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Further Examination of the Immediate Impact of Television on Children's Executive Function

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Three studies examined the short-term impact of television (TV) on children's executive function (EF). Study 1 ($N = 160$) showed that 4- and 6-year-olds' EF is impaired after watching 2 different fast and fantastical shows, relative to that of children who watched a slow, realistic show or played. In Study 2 ($N = 60$), 4-year-olds' EF was as depleted after watching a fast and fantastical educational show as it was after a fast and fantastical entertainment 1, relative to that of children who read a book based on the educational show. Study 3 ($N = 80$) examined whether show pacing or fantasy was more influential, and found that only fantastical shows, regardless of their pacing, disrupted 4-year-olds' EF. Taken together, these studies show that 10–20 min watching televised fantastical events, relative to other experiences, results in lower EF in young children.

Keywords: preschool, TV, executive function

Executive function (EF) comprises the cognitive skills that undergird self regulation (Blair & Raver, 2012), including working memory and updating, flexibility shifting from one set of rules to another, and inhibitory control (Diamond, 2013; Miyake, Friedman, Emerson, Witzki, Howerter, & Wagner, 2000). EF is a strong predictor of success in school and life (e.g., Kim, Nordling, Yoon, Boldt, & Kochanska, 2013; Ponitz, McClelland, Matthews, & Morrison, 2009; Röthlisberger, Neuenschwander, Cimeli, & Roebers, 2013). A very large recent study showed that self-control in early childhood predicted a variety of health, wealth, and criminal behavior outcomes at age 32 (Moffitt et al., 2011).

American children watch a lot of TV (TV, used here to indicate all passive forms of screen media, e.g., DVDs, streamed video, etc.). Recent data from a nationally representative sample of almost 9,000 preschoolers indicated that they were exposed to about 4 hr of TV daily (Tandon, Zhou, Lozano, & Christakis, 2011). Because (a) EF is so important and (b) children watch so much TV, reports that TV might diminish EF are very concerning. Although not every study finds an association between early TV and EF (e.g., Ferguson, 2011; Foster & Watkins, 2010), most published studies (e.g., Jolin & Weller, 2011; Nathanson, Alade, Sharp, Rasmussen, & Christy, 2014; Zimmerman & Christakis, 2007), including a recent meta-analysis (Nikkelen, Valkenburg, Huizinga, & Bushman, 2014), do.

Some studies have suggested that content matters for these associations. In one study, both entertainment and violent TV had a negative impact on later attention ratings, but educational TV did not (Zimmerman & Christakis, 2007). Another study found that exposure to adult-directed TV both at ages 1 and 4 predicted poorer EF at age 4, but exposure to child-directed TV did not (Barr, Lauricella, Zack, & Calvert, 2010). Although Nathanson and colleagues (2014) found that overall TV was concurrently associated with lower EF, a content breakdown showed this was the case for only for educational cartoons. PBS viewing (a channel, orthogonal to the educational cartoon category) was positively related to EF, controlling for a variety of important factors (e.g., parent education, child age). In summary, perhaps only certain types of TV are associated with lower EF. Of course, in all these longitudinal correlational studies, it might be that children with attention problems or lower EF watch more TV, or more TV with particular content. Experimental studies are needed to address this issue.

Long-term studies of a TV-EF causal relation are difficult because parents are unlikely to comply with random assignment for TV viewing over a significant period of time. Thus, Christakis et al. produced a mouse model to test the plausibility of a causal relationship. For 6 hr/day, for 42 days, mice pups heard Cartoon Channel audio (at normal volume), whereas LED lights changed color and intensity in concert with the audio changes (Christakis, Ramirez, & Ramirez, 2012). Ten days later the pups were given a battery of behavioral and cognitive tests. Compared with control

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mice pups, the experimental mice were hyperactive, were atypically uncautious in the Open Field test, and performed more poorly on cognitive tests.

TV might have a causal influence on EF, perhaps by influencing neural circuitry in a sensitive developmental period; preschool is a sensitive period for the development of children's EF (Müller & Kerns, in press). Another way to test for a possible causal influence is to examine the short-term influence of TV on EF, as repeated short-term effects might result in a long-term impact. One might also argue that short-term effects are important in their own right.

The Immediate Impact of TV on EF

Six studies have examined the immediate impact of TV on EF. One involved adults, and showed that after 30 min of watching a highly arousing segment of the movie *Doom* or a banal tennis match, participants in the former were impaired on a test of attention (Maass, Klöpper, Michel, & Lohaus, 2011). The other studies involved preschoolers. Children in one study watched either *Mr. Rogers' Neighborhood* or *Mighty Morphin' Power Rangers,* then spent 30 min in a playroom with seven activity centers; a control group went straight to the playroom (Geist & Gibson, 2000). Relative to controls, children who had just watched *Power Rangers* had more task switches and spent less time on each activity than the control group; watching *Mr. Rogers* had no significant impact. Similar findings were obtained over 30 years ago in a short-term longitudinal study in which children viewed *Batman* and *Superman* or *Mr. Rogers*, shows chosen to be aggressive or prosocial, respectively (Friedrich & Stein, 1973). Preschoolers' classroom behaviors were coded at baseline and during 4 weeks of frequent viewing of one of the shows. Those in the aggressive TV condition showed declines in self-regulatory behaviors, whereas those watching shows selected for prosocialness increased in such behaviors. More recently, Lillard and Peterson (2011) found that children who had watched 9 min of the fast-paced show *SpongeBob SquarePants* had lower EF scores than children who had watched *Caillou* (a slow, realistic cartoon about a boy) or played with markers.

The studies just described used TV shows that varied both in formal features (like pacing) and the type of content. Two other studies that held content constant, but systematically varied pacing, found few or no subsequent differences in EF. In one study using the computerized Attentional Network Task or ANT (Cooper, Uller, Pettifer, & Stolc, 2009), very short fast- or slow-paced 3.5-min clips of an adult reading a story were shown to 4- to 7-year-olds. Overall, there were *fewer* errors by those who watched the fast-paced clip, perhaps because of increased arousal. The second study created 40-min fast- and slow-paced episodes of *Sesame Street* (Anderson, Levin, & Lorch, 1977) by splicing together "skits" from full shows. After watching an episode, preschool children were given tests of impulsive judgments and persistence, and were observed in free play. Pacing had no effect, supporting that TV content and not pacing is key to later outcomes (Anderson, Huston, Schmitt, Linebarger, & Wright, 2001).

However, other studies have shown that pacing does have an influence on adults' processing of TV messages (Lang, Bolls, Potter, & Kawahara, 1999; Lang, Zhou, Schwartz, Bolls, & Potter, 2000). Cooper et al. (2009) used such short clips that the fast pacing might not have had sufficient time to challenge viewer's processing resources. Pacing of *Sesame Street* 30 years ago was slower than even that of *Sesame Street* today (Koolstra, van Zanten, Lucassen, & Ishaak, 2004), and even a 2003 analysis indicated that relative to other popular children's TV shows *Sesame Street* is slow-paced (McCollum & Bryant, 2003). In summary, for the two studies that showed no effect of pacing on children's EF, perhaps the stimuli were not challenging enough to cause processing impairment that might result in poor EF performance.

In the two studies just reviewed concerning the short-term impact of TV, the structural feature of pacing was the focus. Actually, the other four short-term impact studies also used shows that varied in pacing. *Doom* was certainly faster than the tennis match. Regarding the child studies, a pacing analysis considered *Mighty Morphin' Power Rangers* very fast, *Batman* rather fast, and *Mr. Rogers* very slow (McCollum & Bryant, 2003); *Superman* was not rated, but its pacing is likely comparable with that of *Batman*. *Caillou* and *SpongeBob* were not rated in this study, but Lillard and Peterson (2011) reported the frequency of scene changes as a measure of pacing, and those two shows were widely divergent, with *Caillou* presenting a fraction of the number of scene changes presented in *SpongeBob*. In summary, it seems possible that pacing is an issue for children's TV processing and subsequent EF.

In addition to pacing differences, another critical difference in the stimuli that were associated with lower subsequent EF is the presence of fantastical content: physically impossible events. Batman and Superman can fly, the Power Rangers have magical swords, and *SpongeBob* is replete with physically impossible events like multitudes of sea urchins fitting in a narrow space under a dishwasher. Humans are theorized to have a "naïve physics," an innate representation of the laws governing physical events (Spelke, 1994). Even if representations of laws governing everyday physical events are not innate, many such representations are apparently in place very early in life, such that even infants have strong expectations of how events should occur (Carey, 2009). Frequent violation of these expectations might overload processing, because fantastical information cannot be assimilated to stored patterns. Events that violate innate or well-rehearsed representations should be difficult to process, and thus require more cognitive resources than events that adhere to reality. Thus, a second possible reason for lower EF, besides fast pacing, is the presentation of fantastical or physically impossible events.

A related difference across the shows used in the preschooler studies is their intent to educate versus to entertain. Shows that purport to educate (*Sesame Street*, *Mr. Rogers*, and *Caillou*) did not disrupt EF, whereas those purported to entertain did. Recall that longitudinal studies have found entertainment but not educational content predicts poor EF. Perhaps only entertainment shows have a negative impact on EF, regardless of pacing or fantastical elements. Therefore, investigating a fast-paced educational show would be useful.

In summary, several studies have shown that TV programs that are fast, fantastical, and aimed at entertainment have a negative influence on EF-related processes just after viewing. The current studies explore these effects with an eye to determining their generalizability and what aspect of the TV programs might be responsible.

The Current Studies

The present studies briefly exposed children to a TV show or control activity, then examined EF with test batteries. Test batteries were used because individual tests of EF in young children are "noisy," whereas aggregated measures are stable and robust (Willoughby, Wirth, & Blair, 2011). Revealing this noise, intercorrelations among EF tasks (including here) are often not particularly high. The noise is speculated to result from the fact that EF tests tap into many underlying processes, all of which are developing in young children. As the neural architecture supporting these different processes develops at different rates in different children, and is supported by different internal and external features at the moment of testing, what results is noisy test–retest reliability over a time span of a few months. To obtain a reliable estimate of young children's EF, "researchers should aggregate over conceptually similar measures" (Müller & Kerns, in press, p. 599). In addition, whereas in adolescents and adults an underlying factor structure is clear (Miyake & Friedman, 2012), young children typically show one undifferentiated factor (Lee, Bull, & Ho, 2013; Miller, Giesbrecht, Müller, McInerney, & Kerns, 2012). Despite the developing factor structure and "noise," EF tasks in young children are strongly predictive of later success.

In the current studies we gave children several tests that are widely agreed to measure EF. Because each task uses a different scale, aggregating the measures requires converting results to Z-scores, and then summing the Z-scores for an EF composite score. However, delay of gratification tests, thought to mainly tap "hot" inhibitory control (Metcalfe & Mischel, 1999), often do not hang with tests that seem to rely more heavily on "cool" inhibitory control, like working memory, set shifting, and attention (Diamond & Lee, 2011; Huizinga, Dolan, & van der Molen, 2006; Lillard & Peterson, 2011; Zelazo & Carlson, 2012). When hot EF task performance appeared to diverge from performance on other tasks, it was examined separately.

A limitation imposed by using Z-scores is that they reveal only relative performance, not absolute levels of performance. A solution is to give the same test battery at pre- and posttest and examine raw scores for intraindividual change. This approach is not advised with EF tests, because an essential feature of EF tests is novelty: EF tests ask children to respond in nonroutine ways (Müller & Kerns, in press). Once performance becomes automatized, a task no longer assesses EF. The one EF component task that does not appear subject to this issue is working memory (Müller & Kerns, in press). In Study 3, a working memory test is given as part of both pre- and posttest EF batteries, allowing for examination of the absolute level of posttreatment performance relative to pretreatment performance. Anticipating the result that working memory performance did decline in Study 3, in the manuscript we at times refer to EF depletion; it should be understood that this is a relative statement where Z-scores are used.

Three studies are described here. The first tested whether the short-term effect seen most recently in Lillard and Peterson (2011) would replicate with a different and full-length (11 min rather than 9 min) episode of *SpongeBob* and a different fast and fantastical show, compared with a different slow and nonfantastical educational show and a different control task. Because *SpongeBob* might only disrupt 4-year-olds because it is targeted at children ages 6+, this study also examined whether 6-year-olds were affected. Finally, although Lillard and Peterson (2011) found no effect on creativity with an alternate uses task, in Study 1 a different creativity task was administered for validation. Study 2 tested a fast and fantastical show that was designed to teach children vocabulary; Study 2 also used longer episodes to increase ecological validity. Study 3 aimed to discern the contribution of fantasy versus fast pacing, with four conditions in which the TV shows varied systematically (in a bimodal fashion). All three studies used commercially available shows that were "on the air" at the time the studies were conducted; information on these shows, their length, and coded features are in Table 1. Although there is benefit to using shows that children can actually watch in their real lives, experimental control is sacrificed, leaving open the possibility that results are driven by features other than those intended. Using multiple stimuli across studies reduced those possibilities.

Study 1

Method

Participants. Participants were 160 children who were approximately 4 ($M = 55$ months, $SD = 5.3$ months, range = 48–66 months) and 6 ($M = 76$ months, $SD = 5.5$ months, range = 67–91 months) years old. Family demographic information was not col-

Table 1
Pacing and Fantasy Characteristics of TV Programs in Studies 1–3

Program	Length	Pacing (scenes per minute)	Fantasy rate (events per minute)	Number of fantasy events (reliability %)
Study 1				
SpongeBob	11:05	35	3.25	36 (100)
Fan Boy	12:05	38	3.31	40 (85)
Arthur	11:01	22	0.0	0 (100)
Study 2				
SpongeBob	22:30	42	1.56	35 (100)
Martha Speaks	22:29	41	2.36	53 (100)
Study 3				
SpongeBob	8:01	45	3.99	32 (91)
Phineas and Ferb	7:41	41	0.13	1 (100)
Little Einsteins	8:34	11	1.28	16 (100)
Little Bill	8:22	17	0.12	1 (100)

lected, but children were drawn from a database of families willing to participate in experiments, and the children were mostly white and middle class. An additional 12 children were replaced because of experimenter error (4), noncompliance or experiment interruption (4), or video malfunction (4).

Materials and procedure. Children came individually to the laboratory. They were randomly assigned at each age level to one of four conditions with the caveat that each condition was comprised of equal numbers of girls and boys. This resulted in no significant age differences across conditions. After consent procedures, children went to a small room for intervention and testing, while their parents filled out questionnaires in the waiting room. Children were told that they were going to get to watch a TV program or play with some toys, and then would get to play some games with the experimenter.

Conditions. Children watched one of three TV shows on portable 15″ MacBook computers with headphones or played with toys for 11 min. Shows were coded for fantasy events and pacing. In no study were commercials shown with the TV shows.

Fantasy events included impossible transformations in which objects or characters change shape or identity in impossible ways, exhibit impossible attributes like violations of gravity, and undergo magical genesis in which objects or characters appear our of nowhere. If the same event occurred more than once, it was counted only once, on the assumption that subsequent instances would require fewer processing resources. Events were coded by their time stamp, and they did not occur simultaneously; for example, in the *FanBoy* episode used in this study, at 5:54 a bubble explosion impossibly went through the roof, and at 5:56 the explosion caused the character to fly impossibly far away; these were considered separate events. The TV stimuli in this and the remaining two studies were first coded separately by two coders, who then discussed disagreements to arrive at a standard coding. A third coder then coded 20% of each of the shows (beginning at a randomly generated start time during the first 80% of the show) and reliability with the standard coding was measured; this is reported for each show.

Pacing estimates were provided by *Scene Detector* (Scene Detector Pro, 2002), a computer program that estimates scene changes as a percentage of pixel change from frame to frame. The standard 85% pixel change criterion was considered a scene change. Imperfections in program quality (e.g., blurry pictures) lead to some variability in Scene Detector results. Therefore, it was run 10 times on each program, and the mean estimates are reported in Table 1. For most programs, 8 or 9 of the 10 readings were exactly the same, but for *Arthur*, which was of poorer quality, there was more variability; however, its range was still reasonably tight and revealed slow pacing (20–24 scenes/min). The episodes used in this study are described next.

SpongeBob SquarePants. *SpongeBob* is a fast-paced, fantastical show about a talking kitchen sponge that lives under the sea and his friends. *Doing Time*, the episode used in this study concerned SpongeBob's driving teacher being put in jail when SpongeBob crashed a car.

Fanboy and Chum Chum. This is a fast paced cartoon based on the adventures of two high-energy friends whose active imaginations get them into trouble. In *Fan-Boy in a Plastic Bubble*, the episode used here, the boys flew around in a plastic bubble they found at a yard sale; they rode the bubble into outer space, but then bounced on and crushed the yard sale.

Arthur. This is a slow-paced, realistic cartoon based on the life of an 8-year-old aardvark. Two short episodes were used here, *Arthur and D.W. Clean Up* and *Arthur and DW's Library Card*. They involved Arthur cleaning his room and checking out a library book.

Free Play. Children were given a variety of toys (e.g., blocks, cars, stuffed animals) with which to play while the experimenter ostensibly worked in the corner of the room.

Child Assessments. After the video or play period, children were given five tasks arranged in a Latin Squares design. All test sessions were videotaped for later scoring. Four posttasks tapped EF, and one tapped creative problem-solving.

Delay of Gratification. Following the classic procedure (see Mischel, Shoda, & Rodriguez, 1989), children were shown a bag of marshmallows and a bag of M&Ms and asked which they would like to have. The experimenter put eight pieces of the chosen snack on one plate and four on another, then placed a bell between the plates. Children were told, "You can eat the 8 pieces if you wait for me to return, or you can ring this bell anytime, and I'll come back, and then you can have 4 pieces right away." A child's score was the time in seconds from when the experimenter left until the child rang the bell or ate the snack, or 330 s if neither occurred. Seven children in the FanBoy condition and three each in the Arthur and Playtime conditions were not interested in any snacks so did not participate in this task. Many children arrived at the lab during summer testing with snack food in hand, perhaps explaining the lack of interest.

Auditory Working Memory. This subtest from the *Woodcock-Johnson III Test of Cognitive Abilities* (Woodcock, McGrew, & Mather, 2001) measures auditory memory span. The experimenter said, "I am going to say some things, like animals or foods, and some numbers. After I say them, I want you to say them in the same order. Say the thing first, then the number." An example list began with one thing and one number (e.g., "dog, 3"). Once children performed correctly on an example, basal scores were established, and the experimenter continued until the child made three consecutive errors. Children received 1 point for each correct answer.

Tower of Hanoi. The adapted Tower of Hanoi task (see Welsh, Pennington, & Groisser, 1991) used three monkeys (constructed from three nested paper cups) playing on three trees (pegs). Children were told to arrange the monkeys on their trees to match three increasingly difficult patterns; children who succeeded were given two even more difficult patterns. Three rules governed how the monkeys could be moved: (a) only one hand could be used (and as a corollary to this, one could hold only one monkey at a time); (b) except when being moved, the monkeys always had to stay on the trees; and (c) a smaller monkey could never go on top of a bigger monkey. Scores were determined by efficiency (i.e., the number of moves children took to get to the solution). The first two patterns could be completed in 2 moves, the next two in 3 moves, and the fifth one in 7 moves. Children who broke a rule or did not finish received 0.

Head-Toes-Knees-Shoulders. For the Head-Toes-Knees-Shoulders (HTKS) task (McClelland et al., 2007; Ponitz et al., 2009), the experimenter taught the child a rule: "If I say to touch your head, I want you to touch your toes, and if I say to touch your toes, I want you to touch your head." After training, the child was given 10 such commands in a fixed order with no command repeated more than twice in succession. Children scored 2 if they immediately followed the instruction, and 1 if they did so after a quick touch of the wrong location. If children scored at least 10 (of 20) on the first 10 commands, a second rule was added: "When I say to touch your knees, you touch your shoulders, and when I say to touch your shoulders, you touch your knees." After training on this command, children were given 10 additional trials involving all four commands. Children who scored at least 15 on this went on to a third phase in which the rules were switched.

Functional fixedness. A functional fixedness task (German & Defeyter, 2000) measured creative problem-solving. Children were told a story about a pig and a zebra who were separated by a large, fast-moving river, shown on a green cardboard. The objective was to get the pig to the other side by using any of several objects on the table, including a straw, a cup, a cylinder-shaped block, a small ball, and a spoon inside a small bowl of sugar. Children were told the pig could not jump, swim, or touch the water at any point to get across. If a child did not solve the problem in 3 min, a hint was given (e.g., "Can you use the spoon to help you get the pig across?") and an additional 30 s was allowed to solve the problem. Children were coded for whether they solved the problem (using the spoon to make a bridge) and for fluency (the number of different solutions they tried). Scoring of this task is not entirely objective, so a second coder coded attempted solutions for 20% of the sample. Interrater reliability was high (r = .95).

Parent questionnaires. Parents were given two questionnaires aimed at whether there were important pre-existing condition differences in EF-related problems or in TV experiences. A media survey asked parents how much time children spent each day engaged in watching TV, DVDs, and videos, as well as whether children watch the shows (e.g., *Arthur*) used in this study. If children did watch one of those shows, parents were asked to specify how much time each week children spent children watching each show. The Strengths and Difficulties Questionnaire (Goodman, 1997) is a child personality inventory with good psychometric properties including high correlation with the Achenbach Child Behavior Checklist (Achenbach & Ruffle, 2000). The inattention and hyperactivity subscale that correlates well with a structured parent interview on inattention and hyperactivity (Goodman & Scott, 1999) was used here.

Results

The four conditions were first compared on the parent measures of child temperament (Strengths and Difficulties attention-related items) and TV exposure (per week: minutes of TV per week, minutes of the three shows watched in the study). Analysis of variances (ANOVAs) indicated no significant condition differences on these variables at either age level. Across the sample, children were exposed to just under 2 hr of TV per day, on average, and they had limited exposure to shows watched in the study (less than 20 min per week, on average). These variables were not considered further.

Correlations between the EF measures were examined next. The three "cool EF" tasks (Working Memory, HTKS, and ToH) were significantly intercorrelated (rs of .55, .41, and .55, two-tailed ps $< .001$); the Delay task was not significantly correlated with the others. The cool task scores were converted to Z-scores with the missing data entered as 0s and summed. A 2 (age: 4 or 6) × 4 (condition) between subjects ANOVA on these EF sum scores yielded a significant main effect for condition ($F(3, 159) = 3.10$, $p = .03$, $\eta_p^2 = .06$) and age ($F(1, 159) = 53.64$, $p < .01$, $\eta_p^2 = .26$) but no Age × Condition interaction. The age effect is of course not surprising; one would expect 6-year-olds to perform better than 4-year-olds on EF tasks.

Because there was a main age effect, and age is a factor in the Z-scores for this main analysis, a second ANOVA was done using Z-scores calculated separately for each age group. This allows more precise determination of the influence of program, regardless of age group, just as one would see using raw scores. With this analysis, of course there was no age group effect, nor was there an Age × Condition interaction, but there was a significant main effect for condition similar to the effect noted above; this is shown in Figure 1. Follow-up Tukey's HSD tests showed significant differences between SpongeBob and Play (Mean Difference = 1.30, p = .041) and between FanBoy and Play (Mean Difference = 1.27, p = .047). SpongeBob and Fan Boy were not different from each other, and Arthur was not different from any other condition.

Delay was examined separately (using raw scores, because there was nothing to aggregate) and an ANOVA also yielded a significant main effect for condition ($F(3, 146) = 3.18$, $p = .03$, $\eta_p^2 = .06$), but no effect of age nor Age × Condition interaction. Follow-up tests showed that children who just watched *Arthur* waited significantly longer (M = 205 s, SD = 127) than children who played (M = 124 s, SD = 120; mean difference = 80.76, p = .03), but there were no other significant condition differences.

The final analysis examined whether the conditions differentially impacted creative problem-solving. An ANOVA on functional fixedness fluency yielded a main effect of age ($F(1, 159) = 7.08$, $p < .01$, $\eta_p^2 = .05$) but not for condition or the interaction. Younger children (M = 6.87, SD = 2.56) performed better than older children (M = 5.73, SD = 2.8), which is consistent with prior research (German & Defeyter, 2000).

Discussion

This study replicated the findings by Lillard and Peterson (2011) for cool EF tasks with a different episode of *SpongeBob*, and

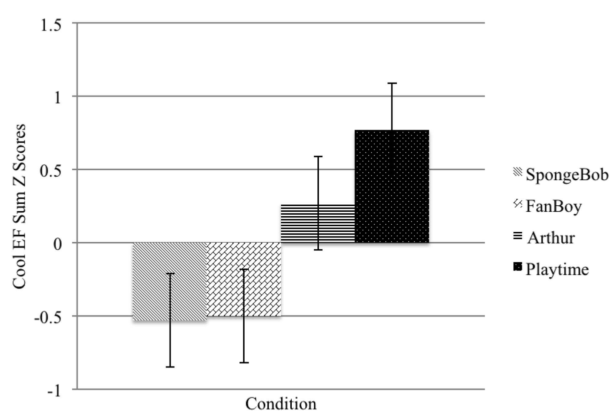

Figure 1. Summed Z-scores for the 3 intercorrelated cool EF measures in Experiment 1. *Note: SE* bars are shown; EF = executive function.

extended those results to a different fast and fantastical show, as compared with a different slow and show that was realistic excepting for anthropomorphized animals, and a different nonmedia activity (play with toys). The lack of an Age × Condition interaction showed the effect was as strong for 6-year-olds—a group within the intended age range for the relatively depleting shows—as for 4-year-olds. As in past research, younger children were less functionally fixed than older children, hence more able to see that a spoon could serve as a bridge. Fantastical shows did not affect this ability.

As in other research (cited earlier), the Delay task did not align statistically with the cool EF measures. Lillard and Peterson's (2011) finding that watching a fast and fantastical show also led to shorter delay times did not replicate here; the only significant difference in the length of time children waited for a treat was between Arthur and Playtime, and children waited longer after *Arthur*. It is possible that play with toys increased children's hunger, because play is active whereas TV viewing is passive. In 5th graders, hunger did not predict wait time on a Delay task (Duckworth, Tsukayama, & Kirby, 2013), but it might predict wait time in younger children.

In this study we used full episodes of the TV shows, but outside of the laboratory children likely watch TV for longer than 10 min. It is possible that with longer view times, children habituate to whatever disturbs their EF, and returning it to baseline by the end of a full programming slot (normally about 22 min showing one or two episodes). This was examined in Study 2 by using a 22-min episode of *SpongeBob*. The second question was whether the relative depletion effects would apply only to entertainment shows, or might also extend to shows designed to be educational. Past research has identified entertainment TV as being problematic for later attention difficulties (Zimmerman & Christakis, 2007), so perhaps an educational show, even if fast-paced and fantastical, would not change EF relative to another non-TV experience.

Study 2

This study had five key extensions to Study 1. First, to examine whether only fast and fantastical entertainment, but not educational, TV shows deplete young children's EF, a group of 4-year-olds was shown an episode of *Martha Speaks*, a PBS show designed to teach children ages 4 to 8 new vocabulary. The comparison conditions were a different episode of *SpongeBob* and book reading (as an extension from the drawing control condition in Lillard and Peterson [2011]; and play control condition in Study 1). The book was about *Martha Speaks* and featured some of the same characters as the video. Ideally it would have been exactly the same story as the TV episode, but an episode-book match was not located. Interestingly, based on the books viewed, *Martha Speaks* books do not include fantasy events (except for featuring a talking dog); how fantasy events in books influence children's EF is an interesting topic for further study. The purpose of including a book condition was the same as the purpose of using a play condition in Study 1: to have a comparison activity other than watching a video.

The second extension was to extend program length to 22 min, because it is likely that most children watch TV for longer than 11 min at once; the book reading was recorded to be of equivalent duration. Only episodes and no commercials were used, but using commercials would be an interesting extension. Third, because the "Delay" tasks had not aligned with other EF tasks in Study 1, four cool EF tasks were used in this study. Fourth, a more widely used measure of child temperament, Putnam and Rothbart's (2006) Child Behavior Questionnaire-Short Form (CBQ-SF), was used. Finally, to see whether children learned what was intended from the *Martha Speaks* book or video, vocabulary learning was tested as well.

Method

Participants. Participants were 60 4-year-olds (M = 55.58 months, SD = 7.02, range 47–67 months) who had not participated in Study 1. Although the majority of children were recruited through the same participant pool and did the study in the laboratory as in Study 1, three participants were recruited through personal contacts and run in their respective homes. All children were randomly assigned to three conditions with the caveat of gender balance. There were no significant age differences across conditions. Two additional participants were excluded for language delay, and one for noncompliance. Other participant characteristics are as in Study 1.

Materials and procedure. The basic procedure was as in Study 1, with a storybook condition replacing playtime. A vocabulary quiz was given at the end of the session.

Conditions. TV programs were shown on a portable DVD player with a 22 cm screen and the storybook audio was played on an iPod Nano.

SpongeBob. The episode used was *Pest of the West*, in which SpongeBob goes back in time to the "Wild West" and defeats a villain to save his town of Bikini Bottom. Fantastical events included items changing shape and clothes moving on their own.

Martha Speaks video. *Martha Speaks* is an educational program created by PBS that presents vocabulary in dialogue and then has a character define the term (e.g., "We took an *oath* . . . an oath is when you promise to do something!"). In the episode used here, *Return of the Bookbots: The Case of the Missing Word,* Martha (a talking dog) and her friends take the role of superhero "BookBots" who must stop an evil man from stealing nouns from books.

Martha Speaks book. A 45-page educational picture book, *Martha Speaks: The Show Must Go On* (White, 2012), with the same characters and educational purpose as the TV program, was read to children. In this story Martha helped her owner overcome stage fright. The only fantastical feature of the book is the talking dog, whose talking is enabled by eating alphabet soup (the letters are said to go to her brain, not her stomach). An audiorecording of an adult reading the book was created as a digital file, and children listened to this audio while following along with the book, with a beep signaling page turns. The audiorecording was 21:38 in length.

Child assessments. Two Study 1 EF tasks (Auditory Working Memory and ToH) were used, with working memory scoring revised to increase sensitivity: 2 points were awarded if both items in a pair were correct, and 1 if just one was correct. The Executive Function Scale for Preschoolers, the scale version (Carlson & Schaefer, 2012) of the Dimensional Change Card Sort or DCCS (Zelazo et al., 2003), was substituted for HTKS; in prior research DCCS and HTKS were highly correlated (Lillard, unpublished raw data). The fourth EF task was an adaptation of Luria's Hand Game (Luria, Pribram, & Homskaya, 1964).

Executive Function Scale for Preschoolers. Based on the standard DCCS, this 7-level task required children to sort cards according to different dimensions. Materials were two black index card boxes with target cards on the front; one target card had a blue star and the other a red truck. The test cards (10 per level) showed red stars and blue trucks. Levels 1 through 4 of the scale were comprised of two parts (preswitch and post-switch), each with five trials. Children who correctly sorted 4 out of 5 cards continued to the next level; those who missed more than 4 out of 5 cards regressed to an easier level. Children all began on Level 4a, the designated level for 48–60 months. Children were first told they were going to play the "color game" where all the blue (truck) cards go in the blue (star) box and all the red (star) cards go in the red (truck) box. After a comprehension check, children were asked to sort 5 test cards with the rules repeated before each trial. Next, at Level 4b, children were told to play the "shape game" in which all the stars go in the star box and all the trucks in the truck box. In Levels 5 through 7, children were presented with two rules simultaneously; these later levels did not have two distinct parts but rather consisted of 10 intermixed trials, requiring children to flexibly shift between rules.

Children were given a point for each card correctly placed at each level, and full credit for each level under their basal level. In some studies the highest level passed is used in analyses instead of the number of cards sorted correctly, but as the correlation between these two measures was almost perfect ($r = .98$), the number of cards sorted correctly was used here.

Hand game. Children demonstrated making a fist and pointing a finger, then were asked to make the same hand shape (point or fist) as the experimenter for four trials. Then children were told they were going to play a "silly" game and that they should make the opposite hand shape from the experimenter. After four practice trials, 12 test trials were given. Two points were awarded on each trial for which the child provided the correct response without any hesitation, one was awarded if the child hesitated or quickly changed to the correct one, and no points were awarded if the child held an incorrect response or failed to respond.

Vocabulary quiz. After a brief warm up in which the experimenter defined the word "pencil" and asked the children to define "chair" (that all children did correctly), children were asked to define six words, three from the video and three from the book. Next children judged whether or not four sentences, each containing one word, "made sense." Two practice trials were given illustrating sensible and insensible sentences, followed by the four test sentences using two words from each source. Children were given 1 point for each correct answer.

Parent questionnaires. Parents were given three questionnaires to fill out while their child participated in the study: the media survey used in Study 1, the CBQ-SF temperament scale, and a vocabulary measure. The CBQ-SF is a 94-item measure covering 15 domains including Attentional Focus, Inhibitory Control, and Impulsivity. Parents rated on a 7-point Likert scale how well each item described their child. An example of an item assessing Impulsivity is, "Usually rushes into an activity without thinking about it." Parents were also asked to circle the words that their child knew from the vocabulary quiz.

Results

One-way ANOVAs on the three CBQ-SF subscales related to attention, as well as on TV exposure, revealed no condition differences. Raw scores on the four measures of EF were all significantly correlated, with *r*s ranging from .41 to .57 and *p*s $\leq .001$, so the EF scores were converted to Z-scores and summed. The aggregated EF score for children who watched *Martha Speaks* was −.89, *SpongeBob* was −.66, and the *Martha Speaks* book was 1.82. A one-way ANOVA on the aggregate scores yielded a significant main effect for condition ($F(2, 59) = 5.77$, $p = .005$, $\eta_p^2 = .17$). Post hoc tests revealed a significant mean difference of 2.71 ($p < .01$) between the book and video of *Martha Speaks* and of 2.48 ($p = .02$) between the *SpongeBob* video and the *Martha Speaks* book.

There were no significant differences in performance on the vocabulary quiz. Children knew on average 3.28 words ($SD = 1.60$), with a range of 0–7, and neither seeing the *Martha Speaks* video nor reading the *Martha Speaks* book made children more likely to know the words than did watching *SpongeBob*. Parent estimates of their children's word knowledge were higher (5.21, $SD = 2.30$, range 0–10) but also did not differ by condition.

Discussion

This study showed that a fast and fantastical show intended to be educational still resulted in relatively lower EF as compared with reading a book based on the educational show; performance after watching the educational show was about the same as after watching an entertainment show that was also fast-paced and highly fantastical. This study also showed that 22 min of viewing—probably a more typical length of viewing time than the roughly 10 min used in Study 1 and by Lillard and Peterson (2011)—is disruptive to EF, relative to reading a book of similar length. Ideally one could also test a book version of the show with fantasy events, but such events are not shown in these books. The trade-off for using commercially available stimuli is that one is limited by what is available; the upside is ecological validity. Animated moving pictures are a supreme medium for showing fantastical events because such events typically involve transformation or movement.

Thus far we have characterized the shows that disrupt EF as fast and fantastical. Study 3 attempted to tease these variables apart by selecting four shows, a pair of which was fast and a pair of which was slow; of each pair, one was fantastical and one was realistic. The studies thus far relied on parent questionnaires to rule out pre-existing levels of EF. Such questionnaire measures are typically correlated with direct laboratory measures, but not perfectly so (Blair & Razza, 2007; Rueda, Posner, & Rothbart, 2005). Although children were randomly assigned to condition, it seemed probative to give a pretest battery of EF tasks and control for this pre-Test EF performance when analyzing posttest EF performance.

Study 3

In addition to varying level of fantasy and pacing to determine whether either characteristic alone caused the relative EF effect, a pretest battery of EF tasks was administered. The pretest is a more direct measure of EF than the parent measures, and therefore, can show more clearly whether there are pre-existing condition differences in EF. Second, with limitations, it can shed some light on the issue of condition differences in EF on an absolute scale; recall that Z-score aggregates only show how conditions perform relative to the other conditions, not relative to their own absolute scores at an earlier time. Ideally one could get around this by using the same EF tests at pre- and posttest, but EF tests rely on novelty (Müller & Kerns, in press). An exception caveat is working memory tests; one (using different items) was administered at pre- and posttest, allowing a view of absolute change in children's level of performance. Although test–retest working memory scores are correlated, they also improve (Kuntsi, Stevenson, Oosterlaan, & Sonuga-Barke, 2001), probably because children do not need to allocate resources to the instructions at retake. Thus, one would expect higher working memory scores at posttest than at pretest, unless watching the shows is depleting.

Because the aim was to ensure that all groups had equal EF aggregate scores at pretest, and random assignment might not result in this, some participants (n = 16 of 80) were assigned to conditions based on their pretest scores (after they took the pretests, but before they watched the film). In this way pretest EF level was balanced across conditions. In addition, because Lillard and Peterson (2011) had seen a condition difference for hot EF performance, here one hot task was used at pre- and posttest. Finally, in a further attempt to ensure that prior TV experiences did not differ across conditions, a daily media diary was added.

Method

Participants. Participants were 80 4-year-olds (M = 52.77 months, SD = 3.4, range = 47–60 months, 40 boys). Most of the children (n = 64) were randomly assigned to one of four conditions with caveat that gender be equally distributed, and the remainder (n = 16) were assigned to specific conditions following the pretest EF battery to balance conditions on pretest scores. There were no significant age differences across conditions. Other features of the sample were as in the prior studies, and again there were no overlapping participants. Thirteen additional children were excluded, 2 because the video malfunctioned, 6 because of experimenter error or test interruption, and 5 for noncompliance or fatigue.

Measures and procedure. Children participated in a pretest battery of EF tests, then watched one of the four shows, then had a posttest battery of EF tests.

Pretest battery. The pretest was composed of four tasks, three taken from Study 2, given in a fixed order: the Executive Function Scale for Preschoolers (the scale version of the DCCS), Hand Game, Auditory Working Memory, and Gift Wrap Delay (Kochanska, Murray, & Coy, 1997), a hot EF task that does not rely on appetite. The only change from Study 2 on the first three tasks was for the working memory test, the pretest substituted the actual items with other items of similar level of difficulty (words from low levels of other Woodcock-Johnson tests).

Gift wrap delay. The child was informed that the experimenter had a surprise, but that she had not yet wrapped it. She asked the child to turn around and face away from her while she wrapped the gift, and then helped the child to turn the chair around. If the child turned around during the wrapping, the experimenter said, "Remember, don't look at the present; I'll tell you when I'm done." After 2.5 min of wrapping, the experimenter announced that she needed to leave the room for a minute, but that the child should stay in her chair and not touch the gift until she returned. The child was left in the room for an additional 2.5 min and his or her behavior was monitored from another room using a live video stream. If the child touched the gift before 2.5 min had elapsed, the experimenter returned to the room and moved on to the next phase of the study. The child's time to peek during the wrapping phase and time to touch when the experimenter was absent were recorded and summed, resulting in scores ranging from 0–300.

Conditions. After the pretest battery, children watched on 15″ MacBook portable computers one of four shows crossing the two dimensions of pacing (fast or slow, as indicated by Scene Detector) and fantasy content (abundant or rare).

SpongeBob. This study used *Bad Guy Club for Villains*, in which SpongeBob and Patrick watch a video of superheroes fighting a group of notorious villains.

Phineas and Ferb. This cartoon concerns two mischievous stepbrothers. In this episode, *Flop Stars*, they were in a contest to be rock stars. Although the show contains a secondary plot that is fantastical, scenes related to this were removed so that only one fantastical event remained (a character hung in the air too long after falling).

Little Einsteins. This cartoon is about four preschoolers who each have their own artistic skill. In the episode used here, *Flight of the Instrument Fairies*, the Little Einsteins went on a voyage to the Arctic, where they tried to help a little fairy get Aurora Borealis back into the sky.

Little Bill. This realistic cartoon is about everyday issues that arise in the life of a 5-year-old boy. In the episode used here, *All Tied Up*, Little Bill was learning to tie his shoelaces. There was just one impossible event (his shoes walked away on their own).

Posttest battery. Once the video finished, children completed an EF battery consisting of five tasks in this order: HTKS, Day/Night, Auditory Working Memory Span subtest, Forbidden Toy, and ToH. Three of these were described earlier, and the other two are described here.

Day/night. Children were first asked to identify pictures of the sun and moon and when they normally see each in the sky (Gerstadt, Hong, & Diamond, 1994). Then the experimenter explained that they were going to play a silly game in which they should say "night" when they saw the sun and "day" when they saw the moon. The experimenter then showed children 14 shuffled cards, half of which displayed the sun and half of which displayed the moon. Children received a score of 2 if they immediately stated the correct answer and 1 if they initially provided an incorrect response but then changed their answer, for 14 test trials.

Forbidden Toy. To introduce the Forbidden Toy task (Lewis, Stanger, & Sullivan, 1989), the experimenter presented children with a talking toy robot named Alphie (by Playskool) who asked questions determined by a programmed card inserted into his front side. Children were shown how Alphie worked and were permitted to answer one question correctly. Immediately after Alphie posed the next question (and before children had a chance to answer), the experimenter told children, "I need to leave the room for a few minutes. Please stay in your chair and don't touch Alphie the robot until I get back because I really want us to play with him together." For most children the experimenter left the room for 5 min or until children touched the toy, but for 13 children she erroneously returned after 2.5 min. These children, who waited the whole 2.5 min, were spread across conditions, and were given the wait score of 150. As will be seen later this task was not included in the composite score because it did not align with the other EF measures, regardless of whether these children were included.

Parent questionnaires. The parent measures were those used in Study 2 plus a media diary in which parents were asked to record their child's activities on one weekday and one weekend day before the lab visit, and this information was extrapolated for a per/week media exposure estimate (Barr, Lauricella, Zack, & Calvert, 2010). If the diary was incomplete when parents arrived for their appointment, they filled it out during the visit. The correlation between this and the media survey filled in during the visit was reasonably high regardless of whether parents filled out the diary before or during the visit ($r = .62$ vs. .77).

Results

Preliminary analyses. There were no significant condition differences on any of the CBQ subscales of interest (Attentional Focusing, Impulsivity, or Inhibitory Control). There were also no significant differences in how much overall media exposure children had each week, neither by the diary nor the questionnaire measure of weekly TV exposure, which were well-correlated ($r = .71$). Regarding minutes per week watching the shows used in this study, there was one significant difference: children in the Little Bill condition watched more *Phineas and Ferb* than other children ($F(3, 70) = 4.30$, $p < .01$, $\eta_p^2 = .16$). Inspection of the data showed that this was because of one child who watched the show daily for 1 hr. This child's EF scores were in the normal range so we did not control for minutes spent watching this program.

Next the groups of EF pre- and posttest tasks were examined for intercorrelations. In the pretest data, the cool tasks had good intercorrelations (rs = .43 and .34, ps < .001, between DCCS and Working Memory, and DCCS and Hand Game, respectively, and a trend, $r = .20$, $p = .08$ for Hand Game and Working Memory. The hot "Gift Wrap" task was significantly related to Hand Game, $r = .28$, $p = .01$ but not to DCCS ($r = .18$) or Working Memory ($r = .03$).

On the posttests, again the cool EF tasks showed strong intercorrelations, with every one significant except that between ToH and Day/Night ($r = .13$). ToH and Day/Night were both significantly correlated with HTKS (rs = .29 and .48, ps ≤ .01, respectively) and Working Memory (rs = .25 and .23, ps < .05), which were also significantly related to each other, $r = .41$, $p < .001$. The Toy task had near 0 correlations with all the other tasks. Therefore, it was not included in the EF composite, but the other posttest measures were converted to Z-scores and summed. Because the hot task was not in the posttest composite, we also did not use it in the pretest composite EF score in the main analyses.

Main analyses. A 2 (pace: fast or slow) × 2 (content: fantastical or realistic) ANCOVA on posttest EF aggregate scores controlling for pretest EF aggregate scores yielded a significant condition effect for content ($F(1, 79) = 5.04$, $p = .03$, $\eta_p^2 = .06$) but no main effect of pacing nor Pacing × Content interaction. The posttest aggregate scores for the realistic shows were positive: *Little Bill* (slow) averaged .32 ($SD = 2.7$) and *Phineas and Ferb* (fast) averaged .87 ($SD = 2.7$). The aggregate EF scores for children who watched the fantastical shows were both negative: *Little Einsteins* (slow) −.29 ($SD = 2.8$), and *SpongeBob* (fast) −.90 ($SD = 2.6$).

Exploratory analyses. For interest, another analysis of covariance (ANCOVA) adding pretest Gift Task Z-score to the pretest aggregate was conducted, on the reasoning that it correlated significantly with one of the cool tasks. Controlling for this fuller measure of pretest EF revealed a stronger effect of fantasy content on posttest EF performance ($F(1, 79) = 6.69$, $p = .01$, $\eta_p^2 = .08$). Examining each condition separately revealed a trend for condition ($F(3, 79) = 2.28$, $p = .09$, $\eta_p^2 = .08$) and significant mean differences between the Phineas and Ferb and both the Little Einsteins (1.34, $p = .05$) and SpongeBob (1.42, $p = .04$) conditions, and a trend toward a difference between the Little Bill and SpongeBob conditions (1.87, $p < .10$).

An abiding question is whether each condition experience increased or decreased or had no effect on EF in absolute terms. Different pre- and posttests preclude analysis of this for all but the test of working memory. A 2 (pace: fast or slow) × 2 (content: fantastical or realistic) ANCOVA on posttest working memory scores controlling for pretest working memory scores showed a significant effect of fantasy ($F(1, 79) = 6.13$, $p = .02$, $\eta_p^2 = .08$) but not pacing. For working memory, the scores of children who watched *SpongeBob* and *Little Einsteins* decreased from pre- to posttest (−0.58) whereas the scores of children who watch *Phineas and Ferb* and *Little Bill* increased (0.53). One would expect a slight increase at retest because children no longer need to apportion working memory to remembering the instructions. Working memory is just one measure of EF, but at least for this one measure, performance improved (as would be expected at retake) only for children who had watched nonfantastical show, and deteriorated in those who had watched a fantastical show.

To examine the relation between pretest EF and the parent CBQ-SF measure, we first looked at the intercorrelation of the subscales of interest. These are shown in Table 2. The strong pattern of intercorrelations suggests the pretest EF measures and the CBQ tap into similar constructs, and supports the use of only the CBQ-SF in further research.

Discussion

In this study levels of fantasy and pacing were examined separately by using four shows that varied on the two dimensions. In addition, rather than relying only on parent measures to ensure similar levels of EF at pretest, here a battery of EF tasks was administered and used as a covariate in the analysis of the impact of different types of show on posttest EF scores. This showed that children were equal in EF at pretest, and revealed the relative change in ranking within the sample brought on by the condition experiences. Further, the working memory test given both before and after the condition experiences gave suggestive evidence as to how the experiences influenced children in absolute terms.

The results showed that fast pacing accompanied by realistic content is not detrimental to EF: Children who had watched *Phineas and Ferb*, a frenetically paced cartoon, did relatively well on the posttests of EF. On the other hand, surprisingly, the very slow *Little Einsteins* resulted in low posttest EF. In fact these scores were not significantly different from scores after watching *SpongeBob*, which had twice as many fantasy events (32, vs. 16 in *Little Einsteins*). Although validity concerns with retaking EF tests

Table 2
Intercorrelations Among CBQ-SF EF-Related Items and EF Pretests

	CBQ-SF impulsivity	CBQ-SF inhibitory Ctl	Pretest cool EF Z sum	Pretest hot EF (gift)
CBQ-SF attention	$-.44^{**}$	$.38^{**}$	$.42^{**}$	.13
CBQ-SF impulsivity	—	$-.38^{**}$	$-.26^{*}$	$-.29^{**}$
CBQ-SF inhibitory Ctl	—	—	$.20^{+}$	$.24^{*}$
Pretest cool EF Z sum				$.19^{+}$

Note. CBQ-SF = Child Behavior Questionnaire-Short Form; EF = executive function.
$^{+}p < .10$. $^{*}p < .05$. $^{**}p < .01$.

prevented using the same metric at pre- and posttest, working memory is not subject to this caution. For working memory, it appears that the realistic shows resulted in higher scores and the fantastical ones in lower scores. Hence fantastical shows, but not fast ones, appear to tax at least this one aspect of EF, and it might be the case that a certain threshold number of events lead to the deficit.

Concerning pacing, the results of this study are consistent with a much earlier study that used fast and slow episodes of *Sesame Street* (Anderson et al., 1977). Although that study's lack of results could have been because of the entire show being much slower in the 1970s than are TV shows today, the present study suggests instead that even today's very fast pacing is not problematic for children's EF. Rather, it appears that processing unrealistic events is what compromises children's later performance on laboratory measures of EF.

General Discussion

Across three studies, children's EF was lower after watching fantastical shows as compared with after watching realistic shows or engaged in playing or reading. The first study showed that this was true for 6- as well as 4-year-olds, not only for *SpongeBob* but also for a different fantastical show, *FanBoy and ChumChum*. *Fan-Boy* was also fast-paced—a second variable hypothesized to affect children's EF. On the other hand, anthropomorphized animal fantasy was not problematic for EF (*Arthur*), nor was playing with toys. Study 2 examined whether EF is lower after viewing a show that was designed to be educational, *Martha Speaks*. This high-fantasy, fast-paced show was as problematic as *SpongeBob* for immediate EF performance, as compared with reading a book based on the show, but without fantastical elements. Study 3 used four shows that were high or low on the two dimensions of interest, and controlled for pretest EF performance. Fast pacing was not problematic; fantastical content was. An important issue is children's absolute levels of performance, given that Z-scores are relative measures. Two factors support the idea that the fantastical shows depleted EF. First, on the one test that could be given at pre- and posttest (working memory), children watching realistic content showed the expected increase in performance at posttest, but scores of children watching fantastical content decreased. Second, many studies cited in the introduction, including a meta-analysis (Nikkelen et al., 2014), support a long-term association between more TV and lower EF or attention skills; the experimental studies shown here reveal a causal, short-term effect that is most likely consistent in direction with the long-term one.

Of course it is possible that some other feature of the shows, rather than fantastical content, might be influencing children's relative EF. Real world stimuli have the advantage of ecological validity but the disadvantage of lack of control. Using multiple shows addresses to a degree this lack of control. For example, perhaps *SpongeBob* lowers EF because it is humorous; *Martha Speaks* is also humorous, but *Little Einsteins* is not humorous. Another factor might be comprehensibility, yet *Martha Speaks* and *Little Einsteins* are comprehensible and show the EF effect, whereas *Phineas and Ferb* often seems incomprehensible, but does not affect EF. Still, further research should continue to probe whether fantastical events are indeed the cause, perhaps by presenting episodes of the same program that have varying numbers of fantastical events and seeing whether this results in graded detriments in EF. It might be the case that a certain threshold number is disruptive.

This novel finding has important implications for children's media exposure. Fantastical content is widespread in children's media, and even shows intended to be educational are replete with unrealistic events. That such events might lead to diminished EF—even temporarily—is important for parents and providers of children's media to know. We next present an information processing account of why fantastical TV shows lead to poor performance on EF tasks.

Processing TV

Fast and fantastical TV shows could subsequently diminish EF performance via their influence on attentional and information processing systems. In Lang's (Lee & Lang, 2013) model of TV processing, based on Ohman (1979), TV stimuli are attended to, encoded, processed, and stored. These processes occur simultaneously as new images appear continuously during viewing. EF tasks rely on these same attentional and processing resources (Figure 2).

Attention is elicited both by bottom up processes of orienting (where) and alerting (when), and top down voluntary processes that direct sensory receptors to stimuli. Watching TV particularly uses bottom up resources; in fact, TV appears to be designed to keep attention with visual and sound effects (Lang, 2000; Ravaja, 2004; Singer, 1980). Surprising events also increase orienting, in that people direct gaze toward unexpected events in a visual scene (Itti & Baldi, 2006). Fantastical events are very surprising because they are not what we routinely observe or expect. Therefore, they are likely to elicit many orienting responses. For these two reasons (TV attracts attention, and surprising events attract attention), watching fantastical TV might lead to the attentional system shift-

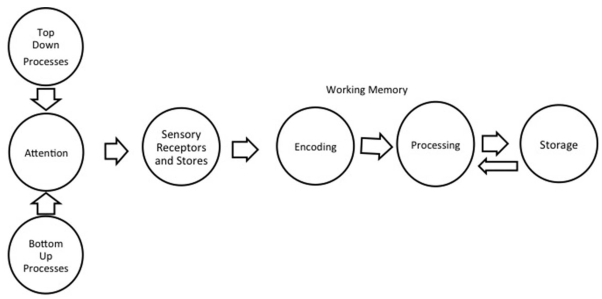

Figure 2. TV Processing. Figure adapted from Lillard, A. S., Li, H., & Boguszewski, K. (2015). TV and children's executive function. In J. B. Benson (Ed.), *Advances in child development and behavior* (Vol. 48, pp. 219–248). New York, NY: Elsevier. Copyright (2015) by Elsevier.

ing resources toward bottom-up processing. Perhaps it takes some time after watching a fantastical TV show for top-down resources, which are required in abundance for EF tasks, to reengage. Repeated viewing of fantastical TV could also lead to more habitual reliance on bottom-up processing.

A second (nonexclusive) possibility is that the problem resides further up in the processing stream. Attended-to events are registered by sensory receptors and passed on for encoding and processing in working memory, where the televised events are compared with immediately prior events and information stored in long-term memory concerning how events typically happen. Fantastical events are difficult to process because there is no stored schematic on which to draw to make sense of the event. Perhaps the brain goes on an extended search for schema by which to make sense of such events. Local neurotransmitters (such as dopamine) could become depleted from such efforts in lateral prefrontal cortex (lPFC), resulting in less neurotransmitter availability immediately thereafter (Brzezicka, Kamiński, & Wróbel, 2013).

An important center of EF processing is the Anterior Cingulate Cortex or ACC (Sarter, Gehring, & Kozak, 2006) that connects to the PFC and also appears to handle error detection (Dehaene, Posner, & Tucker, 1994) and Stroop-like selection, among other processes (Shenhav, Botvinick, & Cohen, 2013). Observing fantasy events presumably exercises these responses, because fantastical events are erroneous and conflict with known reality. Having been activated repeatedly while watching the fantasy events, the ACC might have fewer resources available to for EF tasks, which often ask children to withhold a dominant or prepotent response in favor of a subdominant one (Botvinick, Braver, Barch, Carter, & Cohen, 2001).

A question arises as to whether fantasy TV has this effect on EF because it depletes resources like dopamine, or because it disrupts normal processing. Accounts suggesting that depleting self-regulation in one context saps its availability immediately after (Ackerman, Goldstein, Shapiro, & Bargh, 2009; Muraven & Baumeister, 2000) have been challenged (Job, Dweck, & Walton, 2010), particularly with regard to glucose (Kurzban, Duckworth, Kable, & Myers, 2013). An alternative possibility is Kurzban et al.'s (2013) resource allocation account. It might be that information-processing resources are put into high gear to process fantasy events, but the rewards for doing so are low because the fantastical events are incomprehensible. By this account, automatic computations in the brain allocate processing resources in other ways, again rendering the PFC less active for subsequent EF tasks.

The long-term implications of this information-processing account are important. Training programs can improve EF task performance (Rueda et al., 2005; Thorell & Wåhlstedt, 2006), hence one might ask if watching a great deal of fantastical TV could result in improved EF over time. One argument against this is the lack of positive correlations between early TV viewing (especially entertainment TV and educational cartoons, both of which are likely to feature fantastical events) and later EF. Furthermore, training programs operate by having children concentrate on predictable stimuli that can be interacted with in precise ways to elicit rewards, not by presenting an unpredictable array of passively received stimuli, as is the case when one watches a fantastical TV show. It could be that repeated viewing of these unpredictable stimuli, with the strain they likely impose on the attention and executive control systems, particularly during an intensive period of neural development, impairs the normal development of these systems (Christakis, Zimmerman, DiGiuseppe, & McCarty, 2004).

Future Directions

Future research should examine the long-term effects of watching fantastical TV and also extend to fantasy in books and video games. If processing fantasy can overwhelm developing brain structures in a sensitive period, then perhaps exposure to a great deal of fantastical content during development, regardless of medium, would be more likely to have long term attention problems. Alternatively, perhaps the TV medium is especially problematic because it is not at under viewer control.

Recording brain processes while children watch fantastical TV is important, and will shed light on the cause of the effect on EF. For example, does the PFC show heightened activity when the child first starts watching, but then shut down? Or does it immediately slow down, not attempting to process fantastical events? If the latter, then poorer EF might result from the PFC still being "asleep" when the child is confronted with the tasks, whereas if the former, it has been overloaded and its capacity (perhaps dopamine) is temporarily spent.

It will also be interesting to know if older children and adults are also affected by fantastical TV. Redundancy in neural networks is a feature of brains. Depleted levels of available neurotransmitters in a circuit in adults could lead to recruitment of redundant circuits for accomplishing the same task (circuits not yet established in children); therefore, not showing EF decrements. On the other hand, if resource allocation changes because of a neural calculation regarding the rewards of paying attention to fantastical TV, then one would expect similar depletion in adults and older children.

In summary, this research reiterates and extends earlier findings that young children's EF is reduced after watching certain TV shows, relative to other shows or other activities. It is important for two reasons: (a) Along with Lillard and Peterson (2011), it shows an immediate influence of different lab-based experiences on EF performance in young children, and (b) it suggests caution regarding the content of young children's TV. The key variable in the depleting shows seems to be fantastical events, regardless of whether they are presented at a slow or fast pace, and regardless of whether the show is intended to be educational or merely entertaining. Finally, 6-year-olds show the effect to the same degree as 4-year-olds. Future research should examine what underlies the effect, how best to alleviate it, and its possible long-term consequences for developing attention and cognitive control systems.

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