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# Toddlers on touchscreens: immediate effects of gaming and physical activity on cognitive flexibility of 2.5-year-olds in the US

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**ABSTRACT**

Interactive technologies have become a common play medium for young children; it is not unusual for toddlers to play games on a touchscreen device in lieu of games in the yard. Here, we compared the immediate effects of physical and touchscreen play on 2.5-year-olds' cognitive flexibility, a key aspect of executive function. For nine minutes, toddlers engaged in touchscreen play or physical play; a third group drew and colored (control group). Next, a sorting task measured cognitive flexibility. The physical-play group outperformed the other two groups. Compared to the control group, toddlers' cognitive flexibility benefited from physical play, whereas touchscreen play yielded no significant effect. Interestingly, toddlers who played the touchscreen game in a socially interactive way outperformed those who treated gaming as solitary play. Together, the results bear practical implications on whether and how to introduce young children to interactive technologies for play.

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Toddlers across many communities are provided with ready access to technology as a medium for play (Christakis & Garrison, 2009; Lapierre, Piotrowski, & Linebarger, 2012; Rideout, 2013, 2017; Wartella & Robb, 2008). This is evident in commercial supplies of tablet applications (apps) for toddlers and preschoolers, which constitute the majority (72%) of the top paid apps in the Education section of the Apple App Store (Shuler, Levine, & Ree, 2012). Notably, increased exposure to TV and digital apps is linked to 3- to 15-year-old children's reduced physical activities (Danner, 2008; Hinkley, Salmon, Okely, Crawford, & Hesketh, 2012; Taveras et al., 2007); increases in home media usage were accompanied with decreases in sports, outdoor activities, and non-screen play in 6- to 12-year-olds (Hofferth, 2010). The shift toward technology use and away from physical activity raises the critical need for evidence-based research with children to understand its potential impacts on early cognitive development.

One facet of cognitive development particularly related to early use of technology is executive function (EF), broadly defined as a higher order cognitive process that assists with the management of thoughts and actions. EF undergoes rapid development during the first 5 years as the brain increases its production of synapses (Nelson, Thomas, & Haan, 2006). Children's everyday experiences could affect which synaptic connections get strengthened or pruned (Nelson & Bloom, 1997; Singer, 1995), contributing to

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individual differences in EF that emerge around ages 2–3 years (Carlson, Mandell, & Williams, 2004; Diamond, 2002). EF is generally broken down to various aspects including inhibitory control, working memory, and cognitive flexibility (CF) (Anderson, 2002; Best & Miller, 2010; Carlson, 2005; Miyake et al., 2000; Zelazo et al., 2003).

The present research focuses on the less studied aspect – cognitive flexibility, the ability to switch between sets of rules. CF enables children to shift attention from irrelevant to key information and update current knowledge with new information, and is crucial for early learning. CF in 2- to 4-year-olds has been linked to several areas of development, such as theory of mind, language ability, set shifting, and various measures of academic success (Bull & Scerif, 2001; Carlson et al., 2004; Farrant, Maybery, & Fletcher, 2012; Jacques & Zelazo, 2005). CF is also thought to interact with working memory to update current knowledge with new information (Hendry, Jones, & Charman, 2016) and with inhibitory control to refrain from applying previous strategies that are no longer appropriate for the task at hand, making it possible for children to switch to better strategies (e.g., Best & Miller, 2010; Carroll, Blakey, & FitzGibbon, 2016). Given these important functions, it is surprising that research to date has paid relatively less attention to potential factors that affect early development of CF.

Prior research on media and EF in toddlers has primarily investigated the effects of TV watching on working memory and inhibitory control, leaving out the effects on CF. Research related to CF has been mostly conducted with preschool- and school-aged children, or on the younger end with infants on functional fixation and perseveration (McCarty & Keen, 2005; Moriguchi & Hiraki, 2011; Needham, 2016; Wiebe et al., 2011), leaving an empirical gap of the toddler age. Filling this gap is critical for methodological and theoretical reasons. *Methodologically*, there are unique challenges to measure CF with toddlers: Tasks designed to measure CF generally involve high cognitive demands and lengthy procedures, making them difficult for 2- to 3-year-olds to complete. A sensitive CF task with greater feasibility for toddlers will advance the methodology of this research. *Theoretically*, research on CF has been driven and constrained by the design of existing tasks that tend to measure one single aspect of CF, making it difficult for researchers to gain a comprehensive understanding of this nuanced construct (Carroll et al., 2016; Deák & Wiseheart, 2015). Specifically, many existing tasks designed to measure CF tend to focus on measuring children's ability to overcome perseveration errors. Consequently, they are too narrow to address the contributions of other cognitive processes that could be involved in CF.

Recent research has made theoretical advances to the study of CF, providing new empirical evidence of developing skills in toddlers. Using the Switching, Inhibition, and Flexibility Task, Blakey Visser and Carroll (2016) found that 2- to 3-year-olds develop the ability to switch between rules in the presence of distracting stimuli (i.e., when the incorrect answer does not match the target in any dimension), but not in the presence of conflicting stimuli (i.e., when the incorrect answer matches the target in some dimension). This finding suggests that different aspects of CF may develop at different rates. However, empirical research that focuses on toddlers' CF is still limited. The present research examined the effects of physical activity and technology use on toddlers' CF.

Research on technology use by young children has primarily investigated a particular form of screen activity – TV watching (Lillard, Drell, Richey, Boguszewski, & Smith, 2015; Nathanson, Aladé, Sharp, Rasmussen, & Christy, 2014), by relating young children's history of

TV watching to their attention and EF. This work has yielded somewhat mixed results. For example, early exposure to TV has been negatively associated with children's attention and behavioral problems in the first grade (Christakis, Zimmerman, DiGiuseppe, & McCarty, 2004; Zimmerman & Christakis, 2007). Similarly, Nathanson et al. (2014) found that children who started to watch TV at an earlier age and children who had greater exposure to foreground and background TV tended to perform worse on EF tasks. However, Nathanson et al. (2014) also showed that not all TV watching resulted in a negative impact: Watching educational TV programs on PBS was associated positively with EF. The explanation offered for these mixed results tends to focus on the pacing or the fantastical nature of the content (Lillard et al., 2015; Lillard & Peterson, 2011). However, these findings may not extend to newer forms of screen activity such as using touchscreens for play.

Children's experience with touchscreens differs from TV watching in several respects. First, touchscreens, unlike most TV programs, contingently respond to children's action (Hipp et al., 2016; Hirsh-Pasek et al., 2015). Second, touchscreens provide activities beyond TV watching, including educational and non-educational games, and creative tasks such as drawing. Third, the interactive nature of touchscreens allows toddlers to adjust pacing and difficulty according to their needs and preferences (Hipp et al., 2016; Kirkorian, Choi, & Pempek, 2016). Consequently, individual differences may be greater in children's touchscreen usage than in TV watching. Based on these reasons, whether findings on TV watching will extend to touchscreen play is still an open question.

In contrast to TV watching, physical activity has been consistently linked to positive impacts on children's cognition (Best, 2012; Chang, Labban, Gapin, & Etnier, 2012; Hillman et al., 2009). For example, 20 min of walking on a treadmill produced an immediate boost on 9.5-year-olds' attention and performance on a school-based test (Hillman et al., 2009). In addition, 6- to 10-year-olds' physical activity exertion during exergames (i.e., video games that require body movement) immediately boosts their performance in a flanker task (Best, 2012; Flynn, Richert, Staiano, Wartella, & Calvert, 2014). One potential mechanism underlying these benefits is through physiological arousal that increases activation in brain regions for cognitive functioning (Audiffren, 2009; Best, 2010; Budde, Voelcker-Rehage, & Pietraßyk-Kendziorra, Ribeiro, & Tidow, 2008). Consistent evidence for the benefits of physical activity on cognition has been obtained mainly with school-aged children. The present research directly compared toddlers' CF after they have engaged in physical play or other activities (touchscreen play or drawing), to examine whether toddlers benefit from physical activity as older children do.

Our secondary goal was to investigate how toddlers play game apps on touchscreens. Although surveys have pointed out the increased prevalence of touchscreens in toddlers' lives (Cristia & Seidl, 2015; Holloway, Green, & Livingstone, 2013; Rideout, 2013, 2017), empirical evidence on how they use touchscreens is limited. A recent study quantified the ways in which toddlers completed a touchscreen puzzle during an imitation task and found that although they learned the target actions (i.e., swiping a piece to the right), they did not achieve the goal in the most efficient manner (Moser, Zimmerman, Dickerson, Grenell, Barr, & Gerhardstein, 2015). Despite these research efforts, questions concerning toddlers' approach to playing with touchscreens in everyday life are left open. How do toddlers approach this new form of play? Do they treat it as a socially interactive or solitary activity?

Social interaction has been shown to mediate children's language experience during TV watching. When adult-directed TV was on, parents tended to respond more passively to their children's requests (Kirkorian, Pempek, Murphy, Schmidt, & Anderson, 2009) and used fewer words than when the TV was off (Pempek, Kirkorian, & Anderson, 2014). In contrast, when watching age-appropriate TV programs with their children, parents were more engaged and asked more content-related questions (Barr, 2008), which may have helped children focus on relevant information. Live social interaction also facilitates children's ability to replicate information portrayed on a touchscreen: Zimmerman and colleagues (2016) showed that after watching a person complete a 2D puzzle on a touchscreen, 2.5- to 3-year-olds were better at replicating the completion of a puzzle than after watching the puzzle pieces move into place on their own. Moreover, social guidance mediates children's learning with computers: Flynn and Richert (2015) showed that preschool-aged children demonstrated greater recognition of letters and numbers when parents provided content-focused guidance than device-focused guidance. Finally, it has been argued that social experience, such as parenting, is linked with EF (Carlson, 2009). For example, Bernier, Carlson, and Whipple (2010) showed that maternal sensitivity, mind-mindedness, and autonomy support for 12- to 15-month-olds during puzzle play are positively correlated with EF at 18 to 26 months. It is thus plausible that social interaction during the use of technology may be beneficial for toddlers' EF. We explored this question with a focus on CF.

To summarize, the present research aimed to (1) compare toddlers' CF after physical play, touchscreen play, or drawing and (2) explore whether the effects of touchscreen play on CF are influenced by the level of social interactivity. First, previous research has reported beneficial effects of physical activity (Best, 2012) and potentially negative effects of early exposure to watching non-educational TV (Christakis et al., 2004) on 6- to 10-year-olds' EF. Thus, we expected to observe that toddlers who engaged in physical activity should receive a higher score in a CF task than those who played a non-educational game on a touchscreen or drew for the same amount of time. Second, prior research has reported benefits of social interaction during screen time (Flynn & Richert, 2015; Kirkorian et al., 2009). Thus, we expected to observe toddlers who engaged in more social interactions during touchscreen play to outperform those who engaged in fewer social interactions in a CF task. Given the theoretical links between CF and inhibitory control (Diamond, 2013), we expected toddlers' performance in an inhibitory-control task to differ in the same fashion as we hypothesized for CF.

## Method

### Participants

Seventy-eight children ($M$ = 32 months 13 days; range = 29 months 10 days to 35 months 26 days) were randomly assigned to the touchscreen-play ($M$ = 32 months 14 days; 12 females), physical-play ($M$ = 32 months 14 days; 13 females), or control ($M$ = 32 months, 10 days; 15 females) condition. Families were recruited from birth announcements, local hospitals, or various children's activities in a Northern California city and its neighboring communities. The majority of the children were from middle-class backgrounds (64%). Their ethnic and racial backgrounds were as follows: European-American (65%), Hispanic (3%), Asian/Pacific Islander (3%), mixed race (26%), or other (3%). Parents were offered travel reimbursement but were not otherwise compensated.

### Parent questionnaires

To examine any preexisting differences of child characteristics and experiences across conditions, we asked parents to complete three questionnaires that measured toddlers' temperament using the following measures. First, the Very Short Form of Early Childhood Behavior Questionnaire (ECBQ) designed for 18- to 36-month-olds measured temperament (Rothbart, Ellis, Rueda, & Posner, 2003). It consists of 36 questions that assess negative affect, surgency, and effortful control. Parents were asked to rate, on a scale of 1 (never) to 7 (always), statements such as "when told 'no,' how often did your child become sadly tearful?" Second, the MacArthur-Bates Communicative Development Inventory–III (MacArthur CDI-III) measured language exposure (Carlson & Meltzoff, 2008; Poulin-Dubois, Blaye, Coutya, & Bialystok, 2011); parents selected the words their toddler could say from a list of 100 words. Third, an activity survey gathered parental reports on toddlers' physical activity and exposure to screen media (Christakis et al., 2004; Gustafson & Rhodes, 2006). For example, parents were asked to report how much time toddlers spent on an average day doing each target activity such as "rough and tumble play" and "watch videos or TV shows on a TV set." Responses from three parents were excluded from the analysis because they were more than 3.5 *SD* above the mean.

### Materials

Experimental stimuli for a sorting task (see Procedure) included two cardboard boxes covered with pastel contact paper. One box was decorated with red tapes around the edges, and the other with yellow tapes. On the top of each box was a slit (11 cm) for inserting objects; on the side of each box was a latch for removing objects. The objects consisted of six popsicle-sticks and six pennies covered by yellow and red tapes, respectively. Four index cards were prepared, each with a combination of the target object (a stick or a penny) and the target color (yellow or red) for sorting. These cards were attached to the front of the box and served as visual guides for participants during the task.

### Procedure

After providing informed consent, parents and toddlers were escorted to an adjacent room. Throughout the study, parents were present in the same room with toddlers while completing the questionnaires. The study began with an activity session, for which toddlers were assigned to a touchscreen-play, physical-play, or control condition. Parents were instructed to offer encouragement if needed (e.g., to ensure that it is okay to play) but otherwise let toddlers participate on their own.

#### Activity session

*Touchscreen-play condition*. Toddlers were given 9 min to play the app "BubbleXplode" on an Apple iPad Mini 2 (specifically, the "Chill Out" mode of the app). It is a free game that requires players to use a finger to pop adjacent bubbles of the same color (Figure 1). The app was chosen for its ease of use by toddlers at any desirable pace such that toddlers may stay engaged throughout the session. After toddlers were seated, an experimenter explained and demonstrated the game, and asked toddlers to practice popping a cluster of blue bubbles. Toddlers were then given 9 min to play while the experimenter sat at their right and kept track of time. Three versions of objects were used in the game: bubbles, pumpkins, and jewels. When toddlers were bored or asked to stop, the experimenter switched the appearance (e.g., from bubbles to pumpkins) to boost their interest. All children completed the session.

*Physical-play condition*. This session consisted of three activities (3 min each; Figure 1). Toddlers first played with a mesh tunnel (183 cm long, 91 cm in diameter) in which two balls (11 and 9 cm in diameter) were placed to motivate crawling. Next, they played basketball with a Little Tikes basketball hoop (76 cm tall). Finally, toddlers played with a hopper ball (38 cm in diameter). Parents were instructed to provide encouragement if children did not play spontaneously.

*Control condition*. The control condition served to establish the baseline for comparison. Toddlers were given materials to draw and color with for 9 min. During this time, the experimenter sat nearby with a pencil and notebook to appear busy working. If toddlers lost interest in the activity, they were given blocks to play with to sustain their interest for 9 min. Overall, toddlers devoted the majority (83%) of the session to drawing and coloring.

### Executive function measures

After the activity session, the experimenter escorted the toddler and parent to another room for two EF tasks. To acclimate toddlers to upcoming one-on-one interactions, toddlers were asked to help the experimenter complete four last pieces of a puzzle.

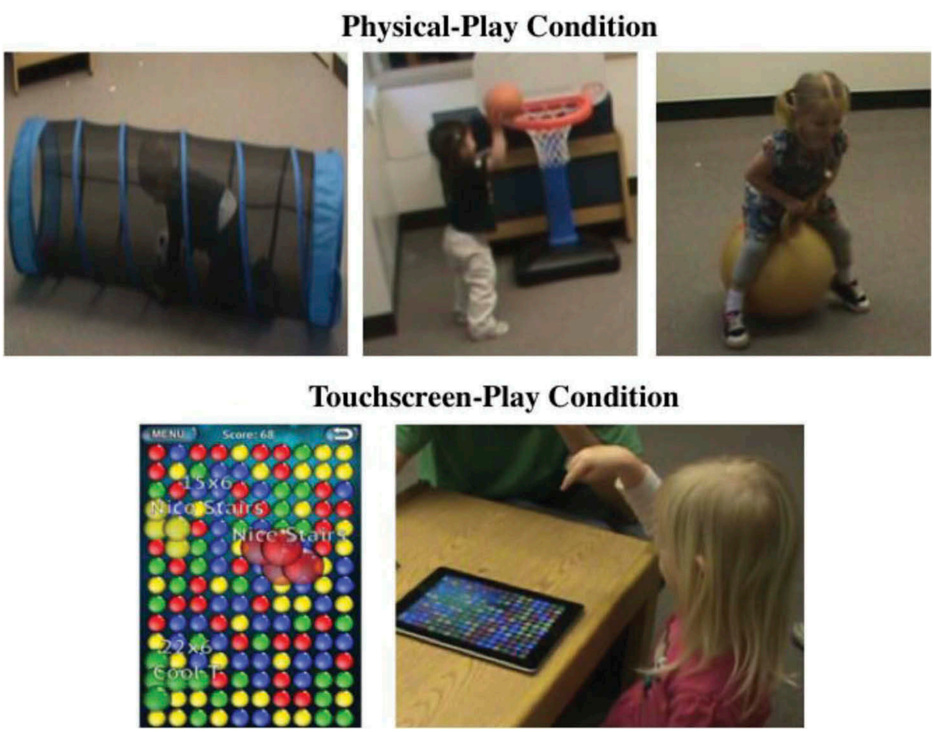


Figure 1. Snapshots of the physical-play (top) and touchscreen-play (bottom) conditions.

### *Sorting task (measuring cognitive flexibility)*

All toddlers received the sorting task first (Figure 2). The task was modified after the standard Dimensional Change Card Sort (DCCS; Zelazo, 2006) to be developmentally appropriate for toddlers. The DCCS is a measure of CF appropriate for 3- to 5-year-olds, involving sorting a set of test cards on one dimension (e.g., color) and then on a different dimension (e.g., shape). Three-year-olds tend to perseverate on sorting by the first dimension, whereas most 5-year-olds are able to switch. Our modified version of the task differed from the standard DCCS in two important ways. First, toddlers were asked to sort 3D physical objects instead of representations of objects on 2D cards. Second, the relevant sorting rule was highlighted through visual (the addition of a colored border to the cards) and verbal (restating the rule after the rule had switched) means. Pilot data suggested that these modifications allowed toddlers to understand the rules while allowing for individual variability in performance.

To start, the experimenter placed two boxes on the table and attached one card to the front of each box; the card depicted either the stick or the coin. Toddlers were told: "Now we're going to play a shape game. In the shape game, all of the sticks go here (the experimenter pointed to one box) and all of the coins go there (pointed to the other)." Next, the experimenter demonstrated by picking up an object (coin first), labeling it, and placing the object above the opening of the correct box (without inserting it). After the demonstration, toddlers were asked to try and given feedback on incorrect attempts.

Once toddlers correctly sorted each object, the first six trials of sorting by shape began. The rule was repeated on every trial before an object was picked up, labeled by its shape, and then given to toddlers to sort. After six trials, the experimenter attached an index card that highlighted the target color to each box and told the toddlers: "Now we're going to play a new game. We're not going to play the shape game anymore. We're going to play the color game. In the color game, all of the yellow ones go here and all of the red ones go there." Toddlers were then given six trials in which they had to sort by this new rule. The rule was repeated on each of the six trials before an object was picked up, labeled by color, and given to toddlers to sort. No feedback was given during these 12 trials.

### *Statue task (measuring inhibitory control)*

The Statue task was adapted from Korkman, Kirk, and Kemp's original task designed for 3- to 6-year-olds (1998, 2007). Based on pilot data, we shortened the trial duration from 75 to 30 s to be suitable for toddlers. They were told: "A statue is something that stays as still as possible." The experimenter demonstrated by standing up, closing eyes with arms down. Toddlers were then asked to do so until they heard "time's up." The 30-s trial included distractions at the 5th (the experimenter coughed), 15th (dropped a pen), and 25th (coughed) second.

## *Coding*

### *Touchscreen-play session*

Initial inspection of the data indicated that toddlers in the touchscreen-play condition varied on how they played. Some toddlers focused solely on the game, whereas others sought out social interaction. Therefore, systematic coding was conducted focusing on the frequency of child-initiated social interactions, operationally defined as initiating verbal (e.g.,

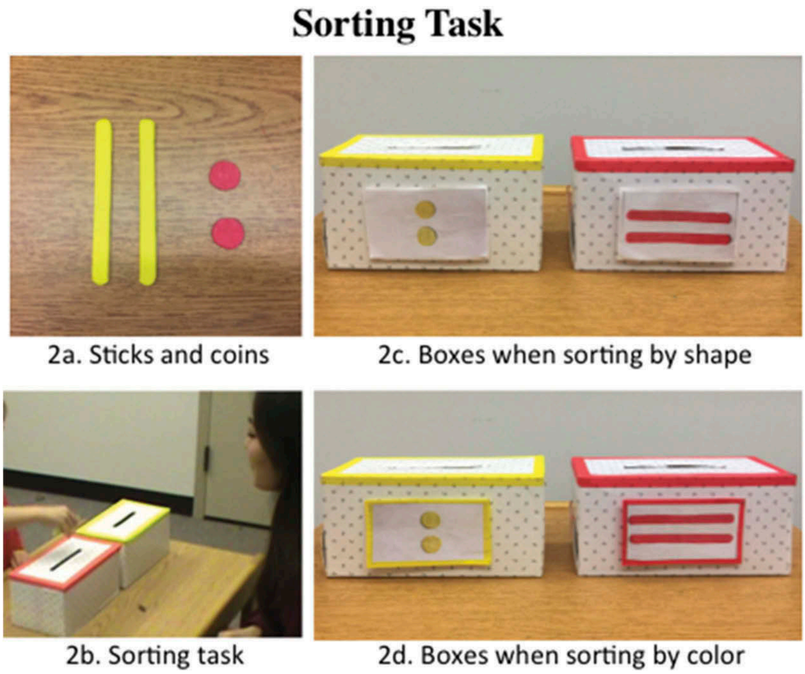


Figure 2. Snapshots of the new sorting task adapted from the standard DCCS (Zelazo, 2006). The toddler in 2b was sorting a coin while the experimenter watched. Notice that the cards on the boxes in 2d are bordered with the appropriate colors.

spontaneously asking the experimenter to pop a bubble) or non-verbal (e.g., looking at the experimenter while pointing at the touchscreen) social exchanges. Toddlers' gaming behavior was also coded on (a) the frequency of intentional taps[1] – the target action to perform for this game defined as taps with clear visual attention to the game and (b) the success rate of taps that resulted in the popping of bubbles. A second coder coded 30% of the responses (randomly chosen). Inter-coder reliability measured by intraclass correlation coefficient (ICC) yielded high measures of agreement for social interactions (ICC = .996, 95% CI [.979, .999]), intentional taps (ICC = .98, 95% CI [.942, .998]), and successful pops (ICC = .99, 95% CI = [.994, .999]).

### Sorting task

Toddlers' responses were coded on whether they correctly placed the stick or coin in the box. One point was given for correct placement for each trial. Two raters independently coded the number of correct responses; inter-coder reliability was 100%.

### Statue task

The 30-s trial was divided into six 5-s intervals. For each interval, responses were scored on postural stability: Two points were given for staying still, 1 point for making one mistake, and 0 points for making more than one mistake. If toddlers made a movement, the new posture served as the baseline for the next interval. Percentage scores were calculated by dividing total points earned by the maximum of 12 points. Toddlers who refused to play ($n$ = 22) or did not complete the task ($n$ = 14) were excluded from this data set (see Discussion section). A second coder coded 30% of the data; inter-coder reliability was high (ICC = .97, 95% CI [.936, .988]).

## Results

Consistent with random assignment of condition, a series of one-way ANOVA indicated no significant preexisting differences (Table 1) in toddlers' temperament (all $ps > .87$), language exposure ($p = .17$), and prior experience watching TV ($p = .87$) or playing games on a touchscreen ($p = .65$). Surprisingly, there was a significant group difference in parental reports of daily physical activity, $F(2, 67) = 6.29$, $p = .003$, driven by the touchscreen-play condition in which daily physical activity ($M$ = 313.57 min, $SD$ = 143.91 min) was reported as significantly higher than the physical-play ($M$ = 182.30 min, $SD$ = 108.97 min), $t(44) = -3.52$, $p = .001$, $d = 1.03$, or control condition ($M$ = 215.79 min, $SD$ = 133.03 min), $t(43) = 2.37$, $p = .02$, $d = 0.71$. However, many parents were uncertain of their child's physical activity levels (e.g., due to children's attending day care). Fifteen parents clearly indicated uncertainty with question marks or written comments. Thus, caution should be made to further interpret this surprising group difference. Moreover, the group difference did not interfere with our interpretation of the primary results (see below) and therefore will not be discussed further.

For a manipulation check, a pedometer measured children's activity level during the activity session. The result confirmed that the physical-play groups were more active (averaged 573.09 steps) than the touchscreen-play (32.85 steps) and control (44.48 steps) groups.

### *Effects of activity type*

Testing our primary hypothesis, we compared toddlers' performance in the sorting task (Figure 3) using a one-way ANOVA. The main effect of condition was significant, $F(2, 75) = 3.31$, $p = .042$. Planned comparisons indicated that toddlers in the physical-play condition ($M$ = 10.85, $SD$ = 1.87) made significantly more correct sorting than those in

Table 1. Demographic characteristics and parental questionnaire responses.

| | Condition | | |
|---|---|---|---|
| | Physical-play | Touchscreen-play | Control |
| Mother's education | 16.36 (2.22) | 15.67 (1.40) | 16.44 (1.73) |
| Father's education | 15.40 (2.22) | 15.42 (1.98) | 15.50 (2.32) |
| Household income | \$50k – \$75k | \$50k – \$75k | \$50k – \$75k |
| ECBQ – negative affect | 3.05 (.60) | 3.02 (.53) | 3.13 (.73) |
| ECBQ – surgency | 5.13 (.70) | 5.18 (.48) | 5.22 (.76) |
| ECBQ – effortful control | 4.98 (.60) | 4.89 (.54) | 4.99 (.51) |
| MacArthur CDI–III | 66.78 (19.65) | 70.13 (16.59) | 65.54 (22.91) |
| *Technology Exposure* (minutes per day) | | | |
| TV watching | 62.75 (59.36) | 63.12 (63.27) | 58.4 (50.30) |
| Playing games on touchscreen | 6.88 (10.39) | 8.43 (16.65) | 10.72 (17.51) |
| Total media use | 69.63 (61.34) | 71.38 (70.62) | 69.12 (55.94) |
| Physical activity (minutes per day) | 182.3 (108.97) | 313.57 (143.91) | 215.79 (133.03) |

Note: Standard deviations appear in parentheses next to means.

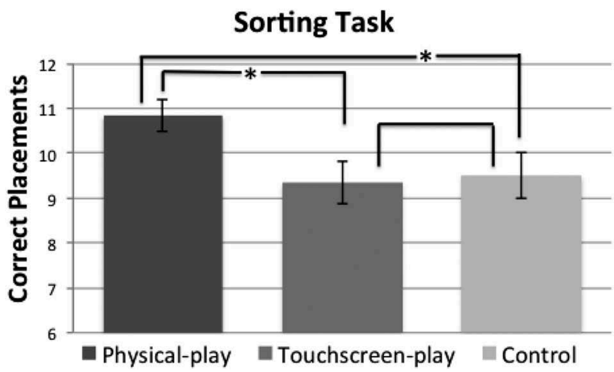


Figure 3. The number of objects correctly sorted by toddlers in the physical-play, touchscreen-play, and control conditions. Error bars represent standard errors. The asterisks denote $p < .05$.

the touchscreen-play condition ($M = 9.35$, $SD = 2.45$), $t(46.76) = 2.48$, $p = .017$, $d = 0.69$, 95% CI of the difference [0.28, 2.72], and those in the control condition ($M = 9.50$, $SD = 2.57$), $t(45.72) = 2.16$, $p = .036$, $d = 0.60$, 95% CI of the difference [0.09, 2.60]. No difference was observed between the touchscreen-play and control conditions ($p = .83$). These results suggest that toddlers who engaged in physical play outperformed the other two groups on CF.

In addition, a one-way ANOVA indicated no significant difference in percentage of time toddlers remained still during the Statue task (Figure 4) between the physical-play ($M = 86.36\%$, $SD = 14.08\%$), touchscreen-play ($M = 73.61\%$, $SD = 18.41\%$), and control ($M = 71.91\%$, $SD = 19.12\%$) conditions, $F(2, 39) = 2.48$, $p = .096$. However, a substantial number of toddlers refused or were unable to complete the Statue task (15 in physical-play, 14 in touchscreen-play, and 7 in control condition). Given the high attrition rate (over 50%) in the physical- and touchscreen-play conditions, the results may not provide conclusive evidence for the effects of activity type on inhibitory control. For the same reason, we will refrain from reporting the inhibitory control results in the next section.

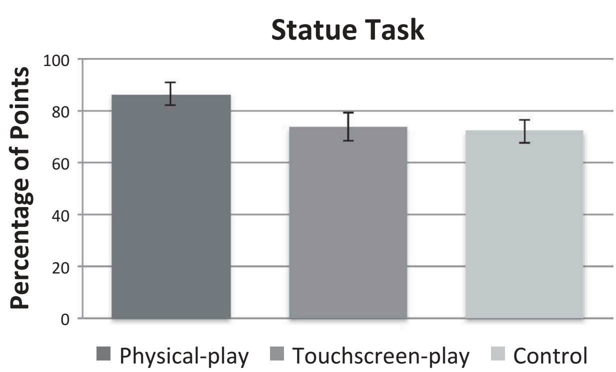


Figure 4. The percentage scores of the Statue task. Error bars represent standard errors.

### *Effects of social interactivity*

Testing our secondary hypothesis, we used the Pearson correlation to examine individual differences in gaming behavior, specifically the number of social interactions that toddlers initiated, and subsequent CF. The results indicated a positive association: Toddlers who initiated more social interactions during gameplay sorted more objects correctly in the sorting task, $r = .42$, $p = .03$.

This finding gave rise to the question of whether the subgroups of toddlers in the touchscreen-play condition performed differently from toddlers in the physical-play condition. To compare, we divided toddlers in the touchscreen-play condition into two groups by a median split of social interactions initiated (Median = 9). As expected, the groups ($n = 13$ in each) differed significantly on the number of social interactions, $t(13.35) = 4.71$, $p < .01$, $d = 1.90$, 95% CI of the difference [8.63, 23.21] (socially interactive: $M = 19.77$, $SD = 11.87$; socially non-interactive: $M = 3.85$, $SD = 2.82$).

Next, we compared the sorting-task scores of the socially interactive and non-interactive subgroups in the touchscreen-play condition with the scores of toddlers in the physical-play condition. The analyses indicated that the socially interactive subgroup ($M = 10.31$, $SD = 1.80$) performed similarly to the physical-play group ($M = 10.85$, $SD = 1.87$) in the sorting task, $t(37) = 0.86$, $p = .40$, $d = 0.29$, 95% CI of the difference [−.73, 1.81]. In contrast, the socially non-interactive subgroup ($M = 8.38$, $SD = 2.69$) performed significantly worse than the physical-play group, $t(17.98) = 2.96$, $p = .008$, $d = 1.07$, 95% CI of the difference [.71, 4.21]. However, the socially interactive and socially non-interactive subgroups' performances did not significantly differ from that of the control group who drew and colored ($p$s = .26 and .22, respectively). This last result was not surprising, given that the average score of the control group ($M = 9.50$) stood between the average scores of the socially non-interactive and the socially interactive subgroup ($M = 8.38$ and 10.31, respectively).

The above results suggest that like physical activity, social interactivity during touchscreen play could benefit toddlers' CF. Alternatively, toddlers who initiated more social interactions could have been less engaged with gaming than those who initiated fewer social interactions. To test this explanation, we used Pearson correlations to examine the relations between social interactivity and (a) the total number of intentional taps and (b) the target outcome of popping bubbles. Our results indicated no significant association between social interactivity and intentional taps ($r = −.26$, $p = .20$) or successful pops ($r = −.19$, $p = .37$), suggesting that toddlers' treatment of the game as a social activity was not related to their engagement with or success at the game.

Taken together, these results indicate that playing a non-educational game on a touchscreen did not yield a significantly different effect on toddlers' CF, compared to drawing. However, a unique approach to playing the game – that is, treating it as a social activity – can be as beneficial for toddlers' CF as engaging in physical activity. This finding bears practical and theoretical implications about touchscreen gaming and young children's cognition. We elaborate on these implications in the Discussion section.

## Discussion

The present research contrasted the immediate effects of touchscreen gaming and physical play on 2.5-year-olds' CF. The toddlers who engaged in physical play performed better in the sorting task than those who played a non-educational game on a touchscreen in a socially non-interactive way or those who drew for the same amount of time. The results suggest that in the short term, physical activity is more beneficial for toddlers' CF than touchscreen play (without social interaction) or drawing. Previous research indicates that physical activity benefits children's cognitive abilities through increased activation of the frontal lobe (Audiffren, 2009; Best, 2012; Budde et al., 2008). Specifically, heightened physiological arousal, as a result of physical activity, activates brain regions that promote attention and cognition. Here, we extended this previous work for the first time to much younger children by showing that physical activity elevates CF in 2.5-year-olds.

### *Touchscreen gaming and social interaction*

Previous research suggests that exposure to non-educational TV in early life could be detrimental to attention and inhibitory control later in life (e.g., Christakis et al., 2004; Nathanson et al., 2014) possibly because TV viewing taxes children's pool of cognitive resources, reducing its availability for later use. For example, Lillard et al. (2015) showed that the fantastical nature and rapid pace of non-educational TV programs were associated negatively with EF, likely due to children's difficulty processing the content (see also Lillard & Peterson, 2011). Here, we showed that toddlers who played the non-educational game app for a short period of time – in particular, those who played in a socially non-interactive way – tended to perform worse in the sorting task than toddlers who engaged in physical activity for the same amount of time. However, our results differed from the findings on TV watching (e.g., Lillard et al., 2015): Compared to drawing, playing with the non-educational game app did not yield any significant effect on toddlers' CF. This discrepancy is likely related to greater contingency between children's action and the device's response afforded by touchscreen gaming. Past research has demonstrated that contingency in general aids young children's cognitive process when they are engaged with screen media. For example, Kirkorian et al. (2016) showed that 24-month-olds learned a word from video on a touchscreen in the absence of a reciprocal social partner, but only when the touchscreen required a specific action. The non-educational game we used allowed toddlers to play at their own pace – a feature typically not afforded by non-educational TV shows – which could explain why touchscreen play did not yield negative effects on toddlers' CF.

Nonetheless, not all touchscreen gaming is equal. Whether gaming exerts negative impacts on children may depend on at least two factors: (a) how children play and (b) the content of the game. Our results showed that social interaction initiated by toddlers during touchscreen play was positively associated with performance in the sorting task. Research of TV watching showed that the benefits of social interaction arise through parental engagement, such as asking more content-related questions to their child (Barr, 2008; Kirkorian et al., 2009) or highlighting relevant information (Kirkorian et al., 2016; Roseberry, Hirsh-Pasek, & Golinkoff, 2014). All of these parental behaviors serve to moderate children's attention allocation in the service of better construction and representation of media content. In our study, playing the non-educational game without social interaction could impose a high processing demand on toddlers' cognitive resources as new bubbles appeared within seconds of disappearing, requiring toddlers to reorient to the constantly updating visual aspect of the task. The social interactions toddlers initiated tended to occur throughout the gaming session, both *during* a spurt of seconds when toddlers focused on the game and *in-between* spurts of focused play. These toddler-driven social interactions might have provided a natural way of shifting attention from the constantly updating visuals. In other words, we speculate that socially interactive players might have treated touchscreen gaming as a joint activity with others (rather than a solitary activity) and distributed their attention across social and gaming activities (rather than focusing their attention on the game that required constant updating), resulting in better preservation of active cognitive resources. How this individual difference arises from child characteristics and/or parental guidance is an important question to address in the future.

Another important factor that moderates the effects of touchscreen gaming is the content of the game. Here, we used a game app that was not designed for educational purposes. Playing with an educational game could be more likely to benefit toddlers' CF. On the other hand, gaming could yield a more negative impact on CF if the content is further draining children's cognitive resources (e.g., involving a faster pace or fantastical content; Lillard et al., 2015). Hirsh-Pasek and colleagues (2015) identified four "pillars" of learning that should be evident in an app for it to be considered educational. To meet these criteria, the app must promote action, be engaging, have meaningful content, and be socially interactive. The app we used met some of these criteria, as it promoted active involvement, was engaging, and elicited social interaction for about half of the toddlers. It would be interesting to examine the impact of apps that fall on the more extreme ends of the pillars (i.e., meeting none or all of the criteria) on toddlers' CF. A direct comparison of the immediate effects of playing different types of games on a touchscreen device will provide crucial insights into this issue.

The toddlers in the present study had not spent much time gaming on touchscreens ($M$ = 8.42 min a day). Their inexperience with gaming activity may have made it more taxing to process the rapid flow of images on the screen as the game unfolded in a way profoundly novel to toddlers. Perhaps, toddlers who have had more experience with gaming might find this activity less taxing. To examine this possibility, future research should examine toddlers' CF immediately after playing a touchscreen game that they have ample experience with.

## *Methodological challenges*

It is worth noting that tasks designed to measure toddlers' CF and inhibitory control are relatively scarce. Here, we modified the original DCCS by using 3D objects and by providing additional visual and verbal cues to adjust the task demand and facilitate toddlers' engagement. Our attempts appear to be successful: The task yielded a useful range of variability in toddlers' performance and a low attrition rate. Thus, the sorting task provides a new measure that is sensitive and developmentally appropriate for 2- to 3-year-old children.

On the other hand, the use of the Statue task yielded unexpected methodological challenges. Despite its successful use with older children (Korkman et al., 1998, 2007), the

Statue task was difficult for the toddlers in the present study; 28% of the toddlers refused to participate in this task and 25% of those who participated dropped out by the end of the trial. However, although performance did not significantly differ between groups, the limited data showed a trend consistent with the CF results: Of the toddlers who completed the task, those in the physical-play condition tended to remain still for a larger proportion of time (84.85%) than those in the touchscreen-play (73.61%) or the control condition (71.93%).

For toddlers, standing still may be more difficult than other forms of inhibitory control (e.g., trying not to say a particular word). Indeed, it has been argued that tasks that claim to measure the same aspect of cognitive function may inherently impose different task demands, resulting in differences in performance (Best & Miller, 2010; Carroll et al., 2016). In addition, the completion rate of the Statue task in the present study was higher in the control group (73%) than the physical-play (42%) and touchscreen-play (46%) groups, suggesting that despite our adjustment of difficulty, the Statue task remained challenging for toddlers who have just engaged in a novel activity. With this in mind, future research on inhibitory control might consider using a procedure that does not require toddlers to stand still immediately after a novel task.

### *Concluding remarks*

To conclude, the present research provides evidence that physical activity is more beneficial for toddlers' CF than touchscreen gaming in the short term. This finding echoes the previous work done with much older children (e.g., Best, 2012). The present research also provides new evidence that social interaction during touchscreen play can affect toddlers' CF in a positive way. Here, we showed that toddlers varied in the extent to which they spontaneously initiated social interaction during gaming. It is plausible that these individual differences may come from toddlers' past experience of using devices wherein parental guidance could have instilled in toddlers a "social script" for device usage, leading some toddlers to expect touchscreen play as a shared activity, whereas others a solitary activity. It follows that the benefits of social interactivity are likely to arise from toddlers' active construction of touchscreen play; as such, one could expect social interactions initiated by others to have less strong effects than child-initiated social interactions. As technology becomes pervasive – and perhaps necessary – in our society, it is important to mindfully incorporate physical activities into toddlers' lives and allow social interaction to be present in their use of technology.

## Note

1. One toddler was not included in this analysis because the number of intentional taps made was more than 5 *SD* above the mean.

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