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Immediate impact of fantastical television content on children's executive functions

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Recent research has suggested that particular content of television programmes, such as watching fantastical scenes, can have negative consequences on cognitive functions in young children. We examined the effects of watching fantastical programmes on executive functions measured at both pre- and post-television viewing. Eighty 5- to 6-year-old children participated and were randomized into either fantastical or non-fantastical conditions. They completed inhibition, working memory, cognitive flexibility, and planning tasks both before and after watching either the brief fantastical or non-fantastical television clip. Whilst there were no differences between the groups at pre-test on any of the cognitive measures, children in the fantastical condition were poorer on inhibition, working memory, and cognitive flexibility tasks at the post-test session. Watching fantastical television content, even briefly, seems to disrupt cognitive function performance in young children across a broad range of aspects of executive function

Statement of contribution

What is already known on this subject?

- Exposure to fantastical content within a television programme may impair executive functions in young children.

What does this study add?

- Exposure to fantastical content within television programmes impairs executive functions in children of early primary school age.
- Impairment extends to all three core aspects of executive functions.
- Watching fantastical clips slows down planning performance without improving accuracy.

The effects of media exposure, particularly screen-based exposure such as watching television, on children's developmental outcomes have been much debated in the media and research literature with researchers examining factors such as screen time, number of household televisions, and television programme content on development (Kostyrka-Allchorne, Cooper & Simpson, 2017). Impairing effects have been reported on a range of aspects of development including sleep duration and timing (Hale & Guan, 2015), obesity

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(de Jong *et al.*, 2013), and psychological function such as emotion understanding (Skalická, Wold Hygen, Stenseng, Kårstad, & Wichstrøm, 2019). Other researchers have reported no negative effects of television exposure on children's development (Lee, Spence & Carson, 2017; Stevens & Mulsow, 2006). A recent systematic review reported weak associations between screen time and an array of different outcomes including sleep, cognitive development, and health (Stiglic & Viner, 2019). These mixed findings raise the question of the factors associated with potential negative effects on children's development. Factors relating to television exposure and their impact on children's cognitive development have become a focus of recent research in this regard with particular attention to higher-order executive functions.

Executive functions (EF) are a set of constructs comprising three core, dissociable components: inhibition, working memory and set-shifting (Diamond, 2013; Lehto, Juujärvi, Kooistra, & Pulkkinen, 2003; Miyake *et al.*, 2000), and a number of higher-level functions such as planning and problem solving (Diamond, 2013). These complex skills enable the maintenance of efficient goal-driven behaviour and underpin optimal social and cognitive functioning. A critical period of EF development occurs at around 3 to 5 years (Davidson, Amso, Anderson & Diamond, 2006; De Luca & Leventer, 2008), and these skills are known to be crucial for smooth nursery to school transition and across the early primary school years (typically ages 5 and 6 years in the United Kingdom) where children are required to show impulse control, adhere to instructions, show task-specific attention focus, and alternate between multiple classroom tasks (Barr, Lauricella, Zack, & Calvert, 2010; Pellicano *et al.*, 2017). Whilst there is an extensive amount of research on the impact of television viewing habits on EF in preschool children, exploration of the impact of television viewing on school children is often neglected (Best, Miller, & Jones, 2009). Early school years constitute a critical time where the child begins to integrate into a cognitively demanding environment and is therefore of high investigative importance (Romine & Reynolds, 2005). Better EF performance in children has been found to predict more positive academic and social functioning at school (Jacobson, Williford, & Pianta, 2011), highlighting the importance of assessing factors that might influence EF performance.

A recent systematic review on the relationship between television viewing and EF generated 76 articles for inclusion (Kostyrka-Allchorne, Cooper, & Simpson, 2017), but despite this volume of data, concluded that findings are mixed with little consensus on the relationship between television viewing and cognitive development. There appears to be a particular lack of consensus in relation to the impairing effect of time spent viewing television programmes or cartoons. Accumulating evidence however has suggested that any deleterious effects may be related to aspects of the television content itself such as the pace of presentation (Lang, 2000; Lillard & Peterson, 2011) or the fantastical content (Lillard & Peterson, 2015) rather than watching programmes per se. Fantastical content refers to that which violates knowledge about and expectations of reality and has become a focus of recent research on television exposure and cognitive function.

Explanations for the negative impact of fantastical television content watching on cognition have been proposed. Children show substantial preference to animated cartoons than live programmes, which may be attributed to the perceptually salient nature of cartoon features, comprising novelty and surprise (Wright & Huston, 1983). When a child is attentively engaged in watching a cartoon, he or she is actively merging and interpreting new incoming information, and thus, cognitive processing is being facilitated through external stimuli. The amount of processing required may depend upon the nature of the content to which the child is exposed (Lillard *et al.*, 2015). For example,

Geiger and Reeves (1993) examined the effects of semantically related and unrelated scene changes on attention in adults and found that different cognitive strategies were involved in processing a scene. Results showed that unrelated sequences of scenes required more cognitive resources, and posed higher attentional demands. This was attributed to the notion of surprise facilitated by unrelated events which elicit requirements for continuous adaptation, and thereby exhaust attentional processes. Contrary to this, related events coincide with a person's expectations and thus employ lower levels of attentional resources.

Several studies have found that children as young as 14 weeks show signs of surprise when their expectations about objects are violated (Baillargeon, 1987; Baillargeon, 2002). From infancy, children have innate knowledge about the core physical laws upon which objects can and cannot operate; this includes solidity of objects and continuity of motion (Spelke, Breinlinger, Macomber, & Jacobson, 1992). Children's understanding of physical laws gradually progresses as their experience with the external world increases (Piaget, 1967). Fantastical programmes tend to include content which violates expectations, making it difficult for the child to comprehend and incorporate these events into existing, and well-established mental representations. As a result, cognitive resources required for an array of behavioural outcomes may be exhausted. Information processing theories would argue that processing of this type of television content depletes the limited attentional resources required for successful EF performance (Lang, 2000; Lee & Lang, 2015).

The effects of television characteristics, such as fantastical content and pacing, on children's cognitive function have been assessed by a number of research studies. Lillard and Peterson (2011) conducted a study to examine the impact of pacing on children's EF. They reported that exposure to a 9-min fast-paced fantastical cartoon resulted in significantly poorer EF scores in 4-year-olds, than children in a slow-paced educational condition, and those in a drawing condition. The researchers argued that fast-paced content impedes the type of cognition which supports thoughtful and deliberate behaviours suggesting that fast-paced cartoons, containing rapidly changing scenes, burden children's cognitive resources to encode the events, thus exhausting their attentional capacity. This could be argued due to the 'bottom-up' attentional focus facilitated by stimuli-driven features (Buschman & Miller, 2007). Popular fast-paced cartoons may encourage children to uniformly expect change, resulting in impulsive responses which are reactive in nature (Nathanson, Aladé, Sharp, Rasmussen, & Christy, 2014).

The findings of pace on cognition within Lillard and Peterson (2011) may have been exacerbated by the fantastical content within the fast-paced cartoon, as noted by the researchers themselves. Within the design of their study, it was not possible to separate the effect of pace from fantastical content. Encoding fantastical events, which do not coincide with the child's understanding of reality, have been suggested to exhaust attentional resources (Goodrich, Pempek, & Calvert, 2009). This is because novel and unexpected events do not have established neural circuitry and encoding requires increased neurocognitive efforts, which could otherwise be used by self-regulation (Gailliot & Baumeister, 2007). McFadden (2015) compared EF performance in 4-year-old children using tasks of inhibitory control, WM, and cognitive flexibility. Children exposed to a fast-paced and slow-paced version of the same realistic cartoon did not differ in performance, suggesting that pacing may not be problematic if fantastical content is absent.

Several studies have now directly examined the influence of fantastical content on aspects of EF. Lillard *et al.* (2015) carried out a comprehensive investigation on both the

immediate influences of pacing and fantastical content on EF in children aged 4 and 6 (Lillard *et al.*, 2015). Exposure to a fast-paced, high fantasy cartoon was associated with lower EF scores immediately after viewing in comparison with children who watched an educational cartoon or engaged in a non-screen-based activity such as playing or reading. In an attempt to explore whether content or pacing was driving EF depletion, Lillard and colleagues found that, whilst fantastical content negatively affected composite EF scores, no such effect was found for children watching realistic, fast-paced cartoons. Lillard and colleagues administered a battery of pre-test and post-test tasks assessing EF. Pre-test assessment comprised inhibitory control (Hand Game and Gift wrap delay), auditory WM, and cognitive flexibility (Executive Function Scale for Preschoolers). Post-test performance was measured using five different tasks, three of which tapped into inhibition (Day/Night task, Forbidden Toy, and Head Toes Knees Shoulders), one focused on auditory WM, and one task assessed planning capacities. Cognitive flexibility was only assessed at pre-test and planning solely at post-test making pre- and post-test comparison of cognitive flexibility and planning difficult. Further research with matched EF tasks across pre- and post-test conditions is warranted. Findings within the Lillard *et al.* (2015) study were also reported as aggregate scores across EF aspects, and as the authors note, this limits the interpretation the impact of fantastical programmes on specific aspects of EFs. Further research examining the role of differential aspects of EF is warranted given growing evidence that like adults EF components are separable in children of this age (Wu *et al.*, 2011).

Another study conducted by Li *et al.* (2018) examined the inhibitory control performance of 4- and 6-year-old children who had either viewed or interacted with fantastical content on an iPad. The study showed that passive exposure to unrealistic content on a video clip from a game resulted in a negative effect on performance on a Go-No-Go inhibitory control task at post-test, whereas active interaction with the same game did not affect performance (Li *et al.*, 2018). Data from functional near-infrared spectroscopy demonstrated that watching fantastical events was associated with increased dorsolateral prefrontal activation, an area strongly associated with EF. These changes were not observed for children that interacted with the game depicting fantastical events. The authors suggested that interacting with fantastical events decreases the psychological distance between the child and the game and thus increases the likelihood that the events are perceived as realistic (Subrahmanyam & Greenfield, 2008). Similarly, White and Carlson (2016) reported that 5-year-olds showed improvements in EF after engaging in an active pretence activity. The findings of Li *et al.* (2018) suggest a link between passive exposure to fantastical content and EF implicating the importance of further research on passive fantastical content watching in this age group. As this research was restricted to a sole focus on inhibition, it is important that future research examines a broader range of aspects of EF.

In the present study, we build upon existing research through examination of the impact of fantastical content on individual aspects of executive function. Inhibition, WM, cognitive flexibility, and planning were measured at both pre- and post-test using parallel versions of the same tasks across these testing sessions. The inclusion of parallel versions of tasks facilitates control of extraneous variables. This design allowed for EF task performance prior to cartoon exposure to be compared directly with post-exposure task performance. The current study benefits from examining the independent effects of cartoon exposure on individual EF processes, rather than a unitary construct. Using a between-subjects design, the present study aimed to examine whether fantastical cartoons negatively affect EF performance in children of early primary school age. Based

on previous research with children of this age, and the account that fantastical events require increased levels of processing, it was hypothesized that children exposed to events violating physical laws will exhaust cognitive facilities, consequently leading to poorer performance in tasks assessing the core aspects of EF namely inhibitory control, WM, and cognitive flexibility. We also examined the impact of fantastical content on planning performance. It was expected that if fantastical content negatively impacts cognition, exposure to the fantasy abundant cartoon would result in low post-test performance across the different EF tasks, immediately after exposure. No such effects were expected for children exposed in the fantasy rare cartoon.

Methods

Participants

Participants included 80 children; forty children, of whom 22 were female, were in the fantastical condition (Mean Age = 71.8, $SD = 5.01$) and another forty children, of whom 20 were male, were in the non-fantastical condition (Mean Age = 71.6, $SD = 6.16$). All children were recruited from two mainstream local authority primary schools in the United Kingdom.

Design

Ethical approval was obtained from the School of Psychological Sciences and Health at the University of Strathclyde, and permission to participate was secured from the local authority and school. The study adopted a 2×2 mixed design with independent variables of condition (fantastical/non-fantastical) and time point (pre-cartoon/post-cartoon). Children were split randomly with 40 participating in the fantastical condition and 40 in the non-fantastical condition. The dependent variable was scores on each of the EF tasks.

Procedure

Children whose parents had consented for them to take part in the study were tested individually during school hours. The study was explained to the child, and verbal consent was obtained from each participant. Following consent, the children completed four EF tasks. Children were randomly assigned to either a 'fantastical condition' or a 'non-fantastical condition' and watched one of two cartoons depending on the condition they had been assigned. Following cartoon presentation, children completed parallel versions of the same four EF tasks in a different order and using different stimuli. Children were verbally debriefed after their participation. Parents were sent a questionnaire about their child's media use to measure participants television exposure at home.

Materials

Cartoons

Children watched one of two cartoons on a 15" laptop screen. Each cartoon presentation lasted 23 consecutive minutes. Cartoons were coded separately for pacing and fantasy events by two independent coders. The second coder was blind to the study. Any disagreements were discussed to arrive at an agreed standard coding. Pacing of scenes

reflected the frequency of camera editing changes to a new visual scene. One point was given for each scene change (see Table 1). Fantastical events included unrealistic events that violated knowledge about, and expectations of, reality. Examples included objects or characters changing shape, evaporating, disobeying rules of gravity, enchanted journeys, and magical events. One point was given for each unique fantastical event according to its corresponding time stamp. Where occurring more than once, the same fantastical event was counted only once as it was assumed re-occurrence of the same fantastical event would require less cognitive resources than upon initial presentation (Lillard *et al.*, 2015).

Little Einsteins

This fantastical cartoon involves four friends each of whom has specific artistic skills but work together on missions. During the episode, *Flight of the Instrument Fairies*, *Little Einsteins* travel to the arctic to help save the instrument fairies. This episode was shown to children in the fantastical conditions.

Little Bill

This non-fantastical cartoon shows everyday issues in the life of 5-year-old Bill. During the 23-min cartoon, two episodes were shown. *Racing Time* involves Bill getting ready for school on time whilst the second episode, *All Tied Up*, involves Bill learning to tie his shoes. There were five fantastical events across the two episodes such as an animal transforming into a different animal and Bill's shoes talking/running away. This episode was shown to children in the non-fantastical condition.

Executive function tasks

Pre-test battery

The pre-test battery comprised four tasks given in a fixed order to all children: *Day/Night* task, *Backward Digit Span*, *Standard Dimensional Change Card Sort (SDCCS)*, and *Tower of Hanoi*.

Day/Night task

This task-measuring inhibition involves children firstly identifying pictures of the sun/moon and suggesting what time of day they appear (day/night-time). They are then introduced to puppet 'Wally the Whale' who mixes things up. Participants are then told that Wally says 'night-time' when he sees the sun and vice versa and the children are instructed to do the same. The children are then shown shuffled pictures of the sun/moon for 14 trials and are scored 2 for guessing correctly first time and 1 for guessing incorrectly then correcting themselves (Gerstadt, Hong, & Diamond, 1994).

Table 1. Pacing and fantasy characteristics of cartoons

Cartoon	Length (minutes)	Pacing (scenes per minute)	Fantasy rate (events per minute)
Little Einsteins	23:30	6.89	0.89
Little Bill	23:09	11.10	0.21

Backward digit span task

This task measures working memory (WM) by assessing children's ability to count backwards. Wally the whale is brought back and it is re-stated that he is 'silly' and because of this he says everything the experimenter says backwards. The children are then given a number sequence such as '1,2', and participants are instructed to respond with what they think Wally would say, for example, '2,1'. This starts as 2-digit sequences and is increased up to 5 digits, with highest level of success recorded (1 = failed to recall 2 digits backwards, 5 = recalled five digits backwards; Carlson, 2005; Davis & Pratt, 1995).

Standard dimensional change card sort (Carlson, 2005; Frye, Zelazo & Palfai, 1995).

Standard Dimensional Change Card Sort measured cognitive flexibility with red/blue cards featuring boats and rabbits. Two white boxes with slots on the lids were placed in front of participants, one with a picture of a blue boat attached to it and one with a red rabbit. Participants were initially invited to play the 'shape game', asking participants to place all boats in the box with the picture of a boat, and all rabbits in the box with the picture of a rabbit irrespective of the colour of the card. To test this, cards could have a picture of a blue or red rabbit and a blue or red boat. During the demonstration phase (two trials), the experimenter demonstrated the shape game by stating 'Here is a picture of a boat/rabbit, so it goes here' and placing the card in the corresponding box. During the pre-switch phase, the experimenter stated the rule of the sorting game before each trial by saying 'If it is a boat then put it here, but if it is a rabbit, put it here', before then presenting a randomly selected card for each trial. After five consecutively correct trials, participants were invited to play the 'colour game', placing all cards into the red/blue picture box, irrespective of shape (post-switch phase) and this continued for an additional five consecutively correct response trials. Thereafter, a rule was announced before each trial and, in line with the method of Carlson (2005) and Frye *et al.* (1995), an additional five post-switch trials were initiated; two were compatible with the old sorting rule, and three trials were incompatible with the old sorting rule (where the old rule would lead to an incorrect response). Although this task was not timed and there was no response deadline, children were encouraged to provide answers as quickly and accurately as possible. The total number of correct incompatible post-switch trials was recorded. On each incompatible post-switch trial children received either a score of 1 for a correct response, or a score of 0 for an incorrect response. The maximum possible score was 3 (Carlson, 2005).

Tower of Hanoi

A computerised version of this task was used to measure planning, and to make this complex task age appropriate, a story involving a family of monkeys was used to illustrate the rules of the task (Klahr & Robinson, 1981). The children were told three discs (Blue/Yellow/Pink) corresponded respectively to a family of monkeys (Daddy/Mummy/Baby), and they had to move them onto the correct trees and match the family of monkeys that were shown above (goal model at the top of the screen). There were two practice trials followed by seven test trials and these increased with difficulty, therefore increasing the number of moves needed to complete the game. The outcome measures were the number of moves made, time taken to initiate a sequence of moves, and subsequent thinking time (time taken to plan a solution following the first move).

Post-test battery

Children were administered the post-test battery immediately after cartoon presentation. At post-test, assessments of EF constructs followed the same order in terms of the cognitive domains tested (inhibitory control, WM, cognitive flexibility, and, lastly, planning). These tasks were analogous to the pre-test battery but featured different stimuli.

Day/Night task

Day/night stimuli were changed to cards with pictures of winter/summer scenes. Participants were again instructed to say the opposite of what they saw.

Backward digit span task

Children were tested using numbers 6–10 as opposed to numbers 1–5 in the pre-test.

Standard dimensional change card sort

Participants were now tested using cards with pictures of monkeys and cars (yellow/green).

Tower of Hanoi

The colour of discs were now green, red, and black, and this time the story told to participants involved a family of dogs moving around in their kennels.

Parent questionnaires

To provide further context to the study, a media questionnaire was administered to participating parents, to examine any pre-existing condition differences in children's television experiences. This survey asked parents to indicate how many hours children spent each week (weekdays and weekends) engaged watching TV/DVDs and videos on typical weekday and weekend, ranging between zero and six. The differentiation between prompting parents to think about TV exposure during weekends and weekdays was important due to the possibility that daily family schedules fluctuate between the week and weekend, resulting in different media exposure. The total number of hours per week was calculated by adding the total number of hours spent watching TV/DVDs and videos across weekdays and the weekend. Moreover, parents were asked to list three television programmes their child spends watching the most throughout the week, which were later coded for propensity to watch fantasy rare or fantasy abundant TV content. Fantastical TV shows were defined as predominantly comprising content that was unrealistic (e.g., *Sponge Bob*, *Power Rangers*, *Paw Patrol*, *Phineas and Ferb*, *Kim Possible*, and *Ben 10*). Non-fantastical TV shows on the other hand were defined as predominantly containing realistic content, often including educational real-life story-lines (e.g., *Peppa Pig*, *Arthur*, *Horrid Henry*, *Fireman Sam*, and *Postman Pat*). For each newly listed cartoon, the coder watched an accessible episode from the cartoon to decide whether the cartoon could be deemed as predominantly fantastical or non-fantastical. One point was awarded for each fantastical TV show listed by the parent, and 0 points were awarded for each TV show deemed as non-fantastical. Responses were

coded as 0 (non-fantastical; 0 or 1 fantastical TV shows listed by parent) or 1 (fantastical; 2 or 3 fantastical TV shows listed by parent).

Results

Analytical strategy

The parent questionnaires and cognitive measure data were screened for skew and missing data scores. Z-scores for between groups (fantastical vs non-fantastical condition) were calculated and 95% of scores fell within -1.96 and $+1.96$, indicating data met requirements of normal distribution (Field, 2013, pp. 179). There were no missing data on any of the cognitive measures. Missing data were identified on both parent questionnaires which examined the time children spent each day engaged watching TV/DVDs and videos (17.5%, $n = 14$) and also on the questions regarding television content of programmes watched (25%, $n = 20$). Patterns in the missing data were checked. The Little's MCAR test obtained for this study's data resulted in a chi-square = 39.147 (df = 31; $p = .15$), which indicates that the data on these measures were missing completely at random (i.e., no identifiable pattern exists to the missing data). As such, missing data were imputed using Multiple Imputation (MI) in SPSS 24. MI is effective for up to 80% of missing data and provides unbiased estimates when the data are missing completely at random as in the current dataset. Imputed values matched original values and five data sets were imputed. MI allowed for analysis on 100% of the participant data. Pooled estimates were created through SPSS version 24. Estimates were averaged across all five imputed data sets when pooled estimates were not available in SPSS (see Jones, Heim, Hunter, & Ellaway, 2014). There was no significant group difference in hours children spent each day engaged watching TV/DVDs and videos ($p = .54$), and no significant group differences in television content ($p = .65$) between the fantastical and non-fantastical group; therefore, these variables were not further considered in the ANOVA.

A 2×2 mixed analyses of variance (ANOVAs) with a between-subjects factors of condition (fantastical, non-fantastical) and a within-subjects factor of time (pre, post) were applied to the data to examine the effects of fantastical and non-fantastical content on post-test inhibitory control, WM, cognitive flexibility, and planning scores. Multiple regression analysis was applied to the data to examine the relationship between parental report of TV content, hours spent watching TV and their interaction on pre-test inhibitory control, WM, cognitive flexibility, and planning scores. TV content was dummy coded as 0 (propensity to watching non-fantastical content at home) and 1 (propensity to watching fantastical content at home). To control for possible multicollinearity when including interaction terms, hours spent watching TV predictor variable was mean-centred. G*Power 3.1.9.2 analysis suggested that with a sample size of 80, there was a 72% chance of detecting a medium effect size at $\alpha < .05$ (Faul, Erdfelder, Lang, & Buchner, 2007).

Statistical results

All pre- and post-test tasks were correlated; inhibition at pre/post ($r = .52$, $p = <.001$), working memory at pre/post ($r = .76$, $p = <.001$), cognitive flexibility at pre/post ($r = .45$, $p = <.001$), planning at pre/post (initial thinking time: $r = .70$, $p = <.001$, subsequent thinking time, $r = .65$, $p = <.001$, and mean number of moves, $r = .28$,

$p = <.012$). Means and standard deviations for pre- and post-test scores between conditions are reported in Table 2. In addition, in each condition pre-test and post-test measures of EF were correlated, except for planning number of moves (non-fantastical condition, $r = .26$, $p = .11$; fantastical condition $r = .28$, $p = .11$; see Tables 3 and 4). Correlations of pre- and post-test scores for the non-fantastical condition are reported in Table 3, and pre- and post-test scores for the fantastical condition are reported in Table 4. Based on parental reports, the mean number of hours spent watching TV throughout the week was 8.9 hrs ($SD = 5.88$), ranging from 30 min to 30 hrs, and 65% of children had a propensity towards TV programmes with non-fantastical content in comparison with 35% of children who had a propensity towards TV programmes with fantastical content.¹

Inhibition

There was no main effect of time, $F(1,78) = 1.51$, $p = .02$, $\eta_p^2 = .019$, with similar pre-test scores ($M = 26.28$, $SD = 1.68$) and post-test scores ($M = 26.05$, $SD = 2.04$) overall. There was a significant main effect of condition, $F(1,78) = 5.48$, $p = .02$, $\eta_p^2 = .066$, with inhibition scores in the non-fantastical condition higher ($M = 26.57$, $SE = 0.25$) than in the fantastical condition ($M = 25.75$, $SE = 0.24$). There was a significant interaction between time and condition, $F(1,78) = 22.89$, $p < .001$, $\eta_p^2 = .23$, with similar pre-test scores between the fantastical TV ($M = 26.30$, $SD = 1.76$) and non-fantastical ($M = 26.25$, $SD = 1.61$); however, post-test scores were lower in the fantastical TV condition ($M = 25.20$, $SD = 2.22$) in comparison with the non-fantastical TV condition ($M = 26.90$, $SD = 1.41$). This shows that children in the fantastical condition had poorer inhibition performance immediately after exposure to fantastical TV content than children in the non-fantastical condition.

Working memory

There was a main effect of time, $F(1,78) = 4.82$, $p = .03$, $\eta_p^2 = .058$, with overall working memory scores higher at time 1 pre-test ($M = 1.83$, $SD = 0.72$) than at time 2 post-test ($M = 1.71$, $SD = 0.72$). There was a significant main effect of condition $F(1,78) = 4.35$, $p = .04$, $\eta_p^2 = .053$, with overall working memory scores in the non-fantastical condition higher ($M = 1.93$, $SE = 0.11$) than in the fantastical condition ($M = 1.61$, $SE = 0.11$). There was a significant interaction between time and condition $F(1,78) = 17.21$, $p < .001$, $\eta_p^2 = .18$, with similar pre-test scores between the fantastical TV ($M = 1.78$, $SD = 0.73$) and non-fantastical ($M = 1.88$, $SD = 0.76$); however, post-test working memory scores were lower in the fantastical TV condition ($M = 1.45$, $SD = 0.64$) in comparison with the non-fantastical TV condition ($M = 1.97$, $SD = 0.70$). This shows that children in the fantastical condition had poorer working memory performance immediately after exposure to fantastical TV content than children in the non-fantastical condition.

¹ Further analysis was conducted on parental reports of hours spent watching TV and children's propensity towards TV content watched at home (fantastical rare or fantastical abundant) with pre-test inhibition, cognitive flexibility, working memory, and planning scores. TV content was as a significant predictor of pre-test working memory scores ($\beta = -.28$, $p = .013$) and planning initial think time ($\beta = -.31$, $p = .02$). All other variables were non-significant ($p > .05$). These results suggest that, based on parental reports, children who had a propensity towards watching TV programmes with fantastical content at home had lower working memory scores, and longer initial think time scores at pre-test.

Table 2. Mean and SD scores for pre- and post-test EF in each condition

Task outcome measure	Non-Fantastical (pre)		Fantastical (pre)		t	d	Non-Fantastical (post)		Fantastical (post)		t	d
	M	SD	M	SD			M	SD	M	SD		
Inhibition	26.25	1.61	26.30	1.76	-1.33	-.02	26.90	1.41	25.20	2.20	4.086***	.92
WM	1.88	0.76	1.78	0.73	0.600	.13	1.97	0.70	1.45	0.64	3.511***	.77
Cognitive flexibility	2.58	0.68	2.70	0.56	-0.899	-.19	2.88	0.34	2.33	0.86	3.773***	.84
TOH Mean number of moves	3.66	0.33	3.78	0.41	-1.419	-.32	3.90	0.91	4.20	0.60	-1.758	-.39
TOH Initial thinking time (s)	46,455.47	30,018.93	49,741.32	30,607.26	-485	-.11	34,109.19	15,954.03	42,870.63	23,341.35	-0.1960	-.44
TOH Subsequent thinking time (s)	19,986.84	12,242.24	17,890.99	10,193.63	0.832	.19	12,448.09	5,223.23	15,153.89	7,875.60	-1.811	-.40

Note. s = seconds; TOH = Tower of Hanoi.
 ***p < .001

Table 3. Pre- and post-bivariate correlations for the non-fantastical condition

Non-fantastical	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
1. Pre-test inhibition	.01	.01	-.42**	-.46**	-.36*	.73**	-.06	.01	.17	-.32*	-.34*
2. Pre-test working memory	—	.24	.08	.27	.20	-.08	.87***	.04	.05	.29	.21
3. Pre-test cognitive flexibility		—	.22	-.18	-.28	.14	.25	.55***	.04	-.15	-.14
4. Pre-test planning number of moves			—	.41**	.15	-.35*	.09	.17	.26	.15	.02
5. Pre-test planning initial think time (s)				—	.90***	-.62***	.28	-.28	-.01	.85***	.73***
6. Pre-test planning subsequent think time (s)					—	-.63***	.17	-.33*	.02	.81***	.76***
7. Post-test inhibition						—	-.08	.14	.07	-.51**	-.50**
8. Post-test working memory							—	-.01	.03	.29	.22
9. Post-test cognitive flexibility								—	.11	-.25	-.26
10. Post-test planning number of moves									—	.21	-.03
11. Post-test planning initial think time (s)										—	.84***
12. Post-test planning subsequent think time (s)											—

*** $P < .001$; ** $P < .01$; * $P < .05$.

Table 4. Pre- and post-bivariate correlations for the fantastical condition

Fantastical	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
1. Pre-test inhibition	.25	.30	.01	-.24	-.35*	.50**	.11	.32*	.19	-.25	-.32*
2. Pre-test working memory		.21	-.09	.05	-.19	.06	.72***	.28	-.22	.01	-.14
3. Pre-test cognitive flexibility			.05	-.56***	-.41**	.30	.24	.63***	.06	-.64***	-.65***
4. Pre-test planning number of moves			-	.02	.07	-.01	-.12	.10	.28	.15	.10
5. Pre-test planning initial think time (s)				-	.65***	-.43**	.11	-.52***	-.19	.62***	.69***
6. Pre-test planning subsequent think time (s)					-	-.51**	-.06	-.30	-.30	.61***	.68***
7. Post-test inhibition						-	.08	.30	.27	-.36*	-.40*
8. Post-test working memory							-	.15	-.33*	.08	.00
9. Post-test cognitive flexibility								-	-.03	-.54***	-.55***
10. Post-test planning number of moves									-	.00	-.28
11. Post-test planning initial think time (s)										-	.85**
12. Post-test planning subsequent think time (s)											-

*** $p < .001$; ** $p < .01$; * $p < .05$.

Cognitive flexibility

There was no main effect of time, $F(1,78) = 0.23$, $p = .59$, $\eta_p^2 = .004$ on cognitive flexibility scores memory, with similar cognitive flexibility scores at time 1 pre-test ($M = 2.64$, $SD = 0.62$) and at time 2 post-test ($M = 2.60$, $SD = 0.70$). There was no main effect of condition, $F(1,78) = 2.91$, $p = .09$, $\eta_p^2 = .036$ on cognitive flexibility scores, with similar cognitive flexibility scores in the non-fantastical condition ($M = 2.73$, $SE = .09$) and in the fantastical condition ($M = 2.52$, $SE = 0.09$). There was a significant interaction between cognitive flexibility scores and the TV condition $F(1,78) = 23.87$, $p < .001$, $\eta_p^2 = .23$, with similar pre-test scores between the fantastical TV ($M = 2.70$, $SD = 0.56$) and non-fantastical ($M = 2.58$, $SD = 0.68$); however, post-test cognitive flexibility scores were lower in the fantastical condition ($M = 2.33$, $SD = 0.86$) than in the non-fantastical condition ($M = 2.88$, $SD = 0.34$). This shows that children in the fantastical condition had poorer cognitive flexibility performance immediately after exposure to fantastical TV content than children in the non-fantastical condition.

Planning

There was a main effect of time, $F(1,78) = 15.14$, $p < .001$, $\eta_p^2 = .163$, with overall planning (number of moves) scores lower at time 1 pre-test ($M = 3.72$, $SD = 0.38$) than at time 2 post-test ($M = 4.05$, $SD = 0.78$). There was a significant main effect of condition $F(1,78) = 4.04$, $p = .05$, $\eta_p^2 = .049$, with overall planning (number of moves) scores in the non-fantastical condition lower ($M = 3.78$, $SE = 0.07$) than in the fantastical condition ($M = 3.99$, $SE = 0.07$). There was no interaction between time and condition, $F(1,78) = 1.16$, $p = .29$, $\eta_p^2 = .015$, with similar pre-test scores in the fantastical ($M = 3.78$, $SD = 0.41$) and non-fantastical ($M = 3.66$, $SD = 0.33$) conditions, and similar post-test scores in the fantastical condition ($M = 4.20$, $SD = 0.59$) and in the non-fantastical condition ($M = 3.90$, $SD = 0.91$).

There was a main effect of time, $F(1,78) = 15.81$, $p < .001$, $\eta_p^2 = .169$, with overall planning (initial think time in seconds) higher at time 1 pre-test ($M = 48098.38$, $SD = 30167.38$) than at time 2 post-test ($M = 38489.91$, $SD = 20,348.20$). There was no significant main effect of condition $F(1,78) = 1.34$, $p = .25$, $\eta_p^2 = .017$, with overall planning (initial think time in seconds) scores in the non-fantastical condition ($M = 40,282.33$) similar to the fantastical condition ($M = 46,305.97$). There was no interaction between time and condition, $F(1,78) = 1.28$, $p = .26$, $\eta_p^2 = .016$, with similar pre-test scores in the fantastical ($M = 49,741.32$, $SD = 30,607.26$) and non-fantastical ($M = 46,455.47$, $SD = 30,018.93$) conditions and similar post-test scores in the fantastical condition ($M = 42,870.63$, $SD = 23,341.35$) and in the non-fantastical condition ($M = 34,109.19$, $SD = 15,954.03$).

There was a main effect of time, $F(1,78) = 30.04$, $p < .001$, $\eta_p^2 = .284$, with overall planning (subsequent think time in seconds) higher at time 1 pre-test ($M = 18,938.91$, $SD = 11,242.65$) than at time 2 post-test ($M = 13,800.99$, $SD = 6,778.04$). There was no significant main effect of condition $F(1,78) = 0.27$, $p = .87$, $\eta_p^2 = .000$, with overall planning (subsequent think time in seconds) scores in the non-fantastical condition ($M = 16,217.47$, $SE = 1,310.61$) similar to the fantastical condition ($M = 16,522.44$, $SE = 1,310.61$). There was a significant interaction between time and condition, $F(1,78) = 6.756$, $p = .011$, $\eta_p^2 = .080$, with pre-test scores lower in the fantastical subsequent think time scores ($M = 17,890.99$, $SD = 10,193.63$) than the non-fantastical condition ($M = 19,986.84$, $SD = 12,242.24$); however, at post-test, the non-fantastical

scores were lower ($M = 12,448.09$, $SD = 5,223.23$) than the fantastical planning subsequent think time scores ($M = 15,153.89$, $SD = 7,875.60$). The interaction was driven by reduced think time scores from pre- to post-testing in both groups, but with a steeper negative slope in the non-fantastical condition which resulted in a significant interaction between time and condition.

Discussion

Previous research has shown that even brief exposure to watching passive fantastical television programmes can disrupt executive functions. We examined the effect of watching a brief passive fantastical clip on a broad range of aspects of executive function namely inhibition, working memory, cognitive flexibility, and planning. Using a pre- and post-test design with randomization of children into fantastical and non-fantastical conditions, our findings show that watching a relatively brief fantastical clip has a fairly generic effect on EF. The impact was associated with a disruption to several aspects of EF we examined namely inhibition, working memory, and cognitive flexibility. Importantly, there were no differences between the two groups of children on any of these cognitive measures at pre-test. We report these effects in a design that incorporated parallel versions of the same tasks at pre- and post-test enabling careful matching of the EF tasks across sessions in contrast to other research in this area (Lillard *et al.*, 2015). Our findings build on previous research that has suggested immediate effects of watching fantastical programmes on cognitive function, here extending to a broad set of executive functions. The findings are also supported by parental reports of time their children spent watching fantastical content; more time spent watching this content was associated with pre-test poorer working memory and shorter planning times. Our findings suggest that the negative effects of fantastical cartoons on children's EF are not exclusive to the preschool age, and continue to persist during the early primary school years.

The current findings suggest that watching a passive fantastical programme clip is associated with poorer accuracy on tasks of inhibition, working memory and cognitive flexibility at least in the immediate term. No impact of content type was observed on planning accuracy or time spent planning. This finding highlights the importance of examining individual aspects of EF. Previous research examining the effect of fantastical TV content on EF has reported impact on aggregate EF scores (e.g., Lillard *et al.*, 2015) or has examined single components (e.g., Li *et al.*, 2018). The present findings suggest that watching fantastical content disrupts a range of aspects of EF, but some aspects are unaffected. This conclusion should be taken with caution though given a factor that may have impacted planning performance and in the light of our parent questionnaire findings. A potential limitation of this study concerns the impact of fatigue on performance, which may have particular relevance for the planning task. Inspection of the data suggests that initial thinking time and subsequent thinking time on the TOH planning task decreased for all children from pre-test to post-test irrespective of which cartoon they were exposed to. This suggests that children spent less time initiating a sequence of moves and planning a solution following the initial move. The number of moves made increased in both groups from pre-test to post-test. Arguably, this may represent a decline in performance on the post-test planning measure, which was administered last, due to child fatigue. This possibility is strengthened when we look at the parent questionnaire data. A regression analysis revealed that parent ratings of time their children spent watching fantastical content was predictive of shorter planning times at pre-test. Given that planning times

may have been affected by child fatigue, further research is necessary to examine the effects of fantastical content on planning using a counter-balanced approach.

A plausible explanation to account for why fantastical content impairs cognitive functioning could be that watching passive fantastical content encourages the child to devote more cognitive resources to encode the unrealistic events observed. Our findings may reflect that the attentional facilities required for optimal performance in the EF tasks are exhausted by the processing of this content. Theoretically, our findings fit with the Piagetian concepts of assimilation and accommodation (Piaget, 1967). Novel and surprising information present in fantastical cartoons may violate children's existing knowledge, requiring them to change their understanding of the information. Accommodation is more cognitively demanding than the process of assimilation during which familiar, realistic information present in the non-fantastical cartoon may have been processed by existing schemas. Lillard, Li and Boguszewski *et al.* (2015) make a plausible suggestion that perhaps the difficulty of processing fantastical events due to the lack of appropriate schema leads the brain to go on an extended search for an appropriate schema to process the event. By this account, fantastical content has its effect on cognitive task performance potentially by depleting neurotransmitters such as dopamine (Lillard *et al.*, 2015). There is some evidence that depleting related self-regulation in one context reduces its availability in another (Muraven & Baumeister, 2000). Baumeister *et al.* (2007) likened this limited resourcefulness of self-regulation to a muscle that gets tired following multiple exertion. The need to engage self-regulation to complete the tasks used in the present study may explain the negative effects of fantastical cartoon processing on EF performance at post-test.

Alternatively, information processing theory suggests that processing of television content depletes the attention resources required during EF tasks (Lang, 2000, Lee & Lang, 2015). Proactive comprehension of a cartoon requires the child to attend, encode, process, and store the incoming information repeatedly scene after scene (Lillard *et al.*, 2015). The initial stage of attention direction is guided both by (1) top-down processes controlled by the child in guiding his/her sensory perception, and (2) relatively automatic and involuntary bottom-up processes, which are elicited by auditory and visual information. Fantastical events that violate expectations create a discrepancy between existing knowledge and perceptual input, resulting in gaze fixation towards such stimuli (Itti & Baldi, 2009; Müller, Alt, Michelis, & Schmidt, 2010). The combined auditory and visual information with that of the impossible events channels the attentional system in a bottom-up fashion, which may become persistent over prolonged periods of fantastical content exposure (Lillard *et al.*, 2015). The competing top-down attentional control, crucial for optimal EF task performance, could be bound by functionally temporal restrictions posed by the exhaustive nature of the fantastical content (Diamond, 2013; Lang, 2000; Lillard *et al.*, 2015). Although the precise length of such overload effects on subsequent information processing is unknown, immediate short-term impairments have been documented (Lang *et al.*, 2013; Lillard *et al.*, 2015; present findings). It may be that it simply takes time to re-engage top-down processes required to perform EF tasks after watching content that has exhausted attentional resources. The current study design precludes identifying the temporal nature of the short-term effects observed beyond the immediate testing period. The questionnaire data reported in the current study suggest longer term effects may be present. Further research with longer gaps between content exposure and EF performance is needed to examine the temporal features of this effect.

We examined exposure to fantastical content at home using a parent questionnaire. There was no significant difference between the groups in hours children spent each day

engaged watching TV/DVDs, and videos and no significant group differences in television content. This finding allows us to infer that the groups were matched on screen time and type of content watched and that findings are not attributable to any pre-existing differences in this respect between the groups. We were also able to show that parental report of children's propensity towards fantastical content is predictive of cognitive function disruption namely poorer working memory and shorter thinking times. Nathanson *et al.* (2014) found that children who spent more hours watching television exhibited lower EF performance than their counterparts with less hours of exposure. Further research examining habitual and duration of exposure to fantastical content is necessary to determine longitudinal consequences on children's attentional capacity. A longitudinal design study could determine whether negative effects of fantastical content persist beyond immediate to long-term impact. This is of course difficult to study. As Lillard *et al.* (2015) note, parents are unlikely to comply with random assignment into television screen time duration conditions over the longer term. In terms of the interpretation of our immediate findings on long-term function, it is in fact possible that the 'impairing' effect of fantastical content on EF we report in the short-term has in fact a positive impact on cognitive function in the long-term. If such content requires the child to engage in deep processing, it is plausible that there may indeed be positive effects to cognition for longer term cognitive function. It is unclear from the current study design as to why the questionnaire data did not link to cognitive flexibility or inhibitory control given the main experimental findings that showed broader impact across aspects of EF. Further research is warranted to examine broad aspects of EF at short- and long-term temporal points.

There were a number of potential limitations within the study design and methodology that may have influenced findings that require consideration. The researchers who conducted the testing were not blind to the conditions. This may be particularly relevant within the current research because in some developmental research, effects obtained with unmasked experimenters disappear when the same study is administered under blind conditions (Lillard *et al.*, 2013). Another limitation is that the cartoons were not matched on some factors that may have influenced their impact on cognitive function. The conditions were not matched for pacing, but both are considered slow-paced, and are similar in pacing speed to previous studies (e.g., Lillard *et al.*, 2015). The language used in each programme across the cartoons for example was not matched. Language is strongly associated with EF, and processing of unfamiliar words may have increased cognitive taxation in children shown within the fantastical cartoon (Gooch, Thompson, Nash, Snowling & Hulme, 2016). Little Einsteins introduces advanced terminology such as 'periscope' and 'oboe', as well as musical terms such as 'Moderato' and 'Adagio' that is unlikely to be understood by children aged 5–6 years. As such, it may be possible that processing the Little Einstein's depleted more of children's cognitive resources to make sense of these words. Furthermore, the Little Einstein's cartoon, unlike Little Bill, is highly interactive and engages the audience in solving problems in the episode (e.g., finding the character's violin). However, research suggests that passive, rather than active, interaction with a fantastical video clip negatively affected inhibitory control performance in children at post-test (Li *et al.*, 2018), suggesting this may not have impacted performance. Future research would benefit from matching cartoons for language and levels of viewer-content interaction in order to explore these issues in more detail. One study reported positive effects of fantastical material on children's executive functions albeit within a short-term design timeline. Kostyrka-Allchorne, Cooper, and Simpson (2019) examined the impact of pace and fantastical impact on cognition including both

inhibition and attention. Their study, conducted with 3- to 5-year-olds, included a different format to previous research as video clips were of actors reading a story in contrast to a cartoon. Their findings differed from previous studies in suggesting that watching fantastical programmes improved inhibitory control as measured by the Day/Night task. The other research studies that show contrasting findings (Lillard *et al.*, 2015; Lillard & Peterson, 2011; current findings) involved cartoons rather than an actor-led story, suggesting certain types of feature can potentially negate short-term negative effects. Further research is required to determine the effects of fantastical content across different programme type and materials. Finally, it is unclear from the current study design as to why the parent report data did not link to cognitive flexibility or inhibitory control given the main experimental findings that showed broader impact across aspects of EF. Further research is warranted to examine differences in parental reported data and the broad aspects of EF at short- and long-term temporal points.

Our findings suggest that children in the early school years show poorer performance on a range of aspects of executive function, namely inhibition, working memory, cognitive flexibility following exposure to a short fantastical television cartoon. Planning times and accuracy were unaffected. Whilst further research is required to determine whether this negative impact has a long-term effect on children's cognitive development, the findings suggest the possibility that it may be certain features of television programmes rather than watching television per se that is associated with any potential negative effects. Further research with longitudinal designs is warranted to determine the long-term impact of television content on children's developmental outcomes.

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