Heliyon 9 (2023) e16892

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Viewing and playing fantastical events does not affect children's cognitive flexibility and prefrontal activation

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ABSTRACT

Media exposure, such as viewing fantastical content, can have negative, immediate, and long-term effects on children's executive function. A recent study showed that watching fantastical content on a tablet can impair children's inhibitory control and prefrontal activation during the performance of a task. However, the same effect was not observed when children played fantastical games on a tablet. We aimed to replicate and extend this research by examining whether the same effects are observed during a cognitive flexibility task. In this study, preschool children ($N = 32$, 15 girls, Mean age in months (SD) = 60.6 (10)) viewed or played fantastical content on a tablet and performed a Dimensional Change Card Sort (DCCS) task before or after the media exposure. We assessed children's behavioral performance and prefrontal activation, as measured by functional near-infrared spectroscopy (fNIRS), and found no behavioral or neural changes after exposure. Our analyses using the Bayes factor supported the null hypothesis that children's cognitive flexibility is unaffected by watching or playing fantastical content.

1. Introduction

Executive function (EF) lacks a consistent definition but is often described as a high-order cognitive process for planning and executing relevant goal-directed behavior and inhibiting irrelevant behavior and thoughts [1,2]. Although the proposed EF sub-components also vary among researchers, in general EF is characterized by three sub-components: inhibition (the ability to suppress irrelevant and inappropriate thoughts for the context), updating (the ability to monitor information held in working memory), and cognitive flexibility (the ability to switch thoughts from one dimension to another) [3]. EF develops throughout the lifespan; it emerges around 2–3 years of age, develops rapidly during early childhood, undergoes gradual development from childhood to adolescence, and finally declines in old age. Abilities associated with EF are closely related to the frontal lobe and are also known as frontal lobe functions [4].

Research suggests that several factors, including parenting and socio-economic status, influence EF development [5,6]. Another factor that may negatively affect children's EF is media exposure (i.e., TV and digital apps). Studies on media use and children's EF have primarily examined the effects of television (TV) viewing. For example, in a longitudinal study investigating the effects of TV viewing on preschool children, Barr et al. [7] reported that children's exposure to TV from ages 1–4 years predicted lower performance on EF tasks at age 4. Another study found that children who started watching TV or were exposed to background TV at an earlier age (e.g., programs that their parents or siblings were watching or TV that was left on when no one was watching it) tended to perform poorly on EF tasks [8]. Moreover, Linebarger [9] classified proximal factors, such as parenting style and media content and distal factors, such as maternal education and poverty, that can affect children's EF. The researchers showed that parenting style moderated the risks of exposure to background TV on EF for high-risk preschool-age children. However, not all TV viewing has a negative effect. Indeed, viewing educational TV programs aired on public broadcasting stations positively affected EF [8]. Linebarger [9] also showed that

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https://doi.org/10.1016/j.heliyon.2023.e16892
Received 1 December 2022; Received in revised form 22 May 2023; Accepted 31 May 2023

educational TV can work as a buffer for high-risk children. These results suggest that the impact of TV viewing on children's EF is affected not only by viewing time but also by the program content. Nevertheless, a recent meta-analysis reported no statistically significant association between overall screen time and EF [10].

Thus, in addition to these correlational studies, experimental studies have reported that certain TV content can have immediate effects on children's EF. For example, Lillard et al. [11] found that fantasy content and fast-paced TV programs temporarily impaired children's EF. Specifically, Lillard et al. [11] assigned 4-year-olds to watch one of four programs with different tempos and realities. The four shows were two realistic programs, one slow-paced (*Little Bill*) and one fast-paced (*Phineas and Ferb*, with the fantasy parts edited out), as well as two fantasy programs, one slow-paced (*Little Einstein*) and one fast-paced (*Sponge Bob*). The results indicated that EF performance was lower for children exposed to fantasy content.

There are two possible explanations for the negative impact of fantasy content on EF. First, children may require more cognitive processing to comprehend things or events that they do not see in their daily lives and are physically impossible. Carey [12] noted that even young children have strong expectations for how events will happen. Stimuli in fantasy scenes, including sounds that differ from expectations, tend to not only consume more cognitive resources but also overload information processing and require subsequent EF. Second, after viewing fantasy content, children take longer to shift from bottom-up to top-down attention, which prevents them from performing well on EF tasks [11]. Moreover, Lillard et al. claimed that although this shifting effect results in short-term functional impairment, the development of information processing systems will be negatively affected due to the repeated functional impairment caused by viewing fantasy content. Nevertheless, to our knowledge, there are few longitudinal data about the relationship between viewing fantasy contents and EF. Thus, it is unclear whether fantasy contents impair EF or work as a training of EF.

The results of the aforementioned studies may not apply to new electronic media such as smartphones and tablet terminals. Tablets have quickly spread to ordinary households; tapping or swiping the screen with fingertips makes them easy to use, even for young children [13]. A child's experience with a tablet device differs from that of watching TV in several ways. First, unlike most TV programs, tablets can react to children's behavior [14]. Tablets also offer activities beyond watching TV, including educational and non-educational games and creative apps for drawing. Additionally, they allow children to adjust their pace and level of difficulty [15,16].

Recently, Li et al. [17] examined the different effects of watching videos vs. playing games on a tablet. In the study, 4- and 6-year-olds performed an inhibitory control task, a Go-No-Go task (before-test), and then watched a video (video condition) or played a game (game condition) containing fantasy events on a tablet. Subsequently, another Go-No-Go task (after-test) was performed, and changes in the performance of the two groups were analyzed. Li et al. [17] used functional near-infrared spectroscopy (fNIRS) to measure brain activity during the Go-No-Go task before and after tablet manipulation. Previous studies have shown that brain activity in the prefrontal regions is associated with nonverbal working memory, shifting, and inhibitory tasks [18] and responds to increased cognitive load [19,20]. Thus, the brain measures can assess Lillard et al.'s hypothesis that information processing systems are over-demanded. At the behavioral level, children's performance on the after-test was lower than that on the before-test in the video condition, but no such difference was observed in the game condition. Specifically, in the video condition, higher activity was seen in the left dorsolateral prefrontal cortex (DLPFC) region during the after-test. These findings suggest that under the video condition, the presentation of fantasy stimuli consumed children's cognitive resources and increased their cognitive load. On the other hand, the children who participated in the game condition may feel that the fantasy contents were more realistic, which may cause less cognitive resource consumption such that no negative impact on subsequent EF tasks has been seen in the game condition.

However, as noted above, a recent meta-analysis reported no statistically significant association between overall screen time and EF [10]. Although the research analyzed the correlational studies, we may find the effect of fantasy contents on EF in experimental studies. This study aimed to conceptually replicate and extend these findings. Specifically, Li et al. [17] showed that videos, but not games, impaired children's inhibitory control and prefrontal activation. Therefore, we examined whether children's cognitive flexibility, another component of EF, and prefrontal activation were affected by videos and games. Li et al. [17] used a within-subject design for a fNIRS experiment in which children participated in both video and game conditions. The children performed the Go-No-Go task four times, and the results could be affected by learning and practice effects. In this study, preschool children (3–6 years old) were divided into two groups (i.e., video and game conditions) and asked to passively watch a game or actively engage with it for 5 min. Before and after doing so, children were given a classical task to assess cognitive flexibility, the Dimensional Change Card Sort (DCCS), and prefrontal activations during the tasks were assessed using fNIRS. We chose preschool children because we aimed to replicate the replicate the results of Li et al. [17], Moreover, preschool-age is an important period to develop EF [1].

Based on the study by Li et al. [17], it was expected that children would perform worse on the DCCS task in the video condition, although no such effect would be observed in the game condition. Second, higher activity in the prefrontal regions would be observed during the post-test in the video condition.

2. Methods

2.1. Participants

Sample size was based on Experiment 2 in the pervious study [17]. Thirty-two preschool children were recruited from Japanese nursing schools and randomly assigned to the video condition (N = 17, 7 girls, *M* = 62 months, 18 days; range = 36–77 months; *SD* = 10 months, 14 days) or game condition (N = 15, 8 girls, *M* = 59 months, 2 days; range = 45–77 months; *SD* = 11 months, 13 days). Children and the parents were explained the purpose of the study. When they agreed with participation, they were invited to participate in this study. Informed consent was obtained from parents before children's involvement in the study. The study was conducted in accordance with the principles of the Declaration of Helsinki, approved by the Research Ethics Review Board at Kyoto University (29-P-18).

2.2. Materials

2.2.1. Dimensional change card sorting task

The DCCS task has been widely used to assess cognitive flexibility in children [1]. Evidence suggests that preschoolers' performance on the DCCS is correlated with their brain activity in prefrontal regions [20,21].

The DCCS task was performed using cards with the two dimensions of shape and color. The children were presented with two sorting trays comprising the target cards (e.g., a green tree and a red pig) affixed to the front. Children were also presented with test cards, which differed from the target cards in both dimensions (i.e., a red tree and a green pig).

2.2.2. Stimuli: game and video conditions

The tablet used for the game and video conditions was an iPad Air (9.7-inch). In the game condition, the game app *Dr. Panda in Space* was used. The fantastical elements of the video were physically impossible events and objects such as magical things, character transformations, impossible attributes, sudden appearances, and magic [22]. Overall, the app had seven potential fantasy events, which were the same fantasy content as that used in the previous study [17]. For the video condition, we used a video recording of the screen operated by the children participating in the game condition.

2.2.3. fNIRS data acquisition

Functional near-infrared spectroscopy (fNIRS) was used to measure brain activity. This technology measures the degree to which near-infrared light is absorbed by hemoglobin, a blood component, and changes in oxygenated hemoglobin (oxy-Hb) and deoxygenated hemoglobin (de-oxyHb). Near-infrared spectroscopy (NIRS) enables non-invasive visualization of brain activity and is suitable for brain imaging studies in infants and young children because it does not require immobilization of the body or head.

In this study, a 16-channel fNIRS unit (OEG-16; Spectratech Inc., Tokyo, Japan) was used to record temporal changes in the concentrations of oxygenated hemoglobin (oxy-Hb) and deoxygenated hemoglobin (deoxy-Hb) in the frontal regions during the tasks and stimuli presentation. The fNIRS probe included 12 optodes placed in the lateral prefrontal cortex of each hemisphere, and a maximum of 16 channels could be measured by combining illumination and light-receiving probes. The region of interest was located near F3/4 (dorsolateral) and F7/8 (ventrolateral), according to the International 10/20 system. This determination was based on previous studies in which these areas were activated during DCCS tasks [23].

2.3. Procedure

All tasks were videotaped for further analysis, and the experiment lasted 20 min for each participant. The experimenter had conversations with the participants to establish a rapport with them before they entered the experimental room. All participants were seated across a low table with the experimenter, and the experiment began after the participants understood the instructions. Children were first given a DCCS task (before-test) and then presented with the stimuli on a tablet (either watching the video or playing the game). Then, the children were again given the DCCS task (after the test).

The DCCS task consisted of two consecutive test sessions. Each session consisted of a rest phase (10 s), a first phase (20 s), a second rest phase (15 s), a second phase (20 s), a third rest phase (15 s), and a mixed phase (20 s). In the first phase, participants were presented with the first rule and were told, "We are going to start the shape (or color) game now. In the shape (or color) game, all of this shape (or color) goes here (the experimenter pointed to one tray), and all of this shape (or color) go there (pointed to the other)." In the second phase, the children were told, "This time, we will play a different game. If the cards have the same color (or shape) as this one, put them in this tray (the experimenter pointed to one tray), and all of this color (or shape) go there (pointed to the other)." In the mixed phase, the children were asked to sort the cards according to the rules (shape or color) given by the experimenter for each trial. For one participant, the order of the rules (e.g., color first) was kept constant over the pre-test and post-test sessions but was counterbalanced across participants. Furthermore, in the mixed phase, the order of the rules was as follows: second (rules used in the second phase), second, first (rules used in the first phase), second, second, first, second, and second.

Between the before-test and after-test, the participants in the game condition operated the iPad game app, *Dr. Panda in Space,* for 5 min, and the participants in the video condition watched the video recording of the screen operated by the participants in the game condition. In both conditions, the experimenter briefly explained the contents of the game to all the children to motivate them to use the app. Brain activity was recorded before and after the DCCS task while children viewed or played the game.

3. Data analyses

For the behavioral data, the performance of the DCCS task was analyzed based on the switching success rate. The success rate of switching was calculated as follows [24]: First, whether the rule could be switched when moving from the first phase to the second phase was determined based on whether more than 90% of the answers were correct in both phases [25]. One point was given when 90% or more of the answers were correct in both phases. The mixed phase included four rule switches. One point was awarded if the correct answer was given at each switch. The number of points for each participant was scored out of a maximum of five, and the success rate of switching was the ratio of the child's score to the maximum. We conducted a two-way ANOVA:2 (condition: game vs.

video) × 2 (test session: before-test vs. after-test) of the switching success rate.

For the fNIRS data, evidence suggests that NIRS signals are contaminated by physiological activities such as heartbeat, respiration, and body movement [26]. In this study, we separated NIRS signals into functional (brain activation) and systematic (physiological noise) components and analyzed the changes in oxygenated hemoglobin (oxy-Hb) as an index of brain activation. To remove physiological noise and body motion, NIRS data were pre-processed using a hemodynamic response function filter. To increase the signal-to-noise ratio, data were averaged into the right (channels 2, 4, and 5) and left (channels 11, 13, and 14) dorsolateral prefrontal regions (DLPFC) and right (channels 2, 4, and 6), and left (channels 12, 13, and 14) ventrolateral prefrontal regions (VLPFC).

For changes in brain activity during the DCCS task, only data within three standard deviations of the mean were further analyzed. A 3-way ANOVA:2 (condition: game vs. video) × 2 (test session: before-test vs. after-test) × 4 (brain region: left DLPFC vs. right DLPFC vs. left VLPFC vs. right VLPFC) was performed to examine differences between groups in brain activity before and after the tablet operation and during the DCCS task.

If we find no significant differences between conditions, we estimate the Bayes factor for a hypothesized model using a null model (B_{10}). The likelihood of getting the observed data under the null hypothesis and the alternative hypothesis can be directly compared using a Bayes factor. The ratios of the likelihood in favor of the null or alternative hypothesis are known as Bayes factor values. A Bayes factor of 1.0 means that the observed data do not distinguish between the null and alternative hypotheses because they provide equal support for each. We set (3/10) as the cutoff point of the Bayes factor for evidence to moderately support the null hypothesis, according to Lee and Wagenmakers [27].

4. Results

4.1. Behavioral results

A two-way ANOVA:2 (condition: game vs. video) × 2 (test session: before-test vs. after-test) was performed (Fig. 1) of the switching success rate. No significant differences were observed for the main effects of condition ($F\ (1, 30) = 0.24$, $p > .63$, $\eta^2 = 0.008$) or test session ($F\ (1, 30) = 0.07$, $p > .80$, $\eta^2 < 0.001$). There were also no significant interactions between the test session and condition ($F\ (1, 30) = 0.21$, $p > .65$, $\eta^2 = 0.001$). We further analyzed the percent correct of each phase, but the results were the same as the analyses above.

4.2. fNIRS results

Three participants were excluded from the analysis: one due to large body movements and the other two due to the refusal to wear the fNIRS device. The final analysis was performed on the brain activity data for 29 students.

A 3-way ANOVA: 2 (condition: game vs. video) × 2 (test session: before-test vs. after-test) × 4 (brain region: left DLPFC vs. right DLPFC vs. left VLPFC vs. right VLPFC) was performed to examine differences between groups in brain activity before and after the tablet operation and during the DCCS task (Fig. 2). The results showed a significant interaction between the condition and brain region ($F\ (3, 81) = 3.29$, $p = .03$, $\eta^2 = 0.021$), but other significant effects were also observed (both *ps* > .10). Post-hoc comparisons for the interaction between the condition and brain region showed no significant simple main effects of a condition or brain region (ps > .05).

We did not find any differences between the video and game conditions at the behavioral and neural levels. For the behavioral results, we compared the null model with the model containing the interaction between the condition and test session. The Bayes factor, B_{10}, was 0.053, lower than the predetermined threshold level (3/10). We conducted the same analyses for the fNIRS results and found that the Bayes factor B_{10} was 0.055. The results supported the null model and suggested no interaction effects in this study.

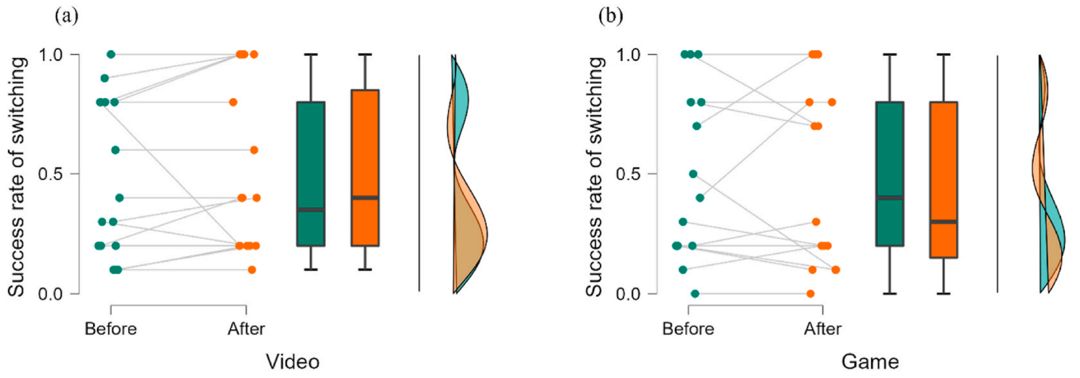

Fig. 1. Behavioral results in video (a) and game (b) conditions.

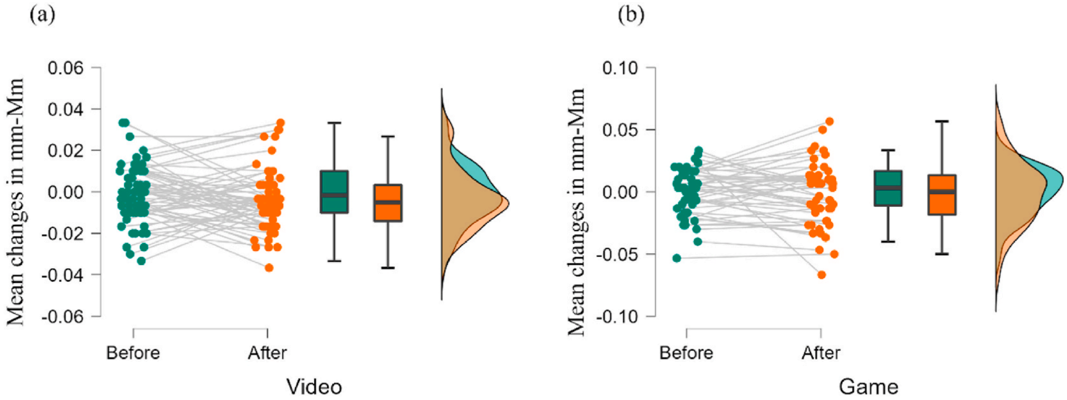

Fig. 2. FNIRS Results in Video (a) and Game (b) Conditions. The mean changes in oxy-Hb during the rest phases were subtracted from those during the task phases.

5. Discussion

In this study, we investigated whether fantasy video viewing and gaming negatively affect children's cognitive flexibility. Based on the results and assertions of a previous study [17], we hypothesized that viewing fantasy content, but not gaming, would impair children's cognitive flexibility. Our results showed no significant difference in behavioral performance and brain activity under either condition in both the before- and after-test. Our analyses of Bayes factors support the null model, in which children's behavioral performances and brain activities did not change before and after fantasy content viewing and gaming.

Previous studies suggest that media exposure can negatively affect EF in children. Longitudinal studies have reported that children's exposure to TV predicts a lowered performance on EF tasks [9,10]. Experimental studies have also reported that fantasy content and fast-paced TV programs temporarily impair EF in children [22]. However, a recent study reported that watching video on a tablet but not playing interactive games negatively affects children's EF performance and prefrontal activations [17]. To the best of our knowledge, this is the only study to show that videos and games affect children's EF performance differently. Given that this study assessed the effect of media exposure on children's inhibitory control, we aimed to replicate the results and extend them to children's cognitive flexibility.

Results showed that playing fantastical games didn't affect children's cognitive flexibility and prefrontal activation, consistent with the previous finding by Li et al. [17], who showed that playing fantastical games did not affect children's inhibitory control and prefrontal activations. Children who participated in the game condition may feel like they were in the game scene by touching the screen of the tablet with their fingertips and feel that the fantasy contents were more realistic. This feeling may cause less cognitive resource consumption such that no negative impact on subsequent EF tasks has been seen in the game condition.

We did not replicate the findings of Li et al. [17] under the video condition; children's performance and prefrontal activations were not affected by merely watching fantastical content, which is consistent with a recent meta-analysis [10]. There are some possible interpretations of the null results for the video condition. One possibility is the difference in the EF tasks. The previous study used the Go/No-Go task [17], often used to measure inhibitory control. In this task, two stimuli (pictures or letters) are provided to participants who are asked to press a key as quickly as possible during one stimulus (Go trial) and not press it for another stimulus (No-Go trial). In contrast, the present study used the DCCS task to measure cognitive flexibility, which requires switching thinking from one dimension to another. However, in an earlier study, Lillard et al. [11] found that children's performance on the DCCS was impaired when viewing fantasy videos. Thus, differences in the EF tasks cannot fully explain why children in this study did not show lower performance after viewing fantasy content.

The second possible interpretation of the null results in the video condition is that the stimulus intensity was relatively weak. We used the same fantastical content with the same stimulus duration as that in a previous study [17]. However, the number of fantasy events children were exposed to during a 5-min operation (game condition) may differ from that in the previous study. Li et al. [17] used videos with seven fantasy events in the video condition. In this study, video recordings of screens operated by participants in the game condition were used as a stimulus in the video condition to control for differences in stimulus intensity. Importantly, the number of fantasy events children were exposed to differed. Therefore, the videos may have included fewer than seven fantastical contents, which may explain the different results between this study and the previous one [17].

Other possible interpretations for the null results are differences in the experimental design. A previous study used a within-subject design (Li et al. [17]. Experiment 2), in which all children participated in both video and game conditions. This design can be useful for detecting the effects of interest, and we considered having the children perform EF tasks four times (before the test in the video condition, after the test in the video condition, before the test in the game condition, and after the test in the game condition). However, we believe there should be repetitive effects on behavioral performance and neural activity. Thus, we adopted a between-subject design, which may be responsible for the null results. In other words, the effects of the game/video may be too small to be detected using the between-subject design. One may argue that our sample size was too small to detect the effect, but our analyses using the Bayes factor moderately and strongly supported the null hypothesis. Thus, it seems unlikely that the sample size explains the null results.

Based on this discussion, future research should discuss and focus on the following points. First, it is necessary to clarify how stimulus intensity affects EF performance in children. Thus, we need to control the number and intensity of fantasy events and examine how different stimulus intensities can affect EF performance. Second, it is unclear whether fantastical components have differential effects on EF components. Most previous studies examined the EF components of inhibitory control and cognitive flexibility; therefore, we should examine the effects on other components, such as working memory. Relatedly, this study used only one measure of cognitive flexibility. There are mainly two reasons for this. One is that compared to inhibitory control and working memory, there are few good cognitive flexibility tasks widely used to test young children. The other is that neuroimaging studies often use a single task to measure brain activations. However, we should use other measures of cognitive flexibility. Third, we need to examine how long fantasy components affect children's EF performance. Most previous studies have demonstrated the immediate effects of fantasy content, although they may have a more prolonged impact. Forth, this study focused on the prefrontal regions because we aimed to conceptually replicate the results of Li et al. [17]. However, a previous study reported that other brain regions as well as functional connectivity between the visual word form area and language, visual and cognitive control regions are also important [28]. Finally, our sample size was based on the previous study, but we need to conduct power analyses before collecting data [29]. In focusing on these points, future research can systematically examine the effects of fantasy content on EF.

Ethics statement

The study was conducted in accordance with the principles of the Declaration of Helsinki, approved by the Research Ethics Review Board at Kyoto University (29-P-18).

Author contribution statement

Jue Wang: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Yusuke Moriguchi: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Data availability statement

Data will be made available on request.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

We thank the parents and children who participated in this study.

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