processes closely related to "attentional focusing, attentional shifting, and inhibition and activation control of behavior" (Nigg, 2017). The new reinterpretation of this construct has led authors to measure EFs in children with instruments that assess Effortful Control (Nigg, 2017; Tiego et al., 2020). Therefore, a comprehensive analysis of the relation between screen time and EFs during this early development period may have included studies of Effortful Control when the scope and nature of the study allow it. Fourth and lastly, we decided *ad hoc* that our study would focus on the relation between EFs and the overall time spent using screens with children aged under 6 years. We did not consider how children's estimates *vs.* Parent's estimates *vs.* Actual logs may impact the validity of the findings. Nevertheless, this is a necessary initial study, but future studies may benefit from the meta-analytic examination of the influence of these variables. Finally from our analysis, we exclude those papers that include samples of children with a disease or disorder. It would be interesting to consider the implication of screen time use regarding special needs and EFs.

## 6. Conclusions

Our study suggests that screen time should be included as an active time during which parents or caregivers and gaming must be present. Moreover, this study highlights the need for further research into the association of different factors and other screen aspects (not only time of use) with EFs, such as content itself. As screen time may influence factors in future health, education and public health professionals should consider supervision and reduction to be strategies for screen-based activities to avoid deteriorating natural EF development in children aged under 6 years. Nevertheless, more in-depth studies about the consequences of excessive screen media use and its association with early EF development are required to correctly advise families, educators and health policy makers.

## Author contribution

MAI conceived this study and was involved in data coding, data interpretation and writing the manuscript. BFC participated in data analysis and writing the manuscript. JCB participated in data interpretation and writing the manuscript. All the authors approved the submitted version.

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## Declaration of competing interest

The authors declare no conflict of interest.

## Data availability

I have shared the link to the data in the text.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.chb.2023.107739.

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The studies included in the meta-analysis are marked by an asterisk *

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