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Mobile use induces local attentional precedence and is associated with limited socio-cognitive skills in preschoolers

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ABSTRACT

Mobile touch screen devices (MTSDs; i.e., smartphones and tablets) are now being used at an early and neuroplastic age by an ever-growing number of children, with this use likely affecting cognitive development. In a cross-sectional study, we investigated whether frequent MTSD user preschoolers exhibit different attentional and socio-cognitive skills compared to non-users. In a second, experimental study, we tested whether exposure to digital and non-digital games is associated with differences in attentional performance, and whether game pace moderates observed effects. Findings of both studies indicate pre-existing and experimentally-induced MTSD use was associated with global precedence in selective attention tasks, but an atypical, local precedence in a divided attention task. Further, playing with a fast digital game eliminated the advantage of selective attention over divided attention observed in the non-digital and slow digital game conditions. MTSD use was not associated with emotion recognition but was associated with worse theory of mind. We argue that the observed correlates and effects of MTSD use, and specifically of games, can be explained by a combination of MTSD characteristics (e.g., screens are rich in local and multiple modes of information, relatively limited social experience) and game characteristics (e.g., fast speed). Our results may be informative for the design and optimization of game structure and function, and may even call for influencing parameters of MTSD use that could affect mental functioning in this sensitive age.

1. Introduction

The effects of early-life experiences on cognitive processes can be long-lasting and robust (Pechtel & Pizzagalli, 2011; Schoenmaker et al., 2015). Use of mobile touch screen devices (MTSDs) in toddlers and preschoolers is markedly increasing (Common Sense Inc., 2017) and the age at which youth begin to use these devices is becoming lower (Konok, Bunford, & Miklósi, 2020). Thus, compared to earlier eras, young children are exposed to different kinds of stimuli during a developmental phase characterized by exceptional neural and cognitive plasticity. The short and long-term consequences of such exposure are largely unknown (but see Bedford, Saez de Urabain, Celeste, Karmiloff-Smith, & Smith, 2016; Herodotou, 2018; Li & Atkins, 2004).

The effects of early exposure to traditional electronic media, e.g., TV, have been extensively studied and results generally indicate that it is associated with deficits in attention, executive functioning, academic performance (e.g., school readiness, reading) and language development (for a review see Christakis, 2009; Kostyrka-Allchorne, Cooper, & Simpson, 2017). For example, in preschoolers, earlier start and greater quantity of TV viewing is associated with poorer executive functions (Nathanson, Aladé, Sharp, Rasmussen, & Christy, 2014) and in primary school children, TV viewing for more than 2 h per day is correlated with attention deficits (Özmert, Toyran, and Yurdakok, 2002). Further, factors such as parenting style, program content, viewing context, and exposure type (background/foreground) have been shown to moderate these effects (Kostyrka-Allchorne et al., 2017a; Linebarger, Barr,

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Lapierre, & Piotrowski, 2014). In preschoolers or school-aged children, educational contents may have positive effects on cognitive development (Anderson & Subrahmanyam, 2017). In infancy, however, TV viewing is especially disruptive to e.g., play and child-parent interactions, and is associated with inattention, hyperactivity, lower executive functions and language delay (for a review see Kostyrka-Allchorne et al., 2017a).

The newest and most dynamically developing media (MTSDs) are different from TV in many respects, including interactivity, involvement of special sensorimotor stimulation (use of touchscreen), variability of activities, and the frequency of solitary activity (Connell, Lauricella, & Wartella, 2015). One of the most frequent MTSD activity is playing games (Konok et al., 2020), making MTSDs similar to other videogame devices, e.g., console or PC games, while also radically distinguishing them from passive TV viewing. Nevertheless, children tend to begin MTSD use at an earlier age than console and PC game use (Kabali et al., 2015), when neurocognitive processes are still very plastic. Based on these trends and data on the ontogeny of human socio-cognitive skills, it stands to reason that use of MTSDs (including playing mobile games) influences cognitive development. These potential effects are, however, rarely investigated. Given the novelty and unique features of these devices, inferences about their effects cannot be made based on results obtained with older media.

1.1. Effects of digital screen media on attention, executive functions[1] and socio-cognitive skills of children

A frequent concern regarding the effects of electronic media use in children is that it leads to attention problems and hyperactivity/impulsivity with empirical findings confirming this concern (for a review see Beyens, Valkenburg, & Piotrowski, 2018). Although in adolescents and adults, videogame use is associated with better visual attention (for a review see Green & Bavelier, 2008), in children, electronic media use is associated with later attentional problems (e.g., Swing, Gentile, Anderson, & Walsh, 2010) and ADHD symptoms, both inattention and hyperactivity/impulsivity (Beyens et al., 2018). This apparent contradiction can be explained by age-specific effects where mature attentional processes are improved, whereas development of immature attentional processes is disrupted. In addition, studies showing improvement of attention measure visual attention, whereas those showing problems in attention as a consequence of electronic media measure sustained attention or ability to sustain adaptive and goal-directed behavioral and mental processes in effortful or boring contexts (Gentile, Swing, Lim, & Khoo, 2012).

Additionally, electronic media use seems to affect executive processes: In preschoolers, video gaming is associated with faster reaction time but not greater accuracy in parallel-processing tasks (see e.g., Yuji, 1996). Moreover, heavy media use is associated with greater externalizing behavior and worse inhibition (McNeil, Howard, Vella & Cliff, 2019). In adolescents, heavy mobile use is associated with a more impulsive (faster but less accurate) response style on higher-level cognitive tasks (Abramson et al., 2009). It is reasonable to assume that attentional control, another executive processes, might also be influenced by heavy media use.

Another frequent concern is that the use of digital media makes social interactions and relationships (including family relationships) superficial or of poor quality, and this may affect child socioemotional development. Some findings indicate that frequent digital device use deteriorates social-emotional development (Raman et al., 2017) and there is a negative association between TV exposure and theory of mind in preschoolers (Nathanson, Sharp, Aladé, Rasmussen, & Christy, 2013).

1.2. Potential mechanisms through which digital media use affects attention, executive function and socio-cognitive development

There are several factors that may account for the effects of digital screen media on attention and executive functions. Overstimulation (i.e., excessive non-normative stimulation; Christakis, Ramirez, & Ramirez, 2012) may be one of these mechanisms (Christakis, 2009). In support, overstimulated mice show increased activity and risk-taking, diminished short-term memory, and decreased cognitive function (Christakis et al., 2012). Movies, TV programs and videogames are often characterized by fast-paced, simultaneous and rich stimuli, with high frequency of attention-grabbing, perceptually salient features such as fast camera cuts, flickering lights or sound effects (Gentile et al., 2012; Goodrich, Pempek, & Calvert, 2009). Arousing and rapid events stimulate bottom-up, stimulus-driven, exogenous attention (Landhuis, Poulton, Welch, & Hancox, 2007) at the expense of top-down, executive, endogenous attention. However, there is a paucity of studies on the association between amount of stimulation (e.g., pace of TV programs) and attention and executive functions, and in the available studies, the factors in question are not systematically manipulated, rendering their findings equivocal (Geist & Gibson, 2000; Lillard, Drell, Richey, Boguszewski, & Smith, 2015; Lillard & Peterson, 2011). Exceptions are the studies by (Kostyrka-Allchorne, Cooper & Simpson (2017)) and Anderson, Levin, and Lorch (1977) where the pace of the films (e.g., number of camera cuts) was systematically manipulated. (Kostyrka-Allchorne et al. (2017b)) showed that after viewing a fast-paced film, children exhibited greater attention shifting than after viewing a slow film. Anderson et al. (1977) did not find evidence for a program pacing effect on executive functions (impulsive/reflective response style and perseverance). Similar experimental designs disentangling individual, specific effects (e.g., pace) of various media contents are necessary to determine how those influence attention or executive processes.

Besides its content being overstimulating, use of electronic media is often characterized by multitasking (consuming more streams of media at once), so that users have to simultaneously process multiple types of stimuli and rapidly shift attention between contents. Frequent attentional shifts may overload the attentional system. Media multitasking has been linked to daily executive problems (Baumgartner, Weeda, van der Heijden, & Huizinga, 2014) and worse academic achievement in adolescents (Cain, Leonard, Gabrieli, & Finn, 2016). In adults, media multitasking was associated with worse selective attention (Ophir, Nass, & Wagner, 2009; but see; Baumgartner et al., 2014). With multitasking being applicable even in early childhood (Kabali et al., 2015), it may affect development of attention and executive functions early on.

Even if a child consumes only one stream of media at a time, the stream itself can consist of multiple stimuli that the child has to simultaneously attend to. This can explain why playing videogames improves visual attention skills, e.g., divided attention, at least in adolescents and adults (Greenfield, DeWinstanley, Kilpatrick, & Kaye, 1994).

One important attentional control process is global-local processing; direction of attentional resources to global or to local features of the visual field. Typically, children and adults show a global attentional bias (Plaisted, Swettenham, & Rees, 1999), thus, the default attentional focus is characterized by a global precedence and global-to-local interference (i.e., faster and more accurate detection of targets at the global, as opposed to the local level). However, experience can affect the typical mode of global-local processing (Colzato, van den Wildenberg, & Hommel, 2008; Nisbett, Choi, Peng, & Norenzayan, 2001). Digital screen contents are usually rich in local information, with an abundance of fine detail. To be better at a game, for example, users have to attend to multiple sources of local information and simultaneously process a lot of salient stimuli. Users also have to respond quickly and organize their motor responses precisely. Of note, proneness to attend to details is increased when movement precision is required (Job, van Velzen, & de Fockert, 2017). Screens only reveals a portion of the whole picture at a time, as we 'scroll' downwards, upwards, or as images and scenes move

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[1] Executive functions include attentional processes, specifically, endogenous, executive, or top-down attentional control (but not exogenous or bottom-up attention).

in and out of the screen. As users can rarely get a sense of the whole pattern (Liu, 2005), extensive MTSD use may alter the typical information processing, training the attentional control system to shift focus onto local patterns.

MTSD use may take time away from other, offline activities ('displacement' hypothesis), including ones essential for appropriate development of cognitive and socio-emotional skills, such as good-quality social interactions with caregivers (Dunn, Brown, & Beardsall, 1991; Fonagy, Steele, Steele, & Holder, 1997) or social, pretend and dramatic play (Ashiabi, 2007; Burns & Brainerd, 1979; Lindsey & Colwell, 2003). Indeed, data show that children who spend more time viewing TV, spend less time with their parents and siblings and with creative play (Vandewater, Bickham, & Lee, 2006). Similarly, more background-TV time is related to fewer and lower quality parent-child interactions (Kirkorian, Pempek, Murphy, Schmidt, & Anderson, 2009). As such, the use of both older and newer types of media negatively affects socio-cognitive and socio-emotional skills (Nathanson et al., 2013; Raman et al., 2017). In contrast, participation in an outdoor camp without access to screen media (and thus perhaps more time spent engaging in social interaction) was associated with improved social perception skills (requiring theory of mind and emotion recognition skills; Uhls et al., 2014). Other results suggest that digital media (TV or videogame) content moderates associations of interest. Whereas violent games and TV programs are linked to lower empathy (Bushman & Huesmann, 2006) and atypical emotion recognition (Kirsh & Mounts, 2007), cooperative/prosocial contents have the opposite effects (Friedrich-Cofer, Huston-Stein, McBride Kipnis, Susman, & Clewett, 1979; Sestir & Bartholow, 2010).

To date, most studies focusing on the effects of digital media on child executive, attention and socio-cognitive skills are observational. Additionally, in most such studies, digital media use in general is measured, despite findings indicating that different devices, contents and contexts of device use may have different effects. Only a handful of experimental investigations have been carried out and some failed to systematically manipulate the factors under investigation (e.g., Lillard & Peterson, 2011). Tightly controlled experimental studies are necessary to investigate the effects of specific contents (e.g., games) and specific features of contents (e.g., pace of games) on attention or executive processes, including divided and selective attention and global-local processing. In addition, it would be important to study how the use of MTSDs in early childhood affect socio-cognitive and socio-emotional development as children being frequently engaged in solitary activities at such an early age is a new phenomenon.

1.3. Current studies: aims and research questions

Our aims were to examine, in two separate studies using different samples of children, whether use of new media (MTSDs) affects attentional control and socio-cognitive/emotional skills. To this end, first, a cross-sectional, laboratory-based observational study (Study 1) was conducted to compare MTSD Users and Non-users on attentional and socio-cognitive/emotional skills. Second, to shed light on pertinent mechanisms, an experimental study (Study 2) was conducted wherein the media content that children were exposed to was manipulated. Our specific question was whether in children, the impact of digital games on attentional control (selective/divided attention, global-local processing) differs from that of non-digital games and whether game pace moderates observed effects (in case of the digital game). Our age-group of interest was preschoolers, given that while the preschool years are a sensitive period regarding cognitive development, preschoolers frequently use MTSDs, even for playing games, considerably more so than infants or toddlers (Konok et al., 2020).

Both studies were carried out in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki) and approved by the United Ethical Review Committee for Research in Psychology (EPKEB) (reference number of approval: Study 1: 2017/10 and Study 2: 2018/38). Written informed consent was obtained from all parents. In Study 2, parents were informed in advance that their child may play with a digital game on a tablet.

2. Study 1

2.1. Hypotheses and predictions

We hypothesized that intensive use of MTSD devices is associated with change in executive/attentional skills (H1.1). Based on previous studies on the assumed underlying psychological mechanisms, we expected atypical attentional control, i.e. local precedence in hierarchical attention tasks (P1.1), better divided attention skills (P1.2) and worse selective attention skills (P1.3) in Users vs. Non-users. Furthermore, we expected also that intensive MTSD use is associated with worse socio-cognitive (P1.4) and socio-emotional skills (P1.5).

2.2. Methods

2.2.1. Design

This study was an observational, cross-sectional study with two groups of children (Users and Non-users, see details below) compared on cognitive and socio-cognitive/socio-emotional tests.

2.2.2. Participants

Children were selected from a larger survey study ($N = 1270$, age range 0–8 years; WITHHELD Konok et al., 2020) wherein parents reported on their child's tablet and smartphone use (e.g., whether they use a device, frequency, length, and purpose or type of use, etc.) as well as demographic information. For inclusion in the current study, children had to be between 4 and 6 years of age and be free of developmental and psychiatric disorders. Using the larger database, the parents of 406 children who met the age criterion were contacted and asked to complete a screening questionnaire (see details below). The parents of 209 children completed the screening questionnaire, and 188 met the inclusion criterion of being free of psychiatric disorders (see section 2.2.3.1). Two clearly distinguishable groups of children were recruited: a "Non-user" (i.e., the child "has not used a tablet or smartphone on more than a few occasions") and a "User" (the child had been using a tablet or smartphone for at least one year, for an average of at least 15 min per day, and for at least one "active activity"[2]) group. Based on the responses in the larger survey, 121 children were clearly distinguishable as a user or a non-user and were thus recruited to participate in the behavioral test.

Of these, a total of 40 children (median age: 5 years; IQR = 4.64–5.56*;* 22 girls and 18 boys; 20 Users and 20 Non-users) participated. Both Non-user (median age: 5.1, IQR = 4.64–5.65) and User (median age: 5 years, IQR = 4.64–5.4) groups consisted of 9 boys and 11 girls. The median time Users spent with using MTSDs was 45 min per day (IQR = 21.1–168.9) and they had been using the MTSD for 3.05 ± 0.97 (*M* ± *SD*) years (range: 1.12–5.72). Nineteen watched videos (18 of them launched these themselves), 18 played with games, 17 used video-sharing websites, and 16 regularly took photos.

2.2.3. Procedure

To screen for psychopathology, the Strengths and Difficulties Questionnaire (SDQ; Goodman, 1997) and a question about prior diagnosis were used. Parents were e-mailed and asked to complete the online questionnaire with these measures. Those fulfilling the inclusion criteria were asked to come in to the laboratory at the Department of Ethology of Eötvös Loránd University (Budapest, Hungary) and participate in the

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[2] Active activity means that the child (besides passively viewing videos or being involved in video chat initiated by others) actively launches videos, plays games, takes photos, initiates calls, etc.

behavioral tests. Users' parents were asked to bring the tablet or smartphone that their child most frequently used at the time.

2.2.4. Materials

2.2.4.1. Screening questionnaire - SDQ. Parents completed the Hungarian version (Turi, Toth, & Gervai, 2011) of the SDQ, a 25-item screening scale validated for use with 3–16-year-old youth. It measures the presence of symptoms indicative of psychopathology in children. The SDQ has well-established psychometric properties, including diagnostic predictive validity (Goodman, 2001; Turi et al., 2011). The measure has five subscales: emotional symptoms, conduct problems, hyperactivity/inattention, peer relationship problems and prosocial behavior. The first four subscales comprise the total difficulties score (He, Burstein, Schmitz, & Merikangas, 2013). In addition, SDQ items on overall distress and impairment are summed to obtain an impact score. In the current study, scores on the first three subscales, the total difficulties and the impact score were used (but not peer relationship problems and prosocial behavior scores as those predict psychiatric diagnosis less; (He et al., 2013). The first three subscales had good internal consistency (αs > 0.75).

Exclusionary cut-off points were based on general practice that $\sim$10% of children fall into the disordered category (e.g., He et al., 2013). Therefore, children were excluded if their scores on any of the first three subscales or on total difficulties were >2 *SDs* above the mean (based on the $N = 209$ parents who completed the screening questionnaire; children with emotional symptoms >6, conduct problems >4, hyperactivity/inattention >7, and total score >18 were excluded) and their impact score was ≥ 1, or if their parents reported they had been diagnosed with a psychiatric disorder. Altogether, these two steps resulted in 21 exclusions, which is $\sim$10% of the questionnaire sample.

Descriptive statistics ($M \pm SD$, *range*) for the final sample ($N = 40$) for the three SDQ subscales are as follows: emotional symptoms 1.57 ± 1.53, range: 0–5; conduct problems: 1.8 ± 1.25, range: 0–4; hyperactivity/inattention: 4.06 ± 2.26, range: 0–9. These values are comparable but somewhat lower than those of another Hungarian non-clinical sample of 156 5-7-year-old children, presumably because contrary to our sample, in that sample, children with high scores were not excluded (Birkás, Lakatos, Tóth, & Gervai, 2008).

2.2.4.2. Behavioral tests. Behavioral tests were administered to measure attentional control (selective versus divided attention, global versus local processing) and socio-cognitive/socio-emotional skills.

2.2.4.2.1. Attentional control: navon test. To assess selective and divided attention and global/local processing of hierarchical stimuli, the adapted, preschool version (Sjöwall, Backman, & Thorell, 2015) of the Navon test (Navon, 1977) was modified and used. In a computerized task (programmed by B·F.) children were presented with large shapes (sun, star, snowman) made up of (congruent or incongruent) small shapes (sun, star, snowman; see Appendix). Children had to respond by pressing one of two buttons ("weak bear" and "sleeping bear"; see Appendix), depending on whether a target shape (sun) was present. First, children were familiarized with the shapes and trained which button to press. Composite shapes were presented only after this familiarization phase. In the selective-local session they had to indicate the presence of target shape only if it appeared at the local level (i.e., as small shapes), in the selective-global session only if it appeared at the global level (i.e., as a large shape), and, in the divided session, if it appeared either at the global or at the local level. Each session consisted of 9 trials: 9 possible combinations of the 3 shapes at 2 levels (3 congruent trials: in 1 trial target appeared at both levels, in 2 trials target appeared at neither level; 6 incongruent trials: in 2 trials target appeared only at the global level, in 2 trials target appeared only at the local level and in 2 trials target appeared at neither level). All sessions started with a practice phase, with a predetermined criterion to proceed to test trials. Half of the children in each group received the selective session (local and global together) first, and the divided session second, while the other half received them in reversed order. As arbitrary shapes and response choices (buttons) would have made working memory load too high for this age group, children were told a story that made the shapes and the buttons "meaningful" (about a bear who is hibernating and has to be woken up when the sun is shining). To maintain their motivation and interest children were also presented with short animations during practice phases (see Appendix). Reaction time (RT) and response accuracy (RA; i.e. whether the child pushed the correct button) were used as dependent variables.

2.2.4.2.2. Socio-cognitive/socio-emotional tests

Theory of mind (ToM)

Two tasks were used to measure ToM skills.

Contents false belief task ***(***Gopnik & Astington, 1988; Hogrefe, Wimmer, & Perner, 1986). This task measures children's ability to attribute a false prior belief to themselves and to comprehend that another person could have a false belief. To solve this task, children have to understand that the knowledge of people is not determined by the real state of the world, but by their often inaccurate mental representations. Children were shown a small container (Smarties box[3]) that contained an unexpected object (pencil). Children were allowed to look in the container and asked to (1) recall what they believed the container contained before having seen the unexpected object and (2) indicate what they believed another person, who has never seen the contents, would have thought was in the container. For saying that they previously thought and that another person would think that the container contained the expected rather than the actual object, children received one point each and for all other responses, children received zero points. Correct responses to two control (memory and reality) questions were prerequisite for children's test responses to be considered in analyses.

Real-apparent emotion task. (One story from the Harris, Donnelly, Guz, & Pitt-watson, 1986 version, modified by Wellman & Liu, 2004). This task is designed to measure whether children understand that overt behavior can differ from covert mental state; children have to recognize that a person can display one emotion but feel another. Children are told a story about a boy who wanted to hide an emotion he had (see Wellman & Liu, 2004, for full description) and then asked to reflect on the boy's portrayed and actual emotions. Children are given a sheet with a 7-point scale (with happy through neutral to sad faces) to use for indicating their response by pointing. In case of the current study, children had to indicate a more negative score for the actual than the portrayed emotion, for a score of 1.

Scores for the two test questions in the Contents false belief task and the Real-apparent emotion score were summed to create a ToM score (ranging from 0 to 3) used as a dependent variable in analyses.

Emotion-recognition

Two tasks were used to measure emotion recognition skills.

Static facial displays. Children were shown 12 photos of a boy and a girl, portraying one of six emotions: anger, fear, disgust, happiness, sadness and surprise, from the Radboud Faces Database (Langner et al., 2010) on a laptop, in random order.

Dynamic gestural displays. Children were shown six videos of 3 adult men, 2 adult women and 1 adolescent girl portraying one of the same six emotions by means of whole-body gestural movements, from the EU-Emotion Stimulus Set (O'Reilly et al., 2016) in random order.

In both tasks, children had to name the portrayed emotion. At the beginning of the static facial displays task, children received the following instructions: "I will show you photos of children, and you have to tell what the child in the picture may feel: whether (s)he is angry, afraid, happy, sad, surprised or disgusted." Following each of the first six photos and the first video of the dynamic gestural display tasks, the

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[3] Children who did not recognize the Smarties box were shown a Band-Aid box, and the unexpected content was a coin.

experimenter verbally listed the six available emotions (“So what do you think: this child/person is angry, afraid, happy, sad, surprised or disgusted?“). For the second six photos and the rest of the videos, the experimenter no longer listed the emotions (unless the child hesitated or was unable to respond). Across the tasks, scores for each correctly recognized emotion were summed to form an emotion recognition score (originally ranging from 0 to 18 but see Results below for stimulus exclusion).

Behavioral tests were administered in the following order, balanced for attentional burden: (1) Contents false belief task, (2) Navon test (3) Emotion recognition from faces, (4) Emotion recognition from body language, (5) Real-apparent emotion task, and (6) Validation of device use (only a subsample of Users). To validate parent report (obtained in the larger study), a subsample of the User children ($N = 13$) were asked to execute certain activities (mainly playing games, launching videos and taking photos) on the tablet or smartphone their parent indicated at the time of pre-screen. Whether the child was able to perform the activity autonomously (1 point), with help from the parent (0.5 point), or not at all even with help (0 point) was scored. The behavioral tests took 35–40 min.

2.2.5. *Data analysis*

Distributions of all variables were considered prior to analyses, and dependent variables with a non-Gaussian distribution were either transformed to obtain a normal distribution, or, when such a distribution could not be obtained, analyzed with non-parametric tests.

We checked if unintentional group-level biases occurred: Users and Non-users were compared given their demographics and order of selective/divided attention sessions of the Navon test with Mann-Whitney and Chi-squared tests.

In case of the Navon test, Users and Non-users were first compared given their performance in different test types (selective-global; selective-local; divided), independently from whether the target shape appeared at the global or local (or both/neither) level. General Linear Mixed Models (GLMM) and binomial Generalized Linear Mixed Models (GzLMM) were used with log-transformed RT on correct trials and with RA as the dependent variables, respectively. Initial models included device use and test type (selective-global; selective-local; divided) as independent variables, and their two-way interactions.

In addition, to investigate effects of target appearance level (local; global; both; neither) within test type (selective-global; selective-local; divided), separate analyses in the divided and in the selective attention sessions were ran. GLMMs of (log-transformed) RT and binomial GzLMMs of RA were constructed in these analyses similarly as above, but test type had two levels only (selective-global vs. selective-local) in the selective attention analysis, whereas this factor was missing from the divided attention analysis. In both analyses, the level of target appearance (local; global; both; neither) was added as a further independent variable.

In all models, non-significant terms were eliminated via stepwise backward model selection.

Emotion recognition scores were analyzed using linear regressions and association of device use and ToM scores was analyzed using ordinal regressions.

2.3. *Results*

2.3.1. *Similarity of groups and validation of device use*

Users and Non-users did not differ in terms of age ($U = 176.5$; $p = 0.525$), gender ratio (9 boys and 11 girls in each group), parental education ($U = 157$; $p = 0.236$) and order of selective/divided sessions of the Navon test ($\chi^2_1 = 0.030$; $p = 0.862$). In the subsample of Users (n=13), consistent with parent-report, children were able to carry out all MTSD activities autonomously, except for one child, who was able to execute one of the activities only with help.

2.3.2. *Attention: navon test*

Comparisons between test types (selective-global, selective-local vs. divided). Reaction time (RT) on correct trials was different between Test types ($F_{2,835} = 24.714$; $p < 0.001$); children were fastest in the selective-global session, and slowest in the divided attention task (Table 1). Response accuracy (RA) was also different between Test types ($F_{2,938} = 3.853$; $p = 0.022$; Table 1), because children gave fewer correct responses in the divided attention task than in the selective-global and the selective-local sessions. In contrast to P1.2 and P1.3, Device use had no significant effect on RT ($p = 0.827$), nor on RA ($p = 0.927$) (see Table 2).

Comparisons between target appearance levels in the divided attention task. Level of appearance had a Device use-specific effect on RT on correct trials, reflected in a significant two-way interaction between these factors ($F_{3,266} = 3.916$; $p = 0.009$). This interaction was driven by Users, relative to Non-users, reacting slower when the target shape appeared only at the global level, but there being no between-group performance difference in the other three trial types (Table 3, Fig. 1). As such, with regards to RT, the result was in line with P1.1. Level of appearance had an independent, main effect on RA ($F_{3,318} = 8.944$; $p < 0.001$), driven by children performing better when the target appeared at both or neither levels, as opposed to when it appeared at one level only (global or local; Table 3). Device use had no significant effect on RA ($p = 0.246$), thus, with regard to accuracy, the result was not in line with P1.1 (see Table 2).

Comparisons between test types and target appearance level in the selective attention task. RT on correct trials was different between Test types (selective-global/selective-local) ($F_{1,562} = 8.270$; $p = 0.004$): children responded more quickly when they had to indicate the target shape on the global as opposed to the local level (Table 4), independently of where the target actually appeared. None of the investigated variables influenced RA. In contrast to P1.1, Device use had no significant effect on RT ($p = 0.542$) and RA ($p = 0.472$) in the selective attention task (see Table 2).

2.3.3. *ToM*

Ordinal regression of ToM scores revealed differences based on Device use ($\chi^2 = 3.915$; $p = 0.048$); in line with P1.4, Users had lower ToM scores (see Table 2).

2.3.4. *Emotion recognition*

During the tests, it became apparent that not all children understood the term ‘disgust’. Therefore, data on photos and videos portraying disgust were excluded from the final analyses, so that emotion recognition scores ranged from 0 to 15. In contrast to P1.5, Device use was not associated with emotion recognition ($\chi^2 = 0.175$; $p = 0.676$) (see Table 2).

Table 1

Results of the GLMM of reaction time on correct trials and the binomial GzLMM of response accuracy (RA) as response variables, and test type (selective-global, selective-local, divided) and device use as fixed effects.

Response variable	Model Term	Parameter estimate ±SE	*t*	*p*
RT on correct trials	Intercept	7.724 ± 0.062	123.998	<0.001
	Test type *[SG → D]*	0.297 ± 0.042	7.003	<0.001
	Test type *[SG → SL]*	0.121 ± 0.042	2.861	0.004
RA (response accuracy)	Intercept	2.306 ± 0.233	9.901	<0.001
	Test type *[SL → D]*	−0.471 ± 0.254	−1.856	0.064
	Test type *[SL → SG]*	0.226 ± 0.288	0.785	0.433

Note. Only the significant effects from the final models are presented, with direction of change in factor levels (in case of interactions separately for the levels of factors) indicated in brackets. SG: Selective, global; SL: Selective, local; D: Divided.

Table 2
Descriptive statistics for the outcome variables separately for Users and Non-users.

Dependent variables			Users (M ± SD or % of correct responses)	Non-users (M ± SD or % of correct responses)
Navon test	All sessions together	RT on correct trials (sec)	3.03 ± 0.12	3.2 ± 0.16
		RA	89.5%	88.6%
	Divided session	RT on correct trials (sec)	3.73 ± 0.26	3.68 ± 0.24
		RA	82.7%	87.5%
	Selective-global session	RT on correct trials (sec)	2.54 ± 0.18	2.95 ± 0.23
		RA	93.5%	90.6%
	Selective-local session	RT on correct trials (sec)	2.85 ± 0.17	2.97 ± 0.17
		RA	92.8%	87.6%
ToM score			1.41 ± 0.87	2 ± 1
Emotion recognition score			10.74 ± 0.51	10.45 ± 0.48

Note. RT: reaction time; RA: response accuracy.

Table 3
Results of the GLMM of reaction time on correct trials and the binomial GzLMM of response accuracy (RA) as response variables, and device use and level of target appearance (local; global; both; neither) as fixed effects.

Response variable	Model Term	Parameter estimate ±SE	*T*	*p*
RT on correct trials	Intercept	7.968 ± 0.107	74.700	<0.001
	Level of appearance *[N → G]*	0.447 ± 0.111	4.027	<0.001
	Level of appearance *[N → L]*	0.026 ± 0.108	0.246	0.806
	Level of appearance *[N → B]*	−0.049 ± 0.120	−0.408	0.683
	Device use *[NU → U]*	−0.060 ± 0.151	−0.400	0.689
	Device use x Level of appearance *[G vs. N, NU → U]*	0.482 ± 0.152	3.163	0.002
	Device use x Level of appearance *[L vs. N, NU → U]*	−0.056 ± 0.151	−0.369	0.713
	Device use x Level of appearance *[B vs. N, NU → U]*	0.178 ± 0.169	1.053	0.293
Response accuracy (RA)	Intercept	2.767 ± 0.353	7.832	<0.001
	Level of appearance *[N → G]*	−1.903 ± 0.439	−4.340	<0.001
	Level of appearance *[N → L]*	−1.835 ± 0.441	−4.163	<0.001
	Level of appearance *[N → B]*	0.752 ± 1.058	0.711	0.478
	Device use *[NU → U]*	−0.643 ± 0.264	−2.434	0.019

Note. Only the significant effects from the final models are presented, with direction of change in factor levels (in case of interactions separately for the levels of factors) indicated in brackets. G: Global; L: Local; B: Both; N: Neither; U: Users, NU: Non-users.

3. Study 2

3.1. Hypotheses and predictions

In Study 2 we aimed to experimentally investigate two hypotheses. First, we hypothesized that even a brief exposure to MTSD use, i.e., gaming, influences attentional control (H2.1). Second, we hypothesized whether the speed of the game moderates the observed effects (H2.2).

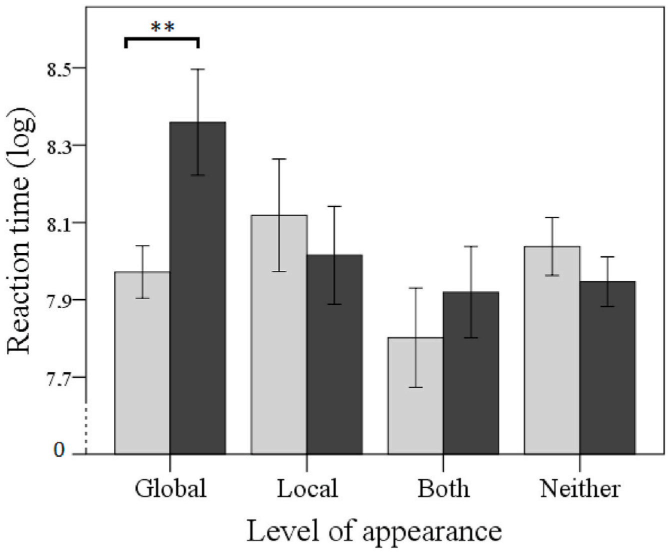

Fig. 1. Log-transformed reaction time (mean ± SE) in the divided attention task of the Navon test. Bars indicate different levels of appearance (global; local; both; neither) of the target shape for Users (black), and Non-users (grey), separately.

Table 4
Results of the general linear mixed model with RT on correct trials as response variable, and device use and test type (local; global) as fixed effects.

Model term	Parameter estimate ±SE	*t*	*P*
Intercept	7.820 ± 0.061	129.23	<0.001
Test type *[SL → SG]*	0.120 ± 0.042	−2.876	0.004

Note: Only the significant effects from the final models are presented, with direction of change in factor levels (in case of interactions separately for the levels of factors) indicated in brackets. SG: Selective, global; SL: Selective, local; U: Users, NU: Non-users.

Based on the results of Study 1, we predicted a similar effect for the brief digital gaming, i.e., local precedence in children playing with digital games and global precedence in those playing with non-digital games in the divided attention task (P2.1). However, based on Study 1, we expected that in a selective attention task, children will show global precedence independently of the experimental exposure (i.e., playing digital or non-digital games; P2.2). Although Study 1 did not find differences between Users and Non-users in divided and selective attention, it is possible that only fast contents improve divided and/or deteriorate selective attention. During fast games, users have to attend to multiple stimuli simultaneously which may improve their divided attention but deteriorate their selective attention skills, whereas during slow games, there are less stimuli simultaneously on the screen. We predicted, therefore, that children previously playing with a fast digital game should show worse selective attention, but better divided attention than children playing with a slow digital game or with a non-digital game (P2.3). Furthermore, due to the possible overstimulation effect of fast games, we expected that the general performance of children playing with fast digital games in the consecutive attention task should be worse than of children playing with slow or non-digital games (P2.4).

3.2. Method

3.2.1. Participants

Children (different participants than those included in Study 1) were selected from the same survey (*N* = 1270, age range 0–8 years; WITHHELD Konok et al., 2020). The study was also advertised online on the Lab home page and social media pages.

For inclusion in the current study, children had to be between 4 and 6 years of age, and they had to be free of developmental and psychiatric disorders.

A total of 62 children participated. One child had a diagnosis of expressive language disorder, but as the tasks did not require speech, she was not excluded. Due to technical reasons (the touchscreen did not always register touch), data of 6 children had to be excluded from analyses. The final sample consisted of 56 children (32 girls; median age = 4.9, IQR = 4.6–5.52).

From the 56 children, 39 used a mobile/tablet at the time of the study, for a median of 20 min daily (IQR = 14.46–48.75), and they had been using it for a median of 2 years (IQR = 1–2.5). 13 children did not use MTSDs, and related data are missing in case of 4 children (the parent did not respond to this question). From the 39 MTSD user children, 31 played games on MTSDs, for a median of 15 min daily (IQR = 10–20).

3.2.2. *Procedure and design*

The experiments were carried out in a test room at Eötvös Loránd University, Budapest, Hungary. Parents (from the database/who applied on our homepage, and whose children met inclusion criteria) were e-mailed and asked to complete a questionnaire electronically about their child's MTSD use, demographics and prior diagnosis as a pre-screen. Children whose parents did not report a prior developmental or psychiatric diagnosis were invited for the experiments.

The experiments took 30–40 min and were video-recorded. Children were tested one by one, and they were accompanied by at least one of their parents.

The experiments consisted of treatment and measurement phases.

Children were randomly assigned to one of three groups receiving different treatments (further details of the treatments are described below):

1. Slow digital treatment (n = 19): children played with a digital game on a tablet (balloon game, slow).
2. Fast digital treatment (n = 17): children played with the same digital game on a tablet as in the slow digital treatment, but the game had faster speed (balloon game, fast).
3. Non-digital treatment (control condition; n = 20): children played with a non-digital game, that was similar in many respects to the digital games, albeit with more variable speed (whack-a-mole).

Children received the treatment in blocks, as assessment (the Navon test) required 10 min, and it was assumed that the effect of the treatment (digital or non-digital game) would fade away in such time interval. (We considered the alternative solution of increasing the duration of the games, but refrained from doing so to avoid risking the games being too long and monotone.) Therefore, the treatment was divided into 2-min-long blocks, and each block was followed by a 3-4-min-long block of measurement and a short break (Table 5).

3.2.2.1. *Treatments*

3.2.2.1.1. Digital treatment. In this game (developed by Zs. J.) balloons are flying upwards, and the child's task is to explode them by touching them with his/her finger. If the child succeeds in exploding the balloon, the balloon disappears accompanied by an explosion sound and animation.

The experimenter could adjust the lifting speed (i.e., how much time it took for the balloons to reach the top of the screen from the bottom) and pop-up interval (time interval between two consecutive balloons to appear). Lifting speed was 5 s in the slow treatment, and 3 s in the fast treatment whereas pop-up interval was 850 msec in the slow treatment and 600 msec in the fast treatment.

3.2.2.1.2. Non-digital treatment. In the classic whack-a-mole game, the child has to push down moles that are popping-up, using their fingers. If the child succeeds in the right moment (when the mole is in the upmost position), then the game makes a sound (music). Therefore, the game is very similar to the digital balloon game, except that it does not appear on a digital, two-dimensional screen but in the three-dimensional reality. The speed of this game was more variable than that of the digital games: the pop-up interval (time duration between mole pop-ups) varied between 100 and 2800 msec.

Table 5
Test phases and durations.

Test phase	Duration
Treatment [Non-digital; Slow digital; Fast digital]	2 min
Navon test: familiarization (story, see section 3.2.3.2)	~2 min
Break	1 min
Treatment [Non-digital; Slow digital; Fast digital]	2 min
Navontest, 1st block: 1 session from all test types with practice	~4 min
Break	1 min
Treatment [Non-digital; Slow digital; Fast digital]	2 min
Navon test, 2nd block: 1 session from all test types	~3 min

3.2.3. *Measures*

3.2.3.1. Questionnaire about mobile use, demographics and psychiatric diagnosis. Prior to the experiments, parents reported on whether their child uses tablets or smartphones (MTSD), the length of time for which the child has been using it, and the length of time for which the child uses it on an average day. Parents were also asked whether their child plays games on the MTSD, and the length of playing time on an average day. Parents also reported on age and gender (for both the parent and child) and parental education level. Parents were asked about their child having a psychiatric diagnosis (and the nature of such diagnosis).

3.2.3.2. Attentional control: navon test. For measuring selective and divided attention and global/local processing, the preschool version (Sjöwall et al., 2015) of the Navon test (Navon, 1977) was modified. The test was almost the same as the one in Study 1, but it was developed as a mobile touchscreen application (programmed by Zs. J.), and the trials differed as follows. Each test type (selective-local; selective-global; divided*)* consisted of 8 trials: in 2 trials target appeared at both levels, in 2 trials target appeared at neither level, in 2 trials target appeared only at the global level and in 2 trials target appeared only at the local level. The order of stimuli was randomized within test type. There were two blocks of test trials (separated with a treatment block and a break, Table 5), and each test block consisted of three test types (selective-local, selective-global and divided sessions), presented in a random order. Before the two test blocks there was a familiarization block. Response accuracy (RA; 0/1) was used as dependent variable.

3.2.4. *Statistical analysis*

First, Chi-square and Kruskal-Wallis tests were conducted to investigate whether the treatment groups differed with regard to demographic variables (child age and gender, parent age and education) and MTSD variables (daily MTSD use, length of use, daily gaming).

In the Navon test, only the test trials were analyzed (i.e., practice trials were excluded). A binomial GzLMM was conducted to assess for effects of treatment, test type (selective-local; selective-global; divided) and daily gaming as fixed effects and their two-way interactions on RA as the response variable.

In addition to the above analyses, the effect of target appearance level was analyzed in the divided and selective attention test types, separately. For the divided attention test type, the binomial GzLMM of RA as the response variable included treatment, target level (local; global; both; neither) and daily gaming as fixed effects, and their two-way interactions. For the selective attention (local and global) test types, the binomial GzLMM of RA as the response variable included treatment, target level (local; global; both; neither*)*, test type (selective-local vs. selective-global) and daily gaming as fixed effects, and their two-way interactions.

In all models, non-significant terms were excluded by backwards model selection.

3.3. Results

3.3.1. Group comparison on demographic variables

Treatment groups were not different with regard to child age ($\chi^2_2 = 0.011$; $p = 0.994$), gender ($\chi^2_2 = 1.764$; p=0.414), parental age ($\chi^2_2 = 1.555$, $p = 0.459$) or education level ($\chi^2_2 = 2.476$; $p = 0.29$). Groups were also comparable in the ratio of children who use MTSDs regularly ($\chi^2_2 = 0.842$; p=0.656) and play games on MTSDs ($\chi^2_2 = 0.096$; $p = 0.953$). In addition, time Users spent on MTSD use ($\chi^2_2 = 0.223$; $p = 0.894$) or gaming ($\chi^2_2 = 0.965$; $p = 0.617$) were also similar between groups, as well as how long they had been using MTSDs ($\chi^2_2 = 0.319$; $p = 0.852$).

3.3.2. Attentional control (navon test)

3.3.2.1. Effects of treatment on general performance, selective attention, and divided attention. In contrast to P2.4, the treatment had no significant main effect on RA ($p = 0.299$) (see Table 6). However, test type had a treatment-specific effect on RA (effect of test type x treatment: $F_{4,2452} = 2.661$; $p = 0.031$). In line with P2.3, in the non-digital group, children tended to perform better on selective-local and selective-global test types than on the divided attention test type ($F_{2,857} = 2.715$; $p = 0.067$). In the slow digital group, this difference was more pronounced ($F_{2,920} = 11.308$; $p < 0.001$). However, in the fast digital group, performance was not different across test types ($F_{2,675} = 0.146$; $p = 0.864$; Table 7, Fig. 2). Comparison of test types across treatment groups in separate GzLMMs showed no group differences in selective-local, selective-global or divided test types (all $ps > 0.12$).

Daily gaming, and its interactions had no significant effect on RA (all $p > 0.3$).

3.3.2.2. Local-global processing in divided attention. On the divided test, target level had a treatment-specific effect on RA (effect of target level x treatment: $F_{6,793} = 2202$; $p = 0.041$; Fig. 3; see Table 8): in line with P2.1., the differences between local and global trials in the digital groups were in the opposite direction (local > global) compared to the non-digital group (global > local). Separate models for each treatment indicated this difference was significant in the slow digital group only (non-digital: $F_{1,135} = 2.544$; $p = 0.113$; slow digital: $F_{1,144} = 12.063$; $p = 0.001$; fast digital: $F_{1,106} = 1.779$; $p = 0.185$; Fig. 3; Table 9). Comparison of the same target levels across treatment groups (i.e., the reverse of the above analyses) showed that child performance on global trials was better in the non-digital group than in the slow digital group, but their performance did not differ across treatments in local trials (local: $F_{2,192} = 1.827$; $p = 0.164$; global: $F_{2,193} = 3.075$; $p = 0.048$; Fig. 3; Table 10).

3.3.2.3. Local-global processing in selective attention. In line with P2.2, on selective tests, only target level had an effect on RA ($F_{3,1652} = 15.693$; $p < 0.001$) with better performance in “neither” and “both” trials than in local and global trials (percentage of correct responses; “neither”: 96.1%; “both”: 93%; global: 84.3%; local: 83.5%).

Table 6

Descriptive statistics for response accuracy (percentage of correct answers) in the Navon test, separately for the three treatment groups.

Session	Non-digital group	Slow digital group	Fast digital group
All sessions together	86.3%	89.1%	86.1%
Divided session	82.4%	81.9%	86.1%
Selective-global session	87.6%	92.5%	87%
Selective-local session	88.7%	92.6%	85.3%

Table 7

Results of the three separate binomial GzLMMs (based on treatment) with response accuracy (RA) as response variable and test type (selective-global; selective-local; divided) as fixed effects.

Treatment	Model Term	Parameter estimate ±SE	*t*	*p*
Non-digital	Intercept	2.028 ± 0.222	9.118	<0.001
	Test type [D → SG]	0.427 ± 0.241	1.774	0.076
	Test type [D → SL]	0.534 ± 0.251	2.131	0.033
	Test type [SG → SL]	0.107 ± 0.262	0.409	0.683
Slow digital	Intercept	2.526 ± 0.240	10.528	<0.001
	Test type [D → SG]	1.010 ± 0.264	3.823	<0.001
	Test type [D → SL]	1.033 ± 0.264	3.910	<0.001
	Test type [SG → SL]	0.023 ± 0.308	0.074	0.941
Fast digital	Intercept	1.862 ± 0.237	7.866	<0.001
	Test type [D → SG]	0.082 ± 0.278	0.296	0.767
	Test type [D → SL]	−0.066 ± 0.273	−0.241	0.810
	Test type [SG → SL]	−0.148 ± 0.274	−0.540	0.589

Note. Direction of change of factor levels is indicated in brackets. SG: Selective-global; SL: Selective-local; D: Divided.

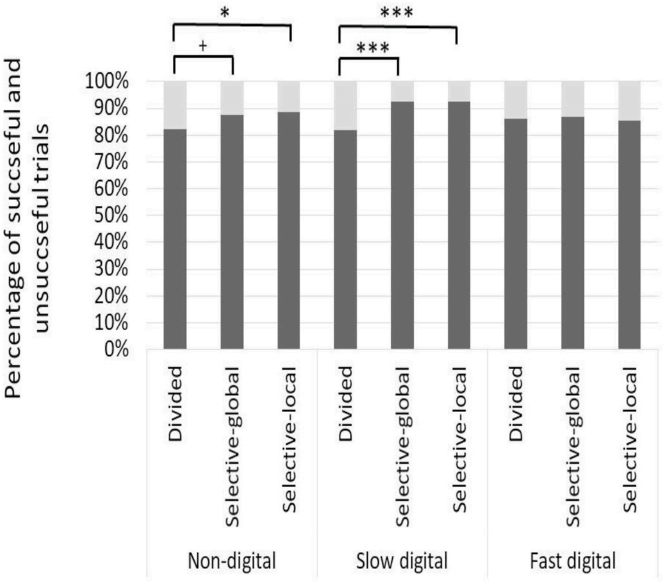

Fig. 2. Percentage of successful and unsuccessful trials (i.e., whether the child pushed the correct button or not) in different test types (divided; selective-global; selective-local), depicted separately for children in different treatment groups (non-digital; slow digital; fast digital). Dark grey colour indicates successful trials, light grey colour indicates unsuccessful trials.

4. Discussion

Our aims across these two studies were to examine associations between mobile device use and attentional control and socio-emotional skills in preschool children, and to investigate the mechanisms underlying these associations by assessing how exposure to fast and slow digital games and a non-digital game affects attentional control in preschoolers. Although correlational studies are available (e.g., Bedford et al., 2016; Li & Atkins, 2004), there are – to the best of our knowledge – none, wherein MTSD use was experimentally and systematically manipulated (but see, for systematic investigations of videogames and TV programs e.g., Sestir & Bartholow, 2010; Kostyrka-Allchorne et al., 2017a).

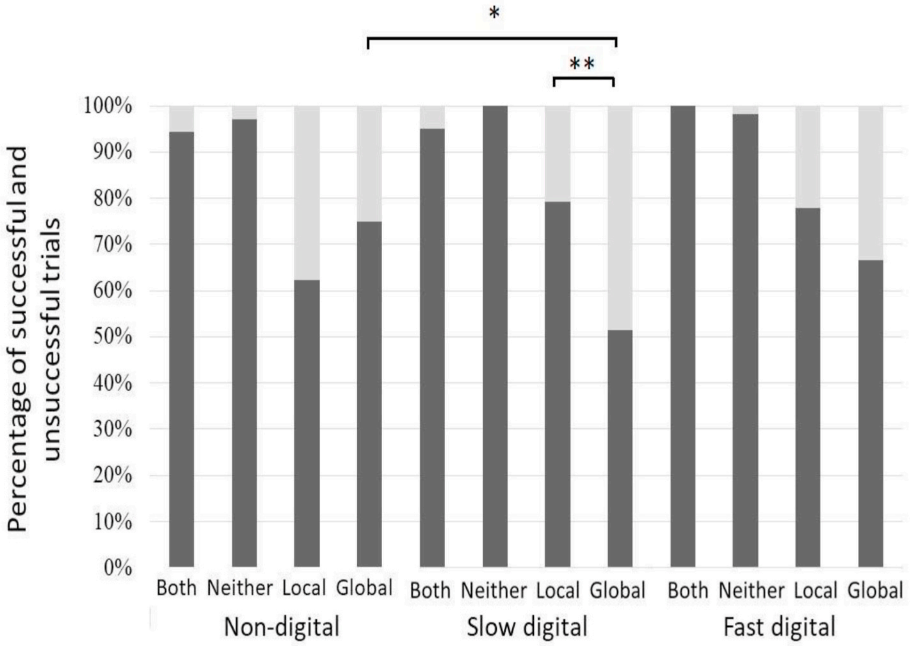

Fig. 3. Percentage of successful and unsuccessful trials (i.e., whether the child pushed the correct button or not) in different target level appearance (both; neither; local; global), depicted separately for different treatment groups (non-digital; slow digital; fast digital). Dark grey colour indicates successful trials, light grey colour indicates unsuccessful trials.

Table 8
Descriptive statistics for response accuracy (percentage of correct answers) in the divided attention session of the Navon test, separately for the three treatment groups.

Level of appearance	Non-digital group	Slow digital group	Fast digital group
Large (global trials)	75%	51.4%	66.7%
Small (local trials)	62.3%	79.2%	77.8%
Both (congruent trials)	94.4%	95%	100%
Neither (congruent trials)	97.1%	100%	98.2%

Table 9
Results of separate binomial GzLMMs for each treatment group (non-digital; slow digital and fast digital) with response accuracy (RA) in the divided attention task as response variable and target level (local; global) as a fixed effect (so that trials when target appeared at both or neither level were excluded).

Treatment	Model Term	Parameter estimate ±SE	*t*	*p*
Non-digital	Intercept	0.498 ± 0.258	1.929	0.056
	Global → Local	−0.598 ± 0.375	−1.595	0.113
Slow digital	Intercept	1.345 ± 0.317	4.247	<0.001
	Global → Local	1.307 ± 0.376	3.473	0.001
Fast digital	Intercept	1.323 ± 0.370	3.578	0.001
	Global → Local	0.590 ± 0.442	1.334	0.185

Note. Direction of change of factor levels is indicated in brackets.

Table 10
Results of the separate binomial GzLMMs based on target level (local; global) with response accuracy (RA) in the divided attention task as response variable and treatment (non-digital; slow digital; fast digital) as a fixed effect.

Target level	Model Term	Parameter estimate ±SE	t	p
Local	Intercept	0.545 ± 0.358	1.522	0.130
	Non-digital → Slow digital	0.923 ± 0.530	1.743	0.083
	Non-digital → Fast digital	0.824 ± 0.568	1.452	0.148
	Slow digital → Fast digital	−0.99 ± 0.589	−0.168	0.867
Global	Intercept	1.100 ± 0.337	3.262	0.001
	Non-digital → Slow digital	−1.076 ± 0.447	−2.409	0.017
	Non-digital → Fast digital	−0.364 ± 0.492	−0.740	0.460
	Slow digital → Fast digital	0.712 ± 0.463	1.537	0.126

Note. Direction of change of factor levels is indicated in brackets.

4.1. Attentional control: local vs. global focus

Findings obtained in Study 1 revealed, consistent with earlier observations of typically developing youth and adults (Plaisted et al., 1999), that both MTSD User and Non-user children exhibited a global precedence in selective attention tasks (i.e., when instructed to attend to either the global or the local aspects of stimuli, their responses were quicker to global aspects). Users differed from Non-users, however, in the divided attention task, the latter group showing a pattern similar to typically developing children (as indicated in prior research; Plaisted et al., 1999). That is, when required to simultaneously attend to global and local aspects of stimuli, Users exhibited local precedence (they were faster when the target appeared at the local level), unlike Non-users or typically developing children, who showed a global precedence. The results of Study 2 provide experimental support for these findings, whereby in the selective attention task, children in all groups showed a global precedence, however, in the divided attention task, children who played with a digital game showed a local precedence in contrast to children who played with a non-digital game. As participants were randomly assigned to experimental groups, our data support the causal inference that, on the short-term, playing digital games results in the observed shift from global to local processing. As Users by definition frequently play digital games, this likely explains why in Study 1 they also showed local precedence in the divided attention task.

This presence of typical global processing in one task but not in the other could mean that, in the absence of voluntary selective attention to global information, Users have a deficit in inhibiting local information (Plaisted et al., 1999). In other words, they are not disabled to attend to global aspects but for them, doing so is not automatic (Koldewyn, Jiang, Weigelt, & Kanwisher, 2013). This may be attributable to MTSD use often requiring focus onto fine details and execution of precise motor movements, thereby enhancing attention to local stimulus features (Job et al., 2017). Additionally, digital screens reveal only a portion of the entire picture or stimulus at a time (one has to scroll downwards or upwards for the entire image; Manguel, 1996) and in contrast to printed documents, where flipping and scanning helps us get a sense of the whole text, scrolling on a computer screen does not support this mode of information processing (Liu, 2005).

4.2. Attentional control: divided vs. selective attention

On the Navon test in Study 2, children in the non-digital and slow digital groups performed better on the selective attention test than on the divided attention test, whereas children in the fast digital group performed similarly on the two tasks, evincing that the advantage of selective over divided attention disappeared. (Although group differences were not large enough to get significant differences between groups in selective and divided attention performance.) Perhaps having to attend simultaneously to multiple stimuli in the fast game trains divided attention (and thus leads to subsequent improvement in performance), but not selective attention. Consistent with this hypothesis, prior results show that in adults, greater experience with videogames is linked to better divided attention skills (Greenfield et al., 1994; for a review see; Bediou et al., 2018), and frequent videogame-player preschoolers react more quickly than non-players in a parallel-processing task (Yuji, 1996). Nevertheless, our experimental setup does not allow for distinguishing whether it was divided attention that improved or selective attention that decayed, or both (neither change was significant). As multitasking has been found to be associated with more limited selective attention (Ophir et al., 2009), it is also plausible that the fast digital game deteriorated this skill. Although we assumed that the fast digital game will be overstimulating and cause a decrement in general performance (this was not confirmed), it seems to affect attentional control in a subtler way, and not necessarily in a negative direction. However, longitudinal studies are needed to definitively determine whether longer use leads to similar effects.

4.3. Socio-cognitive/-emotional skills

4.3.1. Theory of mind

As expected, Users exhibited worse ToM skills than Non-users. This corroborates previous findings on the effects of excessive media use: higher TV exposure has been linked to poorer ToM performance in preschoolers (Nathanson et al., 2013) and more screen activity during daily routines has been linked to delays in social-emotional development (Raman et al., 2017).

The development of ToM skills requires considerable experience with social interactions and non-digital play, and device use takes time away from these activities (Vandewater et al., 2007). MTSD User children are more likely to have parents who are also intense MTSD users (Konok et al., 2020; Pempek & McDaniel, 2016), and parental MTSD use likely decreases resources allocated towards quality family interactions (Radesky et al., 2015), thus delaying or restricting socio-cognitive development in children.

Users may have pre-existing characteristics that may make them more likely to use MTSDs. For example, children with worse social skills may be more interested in solitary activities, such as MTSD use (Mazurek, Shattuck, Wagner, & Cooper, 2012). Therefore, the association between weaker ToM performance and MTSD use could be bidirectional and reinforcing. As Study 1 (wherein ToM skills were measured) was not experimental, findings do not permit causal inferences. However, as our experimental study (Study 2) showed that using digital games leads to local focus, and ToM performance requires a holistic approach (Jarrold, Butler, Cottington, & Jimenez, 2000), it is realistic to assume that using MTSDs leads to local focus in many areas including the social-cognitive domain. This assumption, however, needs to be corroborated by further experimental studies.

4.3.2. Emotion recognition

In contrast to ToM skills, no evidence of worse emotion recognition was observed in MTSD users in Study 1. Emotion recognition is based on phylogenetically ancient mechanisms, e.g., emotional contagion or automatic mimicry, some of the earliest socio-emotional skills (de Waal, 2008), found even in rodents (Langford et al., 2006). In contrast, ToM requires thoughts about the inner states of others and taking the perspective of others (Shamay-Tsoory, 2011). It is intertwined with executive processes (Carlson & Wang, 2007) such as flexibility and inhibition, its building blocks can only be found in a few animal species (including our closest relatives; Call & Tomasello, 2008). It is possible that compared to more basic emotional skills, social experience in early childhood is more important for higher-order, cognitive ToM skills and this may mean that digital media use may have a more detrimental effect on ToM-related skills.

4.4. Limitations and alternative explanations

Sample sizes were relatively small, as a result of participants representing the unique and young subpopulation of heavy user preschoolers. We also intended to minimize both participant and researcher burden. Nevertheless, findings across the two studies with different participants converge, enhancing generalizability of the results.

Study 1 was not an experimental study and, as such, it does not permit causal inferences. Although experimental manipulation in the second study confirmed the global-local focus findings, the socio-cognitive skills results need replication in future studies.

Additionally, Users in Study 1 may have performed worse on ToM but not on emotion recognition tasks because the former were not, but the latter were presented on a laptop. This alternative explanation cannot be excluded. Users may process information on screen better than Non-users and this may overwrite any emotion recognition deficits they may have. It will be important to assess Users' emotion recognition skills in a non-digital setting.

In Study 2, although we aimed to identify a digital and a non-digital game that are as close to each other as possible, in as many respects as possible, additional (beyond being digital/non-digital) differences between the two kinds of games, might have caused performance differences between the groups. For example, the non-digital game (whack-a-mole) plays music when a mole is pushed down, and the toy is colorful. Conversely, in the balloon game, there is no music (only explosion sound effects) and its visualization is relatively simple (simple, single-colored balloon shapes, no background images). It is possible that the rich perceptual information fosters both creative, holistic thinking and global attentional focus, while the simpler 2D images with artificial sounds foster analytic, logical thinking with local focus (Friedman, Fishbach, Förster, & Werth, 2003).

Besides, there are slight differences in the cognitive processes required for successful performance across the two kinds of games; in the balloon game, to tap in the right location and thus pop the balloon, the user has to compute and predict the path of the balloons while those are continuously moving upwards. Conversely, in the whack-a-mole game, the challenge is to compute the right time to whack the moles that are continuously popping-up. Additionally, in the balloon game, only one or a few balloons are presented at a time whereas in the whack-a-mole game, all moles are present at all times. There is a local processing priority for few-element stimuli and a global processing priority for many-element stimuli (Martin, 1979) and this may also potentially contribute to children showing local precedence after the balloon game. Finally, the whack-a-mole game requires some response inhibition (to push the popping mole but not the others), whereas in the balloon game, the goal is to explode all balloons.

4.5. Conclusions

Infants growing up today represent the first generation of individuals who begin using digital devices starting almost as soon as at birth. This presents researchers with an exceptional opportunity to study the development of user children in comparison to non-users, especially given that with the current trends continuing, it may be difficult in a few years to identify non-user children. Therefore, in light of the potentially long-lasting and widespread effects of device use on cognitive skills in children, and thus educational, social, and later occupational functioning, there is urgent need for further empirical research, including longitudinal studies. In addition, focused experimental studies are required to reveal the mechanisms through which MTSD use may impact cognitive development. It is also important to investigate the type of and the aspects of contents (e.g., pace) that have positive or negative effects, to inform parents, teachers and policy about what contents to foster and avoid. The findings of such studies may inform much-needed and novel pediatric guidelines for the appropriate use of MTSDs in childhood which could help preventing potential MTSD-related problems (e.g., socio-emotional and attention problems, addiction, social isolation, depression, etc.), and new applied informatics solutions can be developed to bolster possible positive effects and compensate for negative ones.

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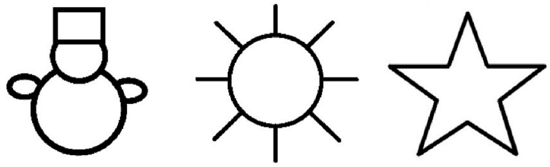
Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.chb.2021.106758.

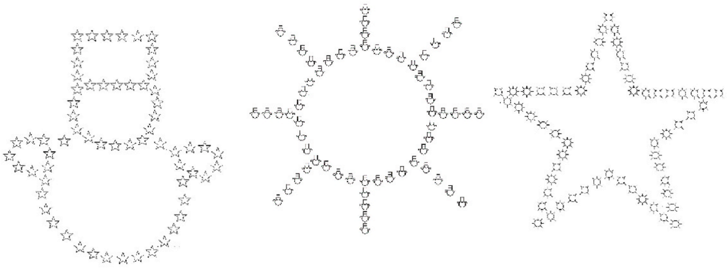
Appendix

Stimuli used in the Navon test.

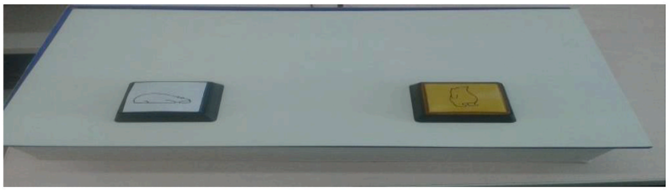
Shapes presented in the familiarization phase:



Examples of the composite shapes used in the test phase:



Buttons in Study 1 (in Study 2, the same icons were used on the touchscreen):



Animations in the familiarization and practice phases (in response to the child's reaction):

Animations in the familiarization and practice phases (in response to the child's reaction):

		Stimuli	
		Sun shape is not present at the level to be attended to	Sun is present at the level to be attended to
Child's reaction	The child pushes the 'sleeping bear' icon	Bear is hibernating	Bear gets thin and hungry because of too long hibernation
	The child pushes the 'wake bear' icon	Bear wakes up but the weather is cold and the bear is shivering	Bear wakes up and happy, as the sun is shining

Credit author statement

Veronika Konok: Conceptualization, Methodology, Investigation, Formal analysis, Writing – original draft. Krisztina Peres: Conceptualization, Methodology, Investigation, Writing – review & editing. Nóra Bunford: Writing – review & editing. Bence Ferdinandy: Software. Zsolt Jurányi: Software. Dorottya Júlia Ujfalussy: Conceptualization, Methodology. Zsófia Réti: Investigation. Ákos Pogány: Formal analysis, Writing – review & editing. George Kampis: Conceptualization, Funding acquisition. Ádám Miklósi: Conceptualization, Writing – review & editing, Supervision

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