CHAPTER SEVEN

Television and Children's Executive Function

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Abstract

Children spend a lot of time watching television on its many platforms: directly, online, and via videos and DVDs. Many researchers are concerned that some types of television content appear to negatively influence children's executive function. Because (1) executive function predicts key developmental outcomes, (2) executive function appears to be influenced by some television content, and (3) American children watch large quantities of television (including the content of concern), the issues discussed here comprise a crucial public health issue. Further research is needed to reveal exactly what television content is implicated, what underlies television's effect on executive function, how long the effect lasts, and who is affected.

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1. INTRODUCTION

Young children watch a good deal of television. There are some indications that television might influence the development of a very important construct called "executive function." Executive function is an umbrella term for processes that underlie our ability to plan and execute actions directed toward a goal (Carlson, Zelazo, & Faja, 2012). For example, one executive function process is working memory, or our ability to keep information in mind and operate on that information. Another is inhibitory control, or the ability to stop ourselves from engaging in an action, or even thinking about something that we do not (on an "executive" level) want to engage in or think of. Another executive function process is changing mind sets or operating by new rules when the situation we are in changes. If watching television early in life impairs these abilities, it is cause for public health action. This chapter reviews the concept of executive function and children's media use before discussing studies of both the long-term and short-term influences of television on executive function. It ends with a model of how television might exert such effects and calls for further research into understanding this relationship.

2. EXECUTIVE FUNCTION

Executive functions are the suite of processes that underlie goal-directed self-regulatory behaviors, including attention, planning, and inhibitory control (Miyake & Friedman, 2012; Miyake, Friedman, Emerson, Witzki, & Howerter, 2000). These abilities have been shown to be highly correlated and to constitute a unified construct, but they are also separable and distinct. The developmental trajectory of these abilities relies heavily on the development of the prefrontal cortex (PFC), which exhibits an extended maturation progression when compared to other areas of the brain (Mueller, Baker, & Yeung, 2013). Very early aspects of executive function are observable within the first year of life; however, a great amount of development occurs during the preschool years (Best & Miller, 2010; Diamond, 2013; Garon, Bryson, & Smith, 2008). Between 3 and 5 years, observable competencies are gained in all distinct executive function abilities. For example, longer delays can be handled on working memory tasks, and larger degrees of conflict can be managed on inhibition tasks. Continued maturation of these skills is seen throughout later childhood and adolescence.

Executive function is beneficial both immediately and prospectively, as it is predictive of positive long-term outcomes across several life domains. Executive function skills have been shown to undergird positive social (Eisenberg et al., 2004) and cognitive function (Blair & Razza, 2007), and executive function is strongly associated with success in school and life (Blair & Razza, 2007; Bull, Espy, & Wiebe, 2008; Diamond & Lee, 2011; Duncan et al., 2007; Espy et al., 2004; Mischel, Shoda, & Rodriguez, 1989; Ponitz, McClelland, Matthews, & Morrison, 2009). A large-scale study showed that childhood self-control predicts myriad health, wealth, and criminal behaviors at age 32 (Moffitt et al., 2011). Due to both the short- and long-term positive outcomes associated with executive function abilities, any common activity affecting this construct is of interest. One activity that appears to influence executive function is modern media, including television.

3. CHILDREN AND TELEVISION MEDIA

Television is, of course, a common pastime for young children. A recent survey found that at both 2–4 and 5–8 years of age, children spend an average of about 2 h/day watching television, DVDs, and videos (Rideout, 2011). Some television programs have positive effects (Linebarger & Vaala, 2010). For example, children have been shown to learn some Spanish words from watching *Dora the Explorer*, and low-income children who watched *Sesame Street* were more school-ready than were those who did not watch the show (for review, see Anderson & Kerkorian, in press). Despite some positive findings, developmental psychologists have long been concerned about children watching television. One theoretical reason for this concern is the passivity of the medium. Passivity is a concern because, as Piaget (Flavell, 1963), Montessori (Lillard, 2005), and others have pointed out, children develop through acting on the environment. A child who passively absorbs stimuli is thought not to absorb them as well. Beyond this theoretical concern, many studies show associations between television and negative child outcomes. For example, children who watch more television show increased obesity, aggression, stereotyped cognitions and other misconceptions, and worse academic performance than children who watch less television (Andersen, Crespo, Bartlett, Cheskin, & Pratt, 1998; Anderson et al., 2003; Anderson, Huston, Schmitt, Linebarger, & Wright, 2001; Schmidt & Vandewater, 2008; Sharif, Wills, & Sargent, 2010). As noted earlier, this chapter addresses another negative outcome with which more television has been associated: poor executive function, including problems with attention. We first discuss evidence of these associations, before turning to short-term experimental studies that suggest the relationship might be causal.

4. LONG-TERM MEDIA INFLUENCES ON EXECUTIVE FUNCTION

There has been much discussion of associations between television and long-term or trait-level attention problems. Most, although not all, of the published studies report that television viewing is associated with lower attention skills concurrently and/or over the long term (Anderson & Pempek, 2005; Ferguson, 2011; Foster & Watkins, 2010; Johnson, Cohen, Kasen, & Brook, 2007; Jolin & Weller, 2011; Landhuis, Poulton, Welch, & Hancox, 2007; Mistry, Minkovitz, Strobino, & Borzekowski, 2007; Obel et al., 2004; Pagani, Fitzpatrick, Barnett, & Dubow, 2010; Russ, Larson, Franke, & Halfon, 2009; Stevens & Mulsow, 2006; Swing, Gentile, Anderson, & Walsh, 2010; Thakkar, Garrison, & Christakis, 2006; Zimmerman & Christakis, 2007). Furthermore, these negative effects of television do not only result from children intentionally viewing television programs. One recent study showed that exposure to adult-directed background television at age 1 and overall household television use at age 4 predicted low executive function at age 4 (Barr, Lauricella, Zack, & Calvert, 2010). Another study showed that earlier exposure to both background and foreground television was related to poorer executive function ability, even when the content was child directed (Nathanson, Alade, Sharp, Rasmussen, & Christy, 2014). Additionally, total television and video game exposure in middle school was found to be related to attention problems 13 months later, controlling for earlier attention (Swing et al., 2010). Johnson et al. (2007) obtained similar findings with adolescents: the amount of television watched at age 14 predicted later attention problems.

Various theories have been proposed to account for these findings. One is that they relate to time use. According to this theory, it is not that the television impairs attention, but rather, that time spent watching television is time away from other activities, such as reading, that train executive capacity. Another is that the rapid scene changes and high levels of sensory stimulation associated with television—especially entertainment and violent content television—interfere with attentional capacities. According to this theory, television during time periods when attentional capacities are developing might be particularly detrimental.

A perennial problem with studies showing that something at Time 1 predicts something at Time 2 is determining causality. Perhaps children with manifest or even latent attention problems choose to watch more television, and the exposure to television has nothing to do with the attention problems. Ideally one could randomly assign children to watch television or not, then examine them for attention and executive function problems several years later. Of course, there are many impediments to such a study, from the fact that few parents would willingly have their child assigned to either group, and parents cannot perfectly control children's television exposure regardless. Mice parents and baby mice are much more controllable, and recently a study was conducted using a mouse model.

This study was carried out by Christakis and his colleagues, who posit that it is not any early television exposure, but rather that it is exposure to particular television content within a sensitive developmental period (Lillard & Erisir, 2011) that impairs the developing attention system (Christakis, 2009; Thakkar et al., 2006). In their study, for 6 h each day, from postnatal day 10 and continuing for 42 days, mice had Cartoon Channel audio (at normal loudness) piped into their cages, while a photo-rhythmic modulator programmed LED lights in each corner of the cage to change color and intensity in concert with audio changes (Christakis, Ramirez, & Ramirez, 2012). Ten days later, when tested on a battery of behavioral and cognitive tests (e.g., open field, mazes), the experimental mice performed worse, were hyperactive, and failed to show species-typical caution, when compared to control mice. The rapid changes in visual and auditory stimuli during a sensitive period of rapid synaptic growth and pruning were thought to explain these subsequent behavioral effects. However, one might argue that these effects are specific to mice; human brains are much more complex, and humans have a good deal of other complex input even when they watch a great deal of television.

Although long-term associations between attention and television have been established for humans, there has been very little investigation of immediate impacts or possible mechanisms by which television might impact executive function. If certain television content makes children less able to concentrate and follow rules immediately afterward, then repeated viewing of such content might lead to longer term impairment. One could also argue the opposite—that repeated viewing might build an attention "muscle" (Baumeister, Vohs, & Tice, 2007). However, this seems unlikely, at least at usual levels of viewing. This is because of a lack of *positive* lagged associations between television and attention. If repeated television viewing builds an executive function muscle, then there should be reports showing that the more television watched in early childhood, the greater one's executive function later. Instead, existing reports show either a negative impact or no impact over the long-term.

5. SHORT-TERM STUDIES OF TELEVISION AND EXECUTIVE FUNCTION

Aside from those conducted in our laboratories (which are described later in this chapter), we have located five studies of the immediate influence of television on executive function; one was conducted with adults and four with preschoolers. With adults, one study showed that after 30 min viewing either a highly arousing clip from the movie *Doom* or a banal tennis match, *Doom* viewers performed worse on a test of attention in which they were required to hold rules in mind and mark symbols according to those rules in a timed test (Maass, Klpper, Michel, & Lohaus, 2011).

Four earlier studies involved preschoolers. Two of these found an influence of television on executive function and two did not. Geist and Gibson (2000) showed preschoolers 30 min of PBS or network television shows, specifically *Mister Rogers' Neighborhood* or *Mighty Morphin' Power Rangers*, then coded their behavior for 30 min in a playroom. The control group went straight to the playroom, which had seven activity centers, such as a water table and a table of math games. Relative to controls, children who had watched *Mighty Morphin' Power Rangers* switched activity centers more often and spent less time at each, whereas children who watched *Mr. Rogers' Neighborhood* behaved no differently than children in the control group.

Similar findings were obtained over 30 years ago in a short-term longitudinal study in which children watched aggressive (cartoon versions of *Batman* and *Superman*) or prosocial (*Mister Rogers' Neighborhood*) shows over 4 weeks in preschool. Classroom behaviors were coded at baseline and during the viewing period. Over 4 weeks, children who watched aggressive television became less patient (waiting for teacher attention) and obedient, whereas those who watched prosocial television became more patient for teacher attention and engaged longer in tasks (Friedrich & Stein, 1973).

Although selected for specific features like aggression, in both of these studies, the shows that had negative effects on executive function abilities also differed in other ways. One other way they differed is what is termed "pacing" in the television literature. Pacing has been defined in myriad ways (see Table 1).

Table 1 Some Prior Operationalizations of Television Pacing

Anderson, Levin, and Lorch (1977)	(a) Frequency of camera or editing actions, (b) frequency of changes to an essentially new visual scene, (c) percentage of active motion, (d) frequency of auditory changes (e.g., change from voice to music), (e) percentage of lively music, (f) percentage of aroused, active talking, and (g) segment length
Cooper, Uller, Pettifer, and Stolc (2009)	Frequency of camera angle changes
Huston et al. (1981)	(a) Variability (rate of changes to scenes not previously shown in the program) and (b) tempo (rate of changes in scenes previously shown in the program plus the rate of character change)
Lang, Geiger, Strickwerda, and Sumner (1993)	Related cuts
Lang, Bolls, Potter, and Kawahara (1999)	The number of times a structural feature known to elicit orienting in attentive television viewers occurs
McCollum and Bryant (2003)	(a) Frequency of camera cuts, (b) frequency of related scene changes, (c) frequency of unrelated scene changes, (d) frequency of auditory changes, (e) percentage of active motion, (f) percentage of active talking, and (g) percentage of active music
Watt and Krull (1974)	Frequency of verbal utterances and set changes
Watt and Welch (1983)	Visual dynamic complexity: the unpredictability, or difference, in light levels on the screen over time

In one study (McCollum & Bryant, 2003) that coded some of the involved shows (among many others—85 popular children's shows in all), pacing was defined as frequency of scene changes (related and unrelated), camera cuts, auditory changes, talking, music, and motion. *Mighty Morphin' Power Rangers* was among the fastest paced shows with a score of 41.90 and *Mister Rogers' Neighborhood* was the slowest, with a score of 14.95. *Batman* (it is not clear whether this was the cartoon or real version—the study mentioned earlier used the cartoon) scored 25.85. In addition, then, to differing in terms of aggressive content, the shows used in these two studies happened to also vary in pacing, with faster-paced shows associated with increases in behaviors associated with poor executive functioning. In the adult study, even without formal study, it seems that the tennis match was more slowly paced than *Doom*. This raises the possibility that fast television pacing causes poor executive function.

Two other studies controlled for content but systematically varied pacing. Cooper et al. showed 4-, 5-, and 6-year-olds fast- or slow-paced (with pacing defined only as camera cuts) 3.5-min clips of an adult reading a story (Cooper et al., 2009), then administered the Attentional Network Task, which tests for the executive function skills of alerting, orienting, and resolving conflict. Afterward, 4-year-olds who saw the slow clip oriented better on the Attentional Network Task, but for 6-year-olds the findings were the opposite: those who saw the fast clip oriented better. Across the whole sample, there were fewer *errors* made by those who saw the fast clip, perhaps due to increased arousal. There were no differences on alerting, conflict, or overall reaction time based on pace. However, as will become clear later, it is possible that despite the differences in pacing, the content (a person reading) presented little encoding challenge, at least in the short presentation period (3.5 min) used in this study.

A second study that controlled pacing, also conducted over 30 years ago, created two 40-min episodes of *Sesame Street* by splicing together fast- or slow-paced bits from four episodes (Anderson et al., 1977). (At that time, the program was in magazine format and composed of several self-contained mini-stories termed "bits.") In this study, pacing referred not only to camera angle changes but also to factors such as voice changes (see Table 1). Pacing was found to have no effect on preschoolers' subsequent impulsivity and task persistence (tested immediately after viewing), which with other findings suggested that television pacing is not problematic for subsequent executive function (Anderson et al., 2001). However, it is possible that even the fast-paced episode was not particularly challenging to encode, in that even fast-paced bits of *Sesame Street* 30 years ago were not fast by today's standards. The show's rate of camera cuts doubled from 1980 to 2000 (Koolstra, van Zanten, Lucassen, & Ishaak, 2004), yet even around 2000, it was one of the slowest paced children's television programs on the air (McCollum & Bryant, 2003).

6. PROCESSING OF TELEVISION

Other studies have looked at the effect of pacing on ongoing attention to and processing of television, which might have implications for its influence on executive function immediately after viewing. Wright and colleagues systematically varied television pacing (defined as scene and character changes), and found more gaze shifts during fast-paced programs, implying that bottom-up attention (Chun, Golomb, & Turk-Browne, 2011) was grabbed by salient features of the shows (Wright et al., 1984). In addition, fast pacing in television shows was found to negatively impact memory for show sequences, suggesting processing overload. Faster pacing also impairs adults' processing of television (Lang et al., 1999; Lang, Zhou, Schwartz, Bolls, & Potter, 2000). Increased reliance on bottom-up attention (rather than top-down attention) and difficulty processing television could both lead to lower levels of executive function subsequent to viewing.

Lang has shown that processing television is a function of resources allocated to processing the message, minus resources consumed by processing it (Lang, Kurita, Gao, & Rubenking, 2013). If one uses more resources than were allocated, then one runs out of resources and cannot process the message. Allocation of resources is increased with increased orienting responses, caused in part by cuts and other structural features of the program being watched. Use of resources is determined by the amount of *new information introduced*, such as new objects, changes in existing objects, and other similar situations. Perhaps for both of the studies that showed no effect of pacing on children's executive function, faster pacing increased the resources allocated to processing television, and there was relatively little new information introduced. As a result, the stimuli were not challenging enough to cause a processing overload that would have then impaired executive function. This proposed relationship will be further explained below.

Thus far, we have focused on pacing as a cause of information processing and executive function problems during exposure to fast-paced television. There is also some support for the view that the content of television programs causes these difficulties (Huston & Wright, 1983). Content presenting fantastical or physically impossible events[1] could be specifically problematic for subsequent executive function performance. When Coyote chases after Road Runner until he is suspended in a cloud, where he remains for an impossibly long time before dropping down ("Zoom and Bored" episode), physics have been violated; the event is *fantastical*. *Doom, Batman*, and *Superman* also show physically unrealistic events. In contrast, events in television shows like *Mr. Rogers* and *Sesame Street* are typically realistic, at

[1] Fantasy can also refer to cartoons or to humanized animals. Although children do not learn *as well* from cartoons as from more realistic pictures, they do learn to some degree from cartoons (Ganea, Pickard, & DeLoache, 2008). Regarding humanized animals, children appear to readily accept them, even interpreting pulsating blobs as having human-like goals or intentions (Hamlin, Wynn, & Bloom, 2007). Fantasy in our discussion refers to *physically unrealistic events*.

least in physics terms. In an earlier era, presentation of such violations was largely confined to magic shows, but moving pictures easily present fantastical events.

Why might observing fantastic events lead to lower executive function? Humans are theorized to possess a "naïve physics," an innate representation of the laws governing physical events (Spelke, 1994). Even if those representations are not innate, they do appear very early in life, such that by age 4 one has strong expectations of how physical events should occur (Shtulman & Carey, 2007). In one view, physically ordinary events are "scaffolded" by expectations formed over ontogeny and phylogeny; human beings are "prepared" to represent them (Williams, Huang, & Bargh, 2009). In Piagetian terms, ordinary events can be assimilated to existing cognitive structures, whereas one's cognitive structures need to be altered to accommodate to novel events. Accommodation clearly takes more processing resources than assimilation, since it must require neuropil alteration (for example, new dendritic spines).

Based on our studies with fantastical television shows, we hypothesize that events that violate these innate or at least well-rehearsed representations are more difficult to process, and thus require more cognitive resources than events that adhere to the physical laws of reality. It might also be the case that we allocate more resources to such events, because they are "attention-grabbing." This possibility is compatible with our hypothesis. Repeatedly needing to allocate more cognitive resources to novel events in fantastical shows is hypothesized to deplete cognitive resources over the course of 10–20 min of viewing time.

Fantastical events can be regarded as "new information" in Lang's model (described above), because they violate expectations of how things should happen; such events might therefore require more processing resources. The processing demands of fantastical events have not to our knowledge been a focus of television research. A prior analysis of children's television shows (Huston & Wright, 1983; Huston et al., 1981) mentions "incongruity" and "visual tricks," but did not focus on these features. Results from our studies of television, discussed next, suggest that the fantastical events contained in television programs might be very important.

7. OUR STUDIES

In our first experiment to test whether fast and fantastical television shows might influence later executive function, Jen Peterson and

I randomly assigned sixty 4-year-olds to watching *SpongeBob*, watching *Caillou* (a slow-paced cartoon about a young boy, devoid of fantastical events), or free drawing in a laboratory testing room for 9 min (Lillard & Peterson, 2011). Pacing was roughly determined by counting scene changes per minute; by this measure, *SpongeBob* was three times faster than *Caillou*. Each child was given four posttests of executive function. One was the Backwards Digit Span (McGrew & Woodcock, 2001), in which children are read increasingly long lists of numbers, and must repeat them backward. Another was a child-friendly version of the classic Tower of Hanoi, in which people need to move objects according to specific rules in order to match a pattern. The third task was Head-Toes-Knees-Shoulders (HTKS) (Ponitz et al., 2008, 2009), a Simon-Says like game in which children must do the opposite of what is asked. The fourth test of executive function was the classic Delay of Gratification task (Mischel et al., 1989), in which children need to wait to receive a larger food reward, or can ring a bell to get a smaller reward sooner.

In addition, we thought that there might be something good about watching *SpongeBob*, namely that it might increase creativity. Our thinking was simply that when watching *SpongeBob* children see reality changed in myriad ways, and this might lead them to think more creatively afterward. To measure this, we administered the Alternate Uses task, in which people are asked to think of all the uses they can come up with for each set of everyday objects (Dansky, 1980). Interestingly, there is some controversy regarding whether creativity is best when one has high or low executive function. Some that one must inhibit the typical uses in order to think of new ones (Diamond, 2013), whereas others find that people are more creative when they are poor at inhibition—thus, theoretically, at inhibiting unusual uses (Thompson-Schill, Ramscar, & Chrysikou, 2009). It seems likely that both processes operate in creativity and that what might be essential is cognitive control: exerting or removing inhibitory processes as needed.

While children were watching the shows and taking these tests, their parents completed a media survey of how much the children watched television and what programs; and "Strengths and Difficulties," a scale addressing attention problems (among other things) that is related to the widely used but longer Achenbach Child Behavior Checklist (Goodman, 1997, 2001).

To examine possible experimenter effects, half of the children in each condition were tested by a posttest experimenter who was blind to the study hypotheses. This will not be discussed further, because it had no impact on results (in fact, effects were larger with the blind tester).

There were no group differences in parent ratings of attention problems nor in the amount of television or specifically *SpongeBob* typically watched by the children. Cronbach's alphas showed that performance on the Delay of Gratification task did not correspond to performance on the other executive function tests, which is a finding consistent with other studies (Diamond & Lee, 2011; Huizinga, Dolan, & van der Molen, 2006). Because a single test of executive function is not as reliable as a composite score (Wiebe et al., 2011; Willoughby, Wirth, & Blair, 2011, 2012), we summed *Z*-scores of responses to HTKS, Backwards Digit, and Tower of Hanoi (to put them on the same scale, equally weighted), and compared these sum scores across the groups. Thus, three executive function tasks were analyzed together (as a sum of the *Z*-scores), and responses to the Delay of Gratification task was analyzed separately. Both using a standard ANCOVA (with age covaried) and regression (with age, attention problems, and television-per-week entered at a first step), and both for the Delay of Gratification measure and the executive function composite, the children who watched *SpongeBob* performed worse than those who drew or watched *Caillou*. We had expected that *SpongeBob* might increase creativity, but it did not. Although there are many differences between our experimental conditions, we hypothesized that the combination of fast pacing and fantasy in *SpongeBob* caused the effect. This is because the fantasy events are difficult to process (we hypothesize), due to the child having no existing scripts or schemas to which to assimilate them, and because these difficult-to-process events are also arriving in rapid succession.

In our second study to test whether fast pacing and fantasy might be at issue, we examined children's executive function following: (1) a new episode of *SpongeBob*, (2) a different fast and fantastical cartoon (*Fan-Boy* and *Chum Chum*), and (3) a different slow, realistic cartoon (*Arthur*). We also changed the control condition to playing instead of drawing, and checked to see if 6-year-olds' executive function was also influenced by these experiences. Furthermore, we used full 11-min episodes of the shows (often two 11-min episodes are paired for a 30-min television slot, with commercials.) In all, 160 children were shown an episode or played, followed by a similar battery of executive function tests; their parents completed the same surveys. Again, there were no *a priori* differences in attention or media exposure between the conditions. A two-way ANOVA with age group (4 and 6) and condition (*SpongeBob*, *FanBoy*, *Arthur*, Playtime) showed a significant effect of condition, $F(3, 159) = 3.34$, $p = 0.02$; *post hoc* *t*-tests revealed that children who had watched the fast and fantastical shows performed worse on the executive function composite than children who had played. The performance of children in the *Arthur* condition was intermediate—worse than players, but better than children who watched *SpongeBob*. This is similar to the *Caillou* children in the initial study. There was no significant *Age* × *Condition* interaction, suggesting that the effect does not wane significantly from age 4 to 6.

The second follow-up study used a 2 × 2 factorial design to examine the separate contributions of fantasy and fast pacing to executive function. Pacing was determined by a computer program called *Scene Detector*, a movie editing tool that uses percentage of pixels changed to determine when a scene has changed. The four shows were *Little Bill* (slow, realistic), *Little Einsteins* (slow, fantastical), *Phineas and Ferb* (fast, realistic; the only fantastical feature in the episode, a talking platypus, was edited out), and a different episode of *SpongeBob* (fast, fantastical) than we had used in the previous two studies. Eighty 4-year-olds were given pre- as well as posttests of executive function, and parents completed the short form of the Child Behavior Questionnaire or CBQ-SF (Putnam & Rothbart, 2006).

There were no preexisting group differences on the CBQ-SF subscales most relevant to executive function or on our pretests executive function. An ANCOVA with age and pretest executive function score as covariates showed a significant effect for fantasy, $F(1, 75) = 5.04$, $p = 0.03$, but not for pacing. Follow-up tests showed that children did as poorly on the executive function tests after *Little Einsteins* (slow, fantastical) as after *SpongeBob* (fast, fantastical), but did equally well after *Phineas and Ferb* (fast, realistic) as after *Little Bill* (slow, realistic). From this study, it appears that fantastical events, but not pacing, are responsible for children's poor executive function skills following certain television shows.

We were also interested in whether educational television might have similar effects. To examine this, Eve Richey conducted a third follow-up with 60 4-year-olds. She tested whether a fast, fantastical PBS show designed to teach children vocabulary, *Martha Speaks*, would be as problematic as *SpongeBob*. Pacing (judged by *Scene Detector*) and fantasy content (the number of unique physically impossible events) were similar in the two shows. In the episode of *Martha Speaks*, for example, a child's school desk dropped through the floor, emerged from the school, and flew through the air. Control group children read a book version of *Martha Speaks*, with the reading taped and signals in the tape indicating when to turn the page; the reading and the videos each lasted about 22 min. Unlike the television show, *Martha Speaks* books do not portray physically impossible events.

We again found that fantastical television, even when intended to teach vocabulary, significantly impaired executive function: $F(2, 59) = 5.51$, $p = 0.007$; follow-up tests showed that children in both video conditions performed worse on the executive function tests than children in the book condition. The vocabulary words were not learned with either *Martha Speaks* presentation.

To summarize our research so far, we have found four television shows that negatively impact executive function relative to control (play, art, and reading) conditions and/or other shows (see Table 2). These effects were seen in children of ages 4 and 6. Fuxing Wang (unpublished raw data) also conducted a study in our laboratory at the University of Virginia with undergraduates, having them watch either *SpongeBob* or *Bob's Burgers*, a funny cartoon without fantastical events. Afterward, they completed a battery of computerized tests of executive function, such as the Wisconsin Card Sort. In undergraduates, there was no evidence that the fantastical events impaired executive function. This suggests the effect disappears sometime between the ages of 6 and 20 (although these authors feel depleted after watching fantastical shows!)

Table 2 Executive Function Results and Some Characteristics of Shows Used in Studies 1–4

Show Diminished Executive Function?	Show	Fast Paced	Fantastical	Producer's Intended Audience Age	"Commonsense Media" Target Age
Yes	*SpongeBob*	x	x	6–11	6
Yes	*Little Einsteins*		x	4–6	4
Yes	*FanBoy & ChumChum*	x	x	6–9	7
Yes	*Martha Speaks*	x	x	4–7	4
No	*Little Bill*			4–6	4
No	*Caillou*			3–6	3
No	*Arthur*			4–8	5
No	*Phineas and Ferb*	x		6–11	5

As can be seen in Table 2, fantasy (in the sense of physically impossible events) appears to be more important than pacing for subsequent executive function. Another variable that could be responsible for the effect is the fact that some shows are aimed at an older target age than was tested (thus, message complexity/comprehensibility might have caused the effect). Although the intended age range and the age recommendation of a respected parent media website (Commonsense Media) were similar for some shows that did and did not cause the effect, it is possible that something about comprehensibility of the story line is responsible; we have not firmly established that fantasy is the reason for our finding. Besides intended audience age, future research might look at themes of a show, identification with show characters, and children's level of arousal while viewing as possible causes.

In other research, we have examined whether Chinese children would show the same effects as American ones. Chinese preschoolers are known to have higher levels of executive function than their American counterparts (Lan, Legare, Ponitz, & Morrison, 2011; Sabbagh, Xu, Carlson, Moses, & Lee, 2006), which might render them impervious to the negative influence of television on executive function found with the samples of American children. In China, there is little research on children's television, and there are no official recommendations regarding children's television viewing. In collaboration with other Chinese colleagues, we investigated both the association between cartoon viewing and executive function, and the immediate influence of two different cartoons (educational vs. entertainment) on children's executive function.

We first employed a parent survey to examine current and predictive relationships between television viewing and executive function from ages 2 to 5. The parent survey was given three times, 6 months apart. Executive function was measured with 15 items intended to tap inhibition, shifting, emotional control, working memory, planning, and organizing; these were adapted from sample items on a published survey (Isquith, Gioia, & Espy, 2004). Example items included, for example, "When asked two things to do, remembers only the first or last" and "Has trouble in concentrating on games, puzzles, or play activities." Parents rated each item as not true, somewhat true, and certainly true of their child; these scores were converted to 3, 2, and 1, respectively, and were added to create an index of EF (ranging from 15 to 45). This 15-item scale was pretested on 855 preschoolers, and the results suggested good statistical properties (e.g., Cronbach's alpha $=0.82$).

Children had watched a total of 867 television shows, many of which were American shows with Chinese language dubbed in; average viewing was between 7 and 8 h per week across the testing points. The great majority of shows were for entertainment, as educational television is rare in China.

Multilevel modeling was used to examine the development of executive function across the three time points. The most striking result was a decrease of 0.012 points on average in children's executive function for each additional hour per week of viewing television, after age and gender were accounted for. Although this in some ways seems small, our scale was of limited range (15–45), and even small differences can be quite meaningful at the population level.

Our second Chinese study attempted to establish whether a similar relationship between television viewing and executive function could be found after short-term exposure in Chinese children. Ninety preschoolers (ages 4–6) were randomly assigned to either an entertaining cartoon group which viewed *Tom & Jerry*, an educational cartoon group which watched *Mickey Mouse Clubhouse*, or a no television group that played freely in their classrooms, using a 3×3 between-subjects design. Scene changes occurred at a similar rate in the two videos, as measured by *Scene Detector*. *Mickey* was agreed by a panel of judges to be educational, and was shown by objective coding to be less fantastical, although it still showed 17 fantasy events lasting a total of 107 s. *Tom & Jerry* was judged by the panel to be an entertainment show, and coding revealed that the stimulus showed 46 fantasy events, lasting 218 s. For a subset of the children, a Tobii T120 eye tracker recorded eye movements during viewing to determine whether increases in attentional processing could be responsible for any effects on executive function.

Next, children in all three groups completed three executive function tasks. These were Backward Digit Span, as in the prior studies; Day–Night (Gerstadt, Hong, & Diamond, 1994), in which children must say "Night" to a picture of a sun and "Day" to a picture of a moon; and the Flexible Item Selection task (Jacques & Zelazo, 2001) in which children must change the criteria by which they categorize a set of items. These are thought to mainly assess working memory, inhibitory control, and set shifting, respectively. A composite executive function score was created from the sum of standardized scores on the three tasks. Parent-report measures of the amount of television children typically watched each week, the content of those television programs, and the child's attention level were used as control variables.

The eye tracking results showed significant differences in how children in the two television exposure groups viewed the videos. Children viewing the entertainment program had significantly shorter average fixation durations during viewing than did children who watched the educational program, $t(16) = -3.68$, $p < 0.005$, Cohen's $d = 1.72$. The average number of fixations per minute in the entertainment group was significantly greater than in the educational group, $t(16) = 4.93$, $p < 0.001$, Cohen's $d = 2.29$. Shorter average fixation durations meant children sustained their attention on one stimulus for shorter periods of time; the greater number of fixations suggests that children shifted their attention more frequently.

There were also significant age effects on executive function, $F(2, 87) = 14.48$, $p < 0.001$, $\eta_p^2 = 0.25$. Because of this, an ANCOVA with age as the covariate was used to analyze whether there was a main effect of condition on executive function. The results indicated that there was a significant condition effect, $F(2, 86) = 6.99$, $p < 0.005$, $\eta_p^2 = 0.14$. *Post hoc* Tukey's tests indicated that children in the entertainment television group had lower posttest executive function scores than children in the educational television group, $t(58) = -2.56$, $p < 0.05$, Cohen's $d = 0.66$, and the control group, $t(58) = -2.95$, $p < 0.01$, Cohen's $d = 0.76$. The latter two groups did not differ. Study 2 suggested increased orienting responses occur during an entertainment show. More direct readings of children's neural activity while watching the shows could be useful to determine the cause of the detriment.

A third study was conducted in China to better investigate the cause of the negative influence of television on executive function found in the two studies just described. We tested activation of the PFC during children's viewing of the same shows used in the prior study, using fNIRS to reveal successive changes in the concentrations of oxygenated (O_2Hb) and deoxygenated (HHb) blood during children's viewing. Data collection with fNIRS is particularly well suited for child participants, because it has far fewer body movement restrictions and is noiseless (Moffitt et al., 2011). Twelve laser optodes (connected to 24 laser sources through bifurcated cables with cables of 690 and 830 nm paired and combined into one laser optode) were used and evenly assigned to subjects who watched the video simultaneously. This allowed us to more directly examine the internal activity of children's PFCs while viewing the television shows. HomER (Hemodynamic Evoked Response) software was used to analyze the changes in oxy-Hb, which were assumed to be a more sensitive reflection of cognitive activation than deoxy-Hb changes (Hoshi, Kobayashi, & Tamura, 2001; Strangman, Culver, Thompson, & Boas, 2002), because previous research

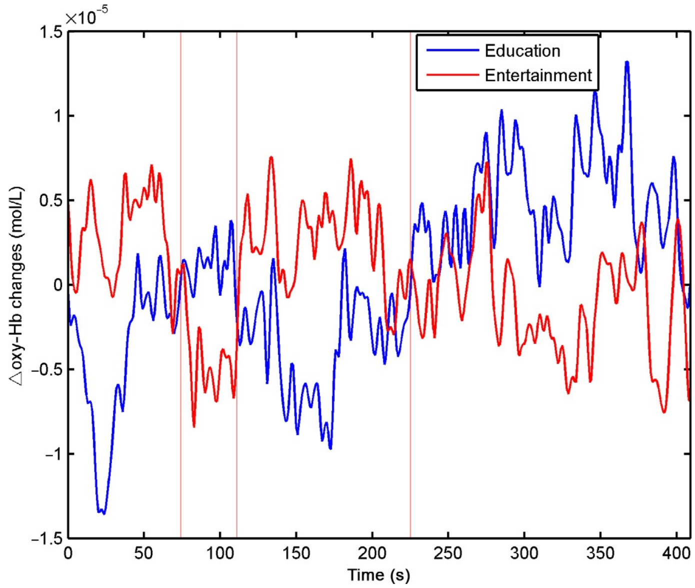

Figure 1 Time course for concentration of oxy-Hb in the prefrontal cortex during the first 6 min of viewing.

has indicated that cerebral blood flow increases in response to neuronal activation (Fox & Raichle, 1986).

Figure 1 shows the level of oxy-Hb in the PFC for each group during the first 6 min of viewing the shows. Summing across the entire 6 min of viewing, the fNIRS results showed no significant group differences in levels of oxy-Hb in the orbitofrontal cortex during viewing. However, visual inspection of the figure reveals four clear epochs in which one group exceeded the other to some degree in prefrontal processing. During the first 74 s of viewing, the level of prefrontal processing was higher for the entertainment group, $t(19)=2.05$, $p=0.05$, Cohen's $d=0.94$. For the next 35 s, although it appears to be higher for the educational group, the difference was not significant. For the next 120 s, from 112 to 225 s, there was also significantly higher activity in the PFC for the entertainment group, $t(19)=2.32$, $p<0.05$, Cohen's $d=1.06$. Finally, during the remainder of the recorded viewing time (226–410 s), the educational group generally showed higher activity; statistical analysis showed this was a trend, $t(19)=1.87$, $p=0.07$, Cohen's $d=0.86$. Thus, it appears that, overall, activity was higher for the entertainment group for approximately the first 4 min of viewing, and then the activity dropped off.

We see two ways to interpret these results. One possibility is that the increased orienting required by the entertainment cartoon increased processing to a point (the first 4 min of viewing). After that, the system became overloaded and prefrontal processing shut down. In support of this, although not directly examining neural activity, Lang and her colleagues showed that adults' allocation of processing resources to television messages becomes taxed when camera angle changes become excessive, reaching cognitive overload (Lang et al., 2013).

The second possibility hinges on the element of fantastical events rather than orienting responses. It is possible that when first shown fantasy events, children attempt to process them (using cognitive resources) and then, because fantasy events are incomprehensible, they stop trying to process them. This would also render the PFC less active for the remainder of viewing, and also for subsequent executive function tasks. Although we know of no literature on how children process fantastical events, we do know that children have difficulty filtering out irrelevant events, which can then overload processing (Ridderinkhof, van der Molen, Band, & Bashore, 1997). Perhaps the fantasy events are similar to irrelevant events: they do not fit the standard schematic narratives of how things happen in the world. In sum, according to this second possibility, cognitive resources are initially allocated to process fantasy events (and notably, the educational cartoon did have some fantastical events in the first minute), but the processing system becomes overloaded by them (particularly with the entertainment cartoon, which shows fantastical events throughout) and ceases to attempt the processing.

It would be useful in future research to compare clips with defined, occasional fantastical events with realistic clips that require repeated orienting responses, to see whether processing reliably decreases during or after fantastical events. Such research could tease apart the two possibilities just mentioned.

8. MODELING HOW FANTASTICAL TELEVISION MIGHT INFLUENCE EXECUTIVE FUNCTION

Here, we present a new theory—hinted at in the preceding pages—regarding why certain television shows deplete executive function. Our thinking is grounded in information processing theory and research on adult television processing (Lang, 2000; Lee & Lang, 2013), attention (Petersen & Posner, 2012), and executive function (Diamond, 2013). The basic premises

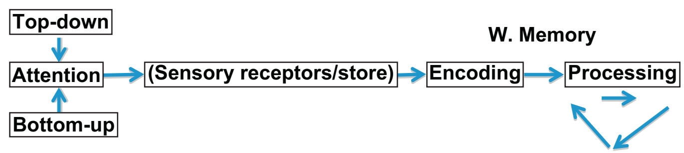

Figure 2 Information flow during television viewing.

are that: (1) information processing resources (such as neurotransmitters and/or perhaps glucose) are limited, (2) some shows use more processing resources than others (Lang, 2000), and (3) those resources are needed to perform our executive function tasks. Taking these premises into account, then, to the extent that the resources are depleted by a show observed just prior, performance on the executive function tasks suffers. Arousal also interacts with this system, as it has an upside-down U-shaped relationship to information processing (Yerkes & Dodson, 1908): too little or too much impairs it. Below, we will spell this theory out more fully (Figure 2).

Watching television entails attending to and encoding messages in auditory and visual streams, processing those messages in working memory, and storing and retrieving them dynamically in order to continuously interpret newly arriving messages (Lang, 2000). Attentional processes direct sensory receptors (eyes and ears) to attend to particular locations or sounds in a top-down fashion, and bottom-up responses (orienting responses to visual stimuli, and alerting responses to auditory ones) also control the allocation of attention resources. Attended stimuli enter the brain through the sensory receptors and are held briefly in the sensory store, from which some of the information is encoded. Encoding involves selecting information from the sensory store, which is then passed to working memory for processing.[2] These same processes are also important to maintaining attention and performing executive function tasks. Our hypothesis is that watching fantasy events quickly exhausts attention and/or processing resources, making them unavailable for the subsequent executive function tasks. This results in the immediate, short-term impairments we record in most of our studies. However, repeated viewing leads to so many of these short-term impairments that it disrupts the normal development of the information processing system.

[2] Although conventionally discussed as if different levels were locations, this is for some levels metaphorical, and a more true description might involve neuron or connection state.

First, consider how these processes are entailed in performing the executive function tasks. For every executive function task, a child must pay attention to instructions and keep attending to those instructions (in working memory) while carrying out the tasks. For example, for HTKS, a child must attend first to instructions ("When I say touch your head, I want you to touch your toes") and then, holding those instructions in mind, must attend to the commands ("Touch your head") and monitor their own behavior to handle the conflict inherent in doing the opposite of the instructions. For the memory span task, a child attends to instructions to repeat a string of words, and then must attend to what those words are, holding them in memory to repeat (and for backward tests, while reversing them). In contrast, for a delay task, a child must attend to, encode, and process instructions to wait, but while waiting might not continuously monitor those instructions; children who perform best often reimagine the circumstances or the desired objects (Mischel et al., 1989). The Tower of Hanoi puzzle task also involves attending to instructions, keeping them in mind, and envisioning how disks (or in our child-friendly version of the task, monkeys) relate to one another while conforming to the rules and adjusting the relationships between puzzle pieces to meet a goal. Our hypothesis is that either fantasy events, and/or repeated orienting responses, on certain television programs quickly deplete these resources, rendering them less available for subsequent executive function tasks. Because we are focused mainly on the influence of fantastical events, next I explain how observing fantasy events on television might deplete these same resources. Although our evidence suggests that fantasy events are the main source of the problem, perhaps when such events are shown in rapid succession (as when shows are fast-paced, and thus more likely to require repeated orienting responses), it is particularly problematic.

8.1. Attention

Both initially (in ontogeny) and perennially (across life) attention is controlled by bottom-up circuits originating in the visual/auditory cortices and extending to the temporal cortex (object identification) and parietal cortex (object locations) (Mechelli, Price, Friston, & Ishai, 2004; Sarter, Givens, & Bruno, 2001). By 4 years of age (Ruff & Rothbart, 1996), attention is also controlled by top-down resources that originate in prefrontal areas (Lang, 1990; McMains & Kastner, 2011; Mechelli et al., 2004).

Fast-paced shows present many stimuli that capture attention in a bottom-up fashion, via both auditory and visual changes. Surprising events—which include fantastical ones, because unreal events are typically unexpected—capture attention as well. Orienting responses increase resources available for television processing to a point, after which the cognitive system is overloaded and incoming messages are not processed (Lang et al., 2013). This is consistent with research showing that children comprehend television better when there are more attention-grabbing sound effects (Calvert & Gersh, 1987), but at some point (and we cannot say at this time exactly what this point is) processing likely becomes overloaded and comprehension declines.

In research to test this theory, use of attentional resources during television viewing could be monitored in at least three ways: eye movements, heart rate (HR), and skin conductance (SC). Increased eye movements while looking at the screen suggest increased bottom-up orienting responses; our Chinese study supports that preschooler's attentional resources were particularly used while watching a fantastical entertainment show (as compared to a less fantastical educational show). Although visual attention can also be voluntarily assigned to a stimulus using top-down processes, young children's television especially (Goodrich, Pempek, & Calvert, 2009; Huston et al., 1981) captures attention in a bottom-up fashion via changes in sound and light that reflect pacing. Young children's attention to television also increases with cuts and movement (Schmitt, Anderson, & Collins, 1999) that are accompanied by sound and light changes. A child looking away from the screen likely indicates inattention, which could stem from boredom or lack of comprehension. When television messages are scrambled or foreign dialog is inserted, making the message incomprehensible, preschoolers look away from the television (Anderson, Lorch, Field, & Sanders, 1981).

Based on prior research by Lang et al. (2013), we would expect that up to a certain level, bottom-up attention (orienting responses) should increase processing resources available. When a television show becomes *too* challenging (i.e., elicits an excessive rate of orienting responses), however, resources become insufficient and executive function is compromised. Reduced attention to the screen (looking away) would also lead to failure to encode show content.

8.2. Encoding/Processing

The process of encoding entails getting the message from the sensory store into working memory. Encoding of television is compromised when pacing or message complexity exceeds information processing capacity (Lang et al., 1999, 2013). Although cuts evoke orienting responses, when a cut is followed by unrelated information, the new information is poorly encoded (Lang et al., 1993). Once information is in working memory, it can be processed and stored, making it available for retrieval; it can then be used both for interpreting later parts of the show and for recall after the show is over. Research with adults has shown that there is an inverted U function for memory and cuts, such that up to a point more cuts (faster pacing) improves memory, but beyond that number, memory is diminished (Lang et al., 1999). The reason for this appears to be that the cuts increase orienting responses, which increases resources allocated to processing; but once processing becomes overly challenging (because the information is too difficult), then the information is not encoded (Lang et al., 2013).

In our experiments so far, we have not examined whether encoding and/or processing are disrupted by the television shows. Further research might examine this in at least two ways. First, one might examine encoding by testing for recognition memory of still shots of key show events (along with distractors) after viewing (a method used by Lee & Lang, 2013). Message difficulty would be expected to interact with recognition (see, for example, Thorson & Lang, 1992). Specifically, if encoding is at issue, recognition memory would be fairly constant for events occurring early and late in the easier shows, but memory for events in difficult shows would decline from the first to last minute of viewing due to overload. To test whether television stimuli create problems at the level of processing, children could be asked to arrange scrambled sets of still shots from the show to reflect their ordering in the show (an approach used by Wright et al., 1984). Children might conceivably do well on the first task, recognizing still shots, suggesting information was encoded, yet do poorly on the second task, suggesting they lack sufficient processing resources to commit the narrative sequence to memory for later recall.

8.3. Arousal

In addition to examining effects at the levels of attention or encoding/processing, future research should examine arousal, which has overall effects on processing of television (Lang, 1990; Lang, Dhillon, & Dong, 1995; Lang et al., 2000). Arousal stems from the reticular system signaling one to pay attention (Ravaja, 2004). High arousal is associated with challenge and excitement. To a point, increases in arousal improve message processing;

at higher levels arousal leads to processing decrements (Lang et al., 1995; Pourtois, Schettino, & Vuilleumier, 2012). Levels of arousal could be indicated in future research on television's effects on children's executive function with measures of SC and HR.

9. CONCLUSION

In sum, we hypothesize that certain television shows impair subsequent executive function because viewing the shows and performing the executive function tasks both draw on the same information processing resources. More attentional resources are allocated to the television shows with increased bottom-up pacing features (camera cuts). Top-down attentional resources and processing of the information in the television shows also use those resources. If processing the show is very challenging, resources are depleted and unavailable for the executive function tasks just after stimuli exposure. Content is more difficult to process when more new and unexpected information is presented. Impossible events are difficult because the human brain is not used to processing such events; novelty requires additional resources relative to familiar stimuli. At a point, however, those resources become unavailable, possibly because they are depleted, or possibly because the system makes a "choice" not to allocate resources to an impossible task. Arousal can improve these processes to a point, but if a child becomes overly aroused by a show, processing will suffer.

Repeatedly experiencing difficult shows early in development could impair the development of processing networks, resulting in long-term executive function problems as suggested by Barr, Christakis, and others. But even short-term impacts are important because children do not function well when their executive function processes are depleted. Knowing what kinds of television cause this depletion will be helpful to those overseeing children's television viewing, and by extension, to children who can benefit from higher executive function in many situations. We believe this line of research can provide valuable information to those who produce television content and also will have public policy implications. In addition, we hope that further research can experimentally determine whether the short-term negative impacts we observe translate into the long-term difficulties seen in some of our and many other laboratories' research on the important issues of television and executive control.

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