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The effect of video games, exergames and board games on executive functions in kindergarten and 2nd grade: An explorative longitudinal study

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A R T I C L E I N F O

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A B S T R A C T

We examined the relation between different kinds of play behavior (video games, exergames, board games) in kindergarten (T1) and components of executive function (EF; inhibition, switching, verbal and visuospatial updating) in kindergarten and second grade (T1 and T2). Ninety-seven children participated in this longitudinal study. Parents were asked to complete a questionnaire regarding children's play behavior, reporting frequency, duration, and game type. The results indicate that play behavior is associated with EF development in children; however, only exergames, electronic puzzle games, and board games predicted EF at T2. Additionally, the time spent on electronic games was negatively related to visuospatial updating at T1 but did not predict EF at T2. The results support further investigation of a potential link between board game and exergame play behavior and EF development.

Executive functions (EF) are an umbrella term for various cognitive processes which involve planning, monitoring, and selecting one's behavior. EF are higher-order cognitive processes operating in a top-down way. They enable the regulation, monitoring, and control of cognitive processes, for example, restraining dominant but inappropriate responses. Furthermore, they enable us to flexibly switch the focus of attention from one task to another, to focus on a specific task, and to adapt to change [49, 21]. Being a heterogeneous set of higher-order cognitive information processes, EF remain subject to ongoing research and have yet to be mapped out fully. Nonetheless, there exists consensus for an influential model that describes three related but distinct constructs: inhibition, switching, and updating [49, 21]. The different factors are argued to undergo a process of differentiation during childhood, to increasingly develop between preschool and primary school, and to support an easier transition to school. Specifically, EF is argued to ultimately contribute to higher school success for children with better EF [9, 22]. Thus, when investigating EF, each of the three factors—inhibition, switching, and updating—ought to be taken into account [29, 21].

There is a well-established body of research indicating the relevance and contribution of play behavior to child development (e.g., [65, 53, 14, 32]); there also exist emerging hypotheses concerning the role of play in supporting EF development [8]. For example, children develop self-control skills by taking turns and thinking before acting in games. By memorizing the rules of a specific game, children can improve their working memory. Finally, by role-playing and taking the perspective of other players, children are given the opportunity to refine switching skills.

Perspectives on play behavior, such as those of Piaget [54], Vygotsky [65], and Bruner [13], have significantly influenced how play is conceptualized within education. This is due, in part, to the importance they assign to the relationship of play with social and cognitive development. Research has shown that play promotes development in multiple domains, such as creativity, cognition, language, and emotion [38]. This makes play "the most natural way children learn all over the world" ([50], p. 1), providing children with opportunities for hands-on experiences, sensory learning, and engagement in a variety of environments [23]. Although play behavior can serve the purpose of education, children play for fun, with learning being a by-product [34].

There exists support for pretend play being positively associated with EF (e.g., [6, 64]). However, modern play behaviors associated with new media—such as exergames or touchscreen games—have received comparatively little attention, especially concerning the development of EF in early childhood. Relatively little is known about the efficacy of

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naturalistic play behavior involving new media in kindergarteners and its effect on EF, that is, regarding playful activities that children spontaneously engage in during their free time after kindergarten or school. As play constitutes a fundamental part of children's everyday lives, research in this area is essential. With this in mind, the aim of the present study was to investigate the effect of play behavior on the development of EF by focusing on the effectiveness of different game types, including exergames, three-dimensional video games, balancing video games, touchscreen games, and board games.

Video games can have a positive impact on aspects of cognition, including EF [51, 56]. Specifically, switching and working memory abilities are superior in habitual gamers [19, 18]. Effects of this kind have been primarily shown in first-person action video games. To compare action and non-action video games, Oei and Patterson [52] investigated the effect of touchscreen games on EF in college students inexperienced in video gaming. The games used in the experiment were: an action video game (Modern Combat), a physics-based puzzle game (Cut the Rope), a real-time strategy game (Starfront Collision), and a fast-paced arcade game (Fruit Ninja). The physics-based puzzle game significantly improved EF, compared to all other game types. However, a recent review was unable to find evidence that off-the-shelf commercial games promote EF skills, or improve performance on non-game EF measures [47]. Moreover, a meta-analysis found a medium effect size of habitual action video gameplay on cognition, and only a small-to-medium effect size of video game intervention studies [2]. Thus, a strong consensus has yet to be established concerning these modern play behaviors and EF.

A newer generation of video games that simulate a more active, whole-body gaming experience are exergames [7]. As the name implies, exergames are a blend of exercise and games. They became popular because game designers can increase the complexity of game rules, speed, or response coordination to engage the player not only physically, but also cognitively [61]. While a few studies report the potential of exergames to promote physical activity (e.g., [33]), empirical research on exergames is limited and generally restricted to intervention studies for children with developmental disorders, such as Attention-Deficit/Hyperactivity Disorder or Autism Spectrum Disorder (e.g., [37, 3]). Despite the growing market of developmentally-appropriate exergames for preschoolers, only a few studies examined the effects of exergaming on preschoolers' health and cognitive functions [7, 67, 30]. Nevertheless, the combination of physical activity and cognitive engagement is a promising type of intervention to enhance EF [28, 57, 4].

Another recently emerged play behavior encompasses games played on touchscreens. Since touchscreens enable interaction by manipulation, but also scaffolding and control, touchscreen-based play behavior has been seen as a more developmentally appropriate media platform [16, 31, 68]. Some studies have shown that the interactivity of a touchscreen is superior to learning from non-interactive screens [40, 42, 43]. Yet other studies suggest a need for caution. For instance, children using touchscreen media actively for more than 30 min a day showed poorer inhibition skills one year later as compared to passive usage (i.e., watching content only; [48]). Altogether, research on modern forms of play provides mixed findings when it comes to the impact of touchscreen use on EF.

In contrast to newer media, board games are an older type of game. Previous research has shown that a home environment with access to board games positively influences the development of school-related skills [46][60, 58]. Intervention studies have shown promising training effects in children with attention-deficit/hyperactivity disorder (ADHD, Estrada-Plana, [25]). As more general school interventions, board games have shown positive effects on children's EF [5]. Finally, specific board games have been developed to enhance EF with promising results [55]. Taken together, these findings indicate that playing card and board games can improve EF.

Given the aforementioned findings, we perceive a need to examine the relationship between play behavior and important aspects of child development—such as EF—by considering the differential impact of different types of games. The present study's purpose was to explore the naturalistic relationship between play behavior of different types of games (i.e., exergames, three-dimensional video games, balancing video games, touchscreen games, board games) in kindergarten (T1) and components of EF (i.e., inhibition, switching, visuospatial and verbal updating) in kindergarten and second grade (T1 and T2). Since kindergarten years constitute a critical period in terms of play behavior and school readiness, this longitudinal study focused on kindergarten children's play behavior and its subsequent effect on EF 18 months later.

The following research questions were formulated:

(1 a) Is the frequency and duration with which kindergarten children engage in play behavior associated with their EF skills?

(1 b) Is the game type with which kindergarten children engage in play behavior associated with their EF skills?

(2 a) Are EF skills at T2 predicted by duration and frequency of play behavior at T1?

(2 b) Are EF skills at T2 predicted by the type of game that kindergarten children played at T1?

These observations can help understand how play behavior and innovative game technologies are currently used and could be optimally used to promote the development of EF in children.

The present study aimed to address the potential influences of specific play behavior (video games, exergames, board games) on children's EF development. While game interventions have recently drawn the attention of researchers, studies have yet to examine their influence while accounting for the natural, habitual manner in which play activities occur in children's everyday life. Moreover, despite the relevance of this topic, most studies are cross-sectional, lacking insight into the long-term consequences of playing games. An observational longitudinal design was employed to address this gap in research.

1. Method

1.1. Procedure

Data came from a longitudinal study investigating children's play behavior and EF in kindergarten and primary school. The dataset comprised measures of play behavior assessed at T1, as well as EF measured at T1 and T2. Data were collected in children's schools by trained experimenters. While EF were assessed during a lesson at children's kindergartens and schools, play behavior was measured by a questionnaire completed by parents (together with the child). On average, testing one child took 50 min.

The study had been approved by the Ethics Committee at the University of authors' affiliation and country, following the Declaration of Helsinki. Written informed consent was obtained from the parents, and children orally agreed to participate.

1.2. Participants

One hundred and sixty-four children participated in the original study. The return rate of the questionnaire at T1 was $N = 120$. Due to dropouts caused by longitudinal design, the final sample consisted of $N = 97$ (46 girls). At T1, all children attended kindergarten and had a mean age of 6.47 years ($SD = 0.39$). At T2 all children were in second grade with a mean age of 8.02 years ($SD = 0.39$). The majority of the children were native speakers at 82.5%, a smaller part was raised bilingually at 12.4%, while 5.2% had another native language. All children were sufficiently fluent in the local language to understand instructions.

1.3. Measures

1.3.1. Inhibition

An adapted version of the flanker task by Eriksen and Eriksen [24] was used to assess inhibition (Röthlisberger, Neuenschwander, Cimeli, Michel, & Roebers, 2012). Children first learned the task during six practice trials. After the practice, two experimental blocks of 24 trials followed. In each trial, five red fish were presented, whereby children had to concentrate on the fish in the middle and feed it by pressing the button on the side to which the fish was looking (left or right). The middle fish was looking either in the same direction as the flanking fish (congruent condition) or in the opposite direction (incongruent condition). The dependent measure was the reaction time for inhibition, computed as the reaction time of incongruent trials controlled for congruent trial reaction time (sensu Lee et al., 2013; on reaction times, see Roebers & Kauer, 2009). The split-half reliability for this experimental task was 0.89.

1.3.2. Switching

Switching was assessed following the inhibition task with a modified version of the flanker task (Diamond, Barnett, Thomas, & Munro, 2007; Röthlisberger, Neuenschwander, Cimeli, Michel, & Roebers, 2012). The task comprised two blocks with a practice session of six (in the first block) and eight (in the second block) trials in the beginning, with 24 and 40 experimental trials, respectively. In the first block, five yellow fish were presented. Children were asked to focus on the flanking fish and feed them by pressing the button on the side to which the fish were looking (right or left). In the second block, the fish were either all red (with the rule to feed the central fish) or all yellow (with the rule to feed the flanking fish). Hence, the children had to be flexible and switch between the two rules. Similar to the inhibition task, we computed the reaction time for switching as the reaction time of switching trials controlled for the reaction time of non-switching trials (Lee et al., 2013). The split-half reliability for this task was 0.75.

1.3.3. Visuospatial updating

A visuospatial form of updating, which is broadly defined as simultaneous recall and processing of visuospatial information, was assessed employing the Matrix task which is part of the subtest Matrix of the test battery AGTB 5–12 [35]. On a laptop screen, a 4 × 4 matrix of squares was given. The squares consecutively were colored in black. Children had to point to the squares which became black on a sheet showing the same matrix as on the screen. As children remembered the consecutive locations of these squares, they had to point with a finger on the sheet by producing the string of locations of black squares backward. After four correctly recalled items, the string of items was lengthened by one location; after three mistakes within one level of difficulty, the task was discontinued. The score on this task was the number of correctly recalled trials.

1.3.4. Verbal updating

A computerized backward color span task [69] was used. A sequence of colored disks appeared on a screen in each trial. The children were asked to recall the presented colors in reverse order. Colors with monosyllabic names were used to keep the task simple and comparable across colors. Three practice trials were displayed and were followed by six experimental trials per sequence length starting with 2 colors (maximum sequence = 7, maximum number of trials = 36). Whenever at least three trials were solved correctly, the sequence length increased by one. However, the task was stopped when children solved fewer than three trials in sequence correctly. The number of correctly solved trials was used for the analysis.

1.3.5. Play behavior

Two questionnaires were used and combined to obtain information about the home environment (Skwarchunk & LeFevre, 2009; [10]) and specifically about the type, frequency, and duration of play behavior. Questions comprised the type of game (board games and video games with the subtypes exergame, touchscreen, three-dimensional, balancing objects, puzzle), the frequency measured on a scale from 1 to 7 times a week (Cronbach's $\alpha = 0.36$), and the duration of a session in minutes. The questionnaires were filled out by the parents with their child at T1 when the children were in kindergarten.

1.4. Data analysis

To explore the relationship between kindergarten children's type and frequency of play behavior and their performance in EF tasks at T1 and T2, bivariate correlations were computed. Prediction of EF at T2 was done by conducting hierarchical regression analyses with significant correlates from play behavior controlling for children's EF skills at T1. First, control variables were entered in the regression models, followed by entering predictors that showed significant associations with the dependent variable based on the results of correlation analyses.

2. Results

2.1. Descriptive statistics

Descriptive statistics such as means, standard deviations, the range of EF, and frequencies as well as the duration of play behavior are reported in Table 1. For the types of games, the number of children who answered yes or no is shown. As can be seen, the majority of children played board games, with the mode of frequency being once a week. Contrary to our expectations due to their perceived popularity and the literature review, exergames were only played by 18 children. In contrast, touchscreen games were the most popular games, played by two-thirds of the complete sample.

2.2. Correlational and hierarchical regression analysis

The correlations between the included variables are shown in Table 2. Correlations between types of games and EF measured at T1 are displayed below the diagonal. Correlations between the types of games at T1 and EF at T2 are shown above the diagonal. The latter correlations are reported due to statistical reasons, such as the requirement of a relationship between predictor and outcome variables. In our analysis and report, we did not inverse inhibition and switching, which correlated negatively with other variables. This negative correlation emerged because we measured reaction times—that is, negative correlations in this instance imply a positive relation, since playing a certain type of game correlates to faster (i.e., lower) reaction times. Specifically, faster reaction times in the inhibition task mean a lower incongruency effect and better inhibition performance. Similarly, faster reaction times mean lower switch costs and better switching skills.

Overall, the correlations were small. Only board games, exergames, and puzzle games correlated with inhibition, switching, and visuospatial updating at T2, and only three-dimensional games and exergames correlated with verbal updating and switching at T1. The duration of play was found to be moderately correlated to visuospatial updating at T2, $r(94) = -0.25$, $p = .014$. The frequency of video games or board games did not show significant correlations with any EF component and is not reported in the tables.

Exploratory hierarchical multiple regression analyses were performed to uncover the predictive values of play behavior on inhibition, switching, and visuospatial updating, after checking for collinearity statistics (tolerance and variance inflation factor were within acceptable limits). Only variables showing a significant correlation with the outcome variables were considered in the regression analysis. Resulting in 3 regression analyses where the predictor variables for inhibition was board games, the predictor variables for updating were board games and the duration of video games, and the predictor variables for switching

Table 1
Descriptive Statistics for EF and Play Behavior.

	Measurement Wave					
	T1 (Kindergarten)			T2 (2nd Grade)		
	M	*SD*	*Range*	*M*	*SD*	*Range*
Executive Functions						
Inhibition [a]	1015.37	363.9	473.88–2180.50	134.76	143.12	87.91–840.35
Switching [a]	1884.33	557.71	652.18–3427.27	692.79	258.3	212.19–1463.63
Visuospatial Updating [b]	3.54	3.4	0–13	9.05	4.41	0–19
Verbal Updating [b]	9.7	3.93	0–18	12.43	3.91	2–21
Games	*M*	*SD*	*Range*			
Video Games Frequency [c]	2.62	2.24	0–7			
Video Games Duration [d]	23.13	22.55	0–120			
Board Games Frequency [c]	1.94	1.34	0–6			
Type of Game	**Yes**		**No**	**Examples**		
Video Games [e]	78		19			
Puzzle [e]	33		62	Memory, Tetris		
3 Dimensional [e]	41		55	Super Mario, Mario Cart, Hay Day		
Balance Objects [e]	23		72	Doodle Jump, Joshi		
Exergames	18		77	Wii Sports, Wii Dance, Xbox Kinect		
Touchscreen	63		32	Cut the Rope, Angry Birds, Candy Crush, Fruit Ninja		
Board Games	93		4	UNO, Ligretto, Ludo, Game of Goose		

Note: Means (M) and standard deviations (SD) and minima as well as maxima (Range) shown for EF at T1 and T2, and play frequency and duration at T1.
[a] milliseconds,
[b] number of correct trials,.
[c] days/sessions per week ("How many days/sessions a week does your child play video games?"),.
[d] minutes per session/day,.
[e] electronic games.

Table 2
Bivariate Correlations between Game Types and EF from T1 and T2.

	1	2	3	4	5	6	7	8	9	10	11
1. Video Games [a]	_	.37**	.43**	.22*	.24*	.65**	−0.1	−0.15	−0.07	.13	0.12
N		95	96	95	95	95	97	97	97	97	91
2. Puzzle Games [a]		_	.08	.01	.11	.27**	−0.29**	−0.1	−0.15	.11	**.29****
N			95	95	94	94	94	95	95	95	89
3. 3-Dimensional Games [a]			_	.17	.40**	.47**	−0.03	.44	.96	.51	.46
N				95	95	95	96	96	96	96	90
4. Balancing Objects [a]				_	.04	.3**	−0.04	.1	.05	.16	.15
N					95	95	95	95	95	95	89
5. Exergames [a]					_	.29**	−0.07	−0.15	.01	.12	**−0.23***
N						95	95	95	95	95	89
6. Touchscreen [a]						_	.00	−0.16	.09	.09	.14
N							89	95	95	95	89
7. Board Games							_	**.23***	.00	**−0.36****	−0.14
N								97	97	97	91
8. Visuospatial Updating	.07	−0.12	.14	.06	−0.08	.00	−0.01	_	.32**	−0.15	−0.15
N	97	95	96	95	95	95	97		97	97	91
9. Verbal Updating	−0.09	−0.03	.04	−0.08	**−0.20***	−0.07	.04	.3**	_	.00	−0.14
N	97	95	96	95	95	95	97	97		97	91
10. Inhibition [b]	.16	.19	.1	.1	.14	.03	−0.2	−0.01	−0.21*	_	.37**
N	97	95	96	95	95	95	97	97	97		91
11. Switching [b]	.00	.10	−0.29**	−0.04	−0.13	−0.14	0.06	0	.01	.45**	_
N	97	95	96	95	95	95	97	97	97	97	

Note.* $p < .05$.
** $p < .01$, Types of games - data from T1; below the diagonal EF from T1; above the diagonal EF from T2; aelectronic games; b not inverted reaction times; Duration and Frequency are not shown in this table but mentioned in the text.

were exergames and puzzle games. In all models, we controlled for autoregression, by introducing as a first step the respective EF component at T1.

Table 3 shows the models for inhibition and visuospatial updating. For inhibition, the play-related board games predictor was significant even after controlling for inhibition skills at T1. Thus, a higher engagement in board games was related to better inhibition skills (lower RT). This pattern was not shown for visuospatial updating. Updating at T2 was only predicted by visuospatial updating at T1, but not by board games and the duration of gameplay.

Table 4 shows the model for switching. After controlling for T1 switching skills, both exergames and puzzle games were significant predictors for switching at T2. The standardized β coefficient is negative because reaction times were chosen as the measure for switching. Thus, higher participation in exergames was related to lower switch costs (lower RT) and therefore better switching performance at T2. While higher participation in puzzle games was linked with larger switch costs (higher RT) and therefore poorer switching performance at T2.

3. Discussion

This study aimed to explore the longitudinal relationship between

Table 3
Hierarchical Regression Models for the prediction of Inhibition and Visuospatial Updating at T2.

		Inhibition T2				Visuospatial Updating T2					
	Step 1 Inhibition T1	*Step 2*	Inhibition T1	Board Games	*Step 1*		Visuospatial Updating T1	*Step 2*	Visuospatial Updating T1	Board Games	Duration Video Games
β	.26**		.201*	−0.316**		*β*	.327**		.326**	.171	−0.191
SD	.098		.099	.481		SD	.098		.094	.494	.004
F	7.07		9.32		F	11.29		7.368			
df	1, 95		2, 96		df	1, 94		3, 95			
p	.001		.00		p	0.001		0			
Total R^2	.069		.165		Total R^2	.107			.194		

Note.* $p < .05$.
** $p < .01$; Inhibition was measured as reaction times - thus negative standardized β coefficient. Outcome variables are displayed in the first row of the table, whereas predictor variables are shown in the third row.

Table 4
Hierarchical Regression Model for the prediction Switching at T2.

	Switching T2			
	Step 1 Switching T1	*Step 2* Switching T1	Exergames	Puzzle Games
β	.302**	.251*	−0.242*	.261**
SD	.103	.099	.253	.2
F	8.65	6.87		
df	1, 86	3, 84		
p	.004	.00		
Total R^2	.091	.199		

Note.* $p < .05$.
** $p < .01$; The outcome variable is displayed in the first row of the table, whereas predictor variables are shown in the third row.

kindergarten children's play behavior and their EF skills, including inhibition, switching, and visuospatial and verbal updating. We examined different types of games, including electronic puzzle games, three-dimensional video games, video games in which one has to balance objects, exergames, and board games. The findings show children's switching ability in second grade to be positively predicted by previous engagement in exergames and negatively predicted by previous engagement in puzzle games. Inhibition at T2 was positively predicted by previous engagement in board games. However, updating was not predicted by the play behavior and neither did duration norfrequency of the play behavior affect EF.

Addressing the first research question (whether the duration and frequency with which kindergarten children engage in play behavior is associated with their EF skills), our results suggest that frequency is not related to EF, but that duration of video game play had a slight negative correlation to visuospatial updating. The time spent on this type of play behavior might prevent children from engaging in other, more socially interactive activities (e.g. play and socialization with adults, siblings, or peers or real-world experiences) that support social and cognitive development. However, there was no detrimental effect of play duration on EF 18 months later. This suggests that the slight negative relation was temporary and may have been compensated by other factors over time.

Addressing the second part of the first research question, concerning game type and EF, we found a negative relation between updating and use of exergames and a positive one between switching and use of three-dimensional games. A possible interpretation for the negative relation is that, because verbal updating skills are used less in exergames, children with weaker verbal updating skills found exergames comparatively more approachable and more convenient to play. However, since a correlation cannot be taken for causality, it could also be the reverse—that is, by choosing exergames, children's verbal updating skills were not as enhanced as by choosing other games. At the same measurement point, we observed that switching skills were positively related to three-dimensional games. Again, since causality cannot be inferred, either children were better trained in switching due to their engagement with three-dimensional games, or they choose to play three-dimensional games because they were already more capable at switching. A striking observation about these correlations is that the selection of games appears not to impact these EF skills 18 months later. This suggests that these effects were only temporary. However, since we did not assess play behavior at T2, further research is necessary to determine whether play behavior remains stable over time.

The answer to the second research question (whether EF are predicted by duration, frequency or game type), will be discussed in the following paragraphs, specifically focusing on the different EF components. To be said in advance is that the duration and frequency of play behavior did not predict EF 18 months later. Looking at the frequencies and duration of our sample, it is noteworthy to say that parents were already managing children's playtime quite strictly. The majority of the children in the sample played around 30 min per session, and between 2 and 3 times a week. Thus, our results are in line with previous studies suggesting that a duration of 30 min per day has no detrimental effects on EF [48].

Inhibition skills were positively predicted by board games. This might be because these games are usually played in groups of 2–4 people. Therefore, children have to adapt and behave in a socially accepted way, wait for their turn, inhibit their reactions to not give away their cards, and so on. It is valuable for children to play with their parents, peers, or siblings, especially during a time of transition and adaptation to more formal schooling. Some researchers have found that there are factors driving children to play alone, and thus, that prevent them from group games until primary school [41]. For example, Kim (2002) found that children preferred to play with their toys alone. Therefore, it may be reasonable to assume that video games and touchscreen games lacking a social component are generally played alone, offering fewer opportunities to practice inhibition skills. This might explain why such games did not predict inhibition skills in the present study.

Taken together, playing board games in a group setting with mixed ages might give the best opportunities for children to develop inhibition skills. Our findings are in line with previous intervention and observational studies (e.g. [5]; Estrada-Plana, [25, 55, 58]), indicating that these playful activities have an enhancing effect on the development of EF.

Switching skills were positively predicted by exergames (negative beta weights in the table due to non-inverted reaction times). In line with previous research, our findings support the assumption that exergaming improves EF in children [30, 62], more specifically with a meta-analysis finding large positive effects of exergames on switching abilities [2]. Exergames combine physical and cognitive challenges through their key game features, which creates a constant need to dynamically alternate between focused and divided attention [39, 45]. Moreover, the context of exergames provides a great variety such that automatization is avoided. It seems plausible that a combination of physically and cognitively engaging activities, where a coordination of various skills is needed, provides opportunities for children to develop more effective switching skills. Since kindergarten children are in the sensorimotor and preoperational period and express themselves more easily through movements and symbolic games [11], this type of game may be an optimal combination of the natural ways in which children engage in while exploring the world.

To our surprise, switching was negatively predicted by puzzle games. One potential reason is that, contrary to what one may expect from their name, puzzle games tend to employ rather simple mechanics and lack more complex goals [59]. According to Rollings and Adams [1], simple puzzle games focus on puzzle solving as the primary game activity and add time pressure to increase difficulty. Typical challenges in puzzle games are spatial and logical reasoning, decision-making, planning, pattern recognition, and visual search [15, 20]. Thus, puzzle games are typically focused on a single, simple rule, and players might not have to switch between different rules; as a consequence, puzzle games may not offer opportunities to train switching abilities. This is in line with previous studies that have shown that EF is only enhanced by puzzle games that employ changing requirements [52] and that 15 h of playing a simple puzzle game did not enhance EF (vs playing an action video game; [63]).

While EF components start developing early in children's lives, it has been suggested that each EF component follows its trajectory [21]. These trajectories seem to operate concurrently, with certain components (inhibition) laying the groundwork for the other components to develop [49]. The development of inhibitory control has been reported to make it possible for working memory to grow, and enable an increase in switching skills. An important stage of life for EF development is the preschool age. Play is the predominant activity at the preschool stage and thus can be a mediator that promotes children's cognitive development [65]. Thus, it may be unsurprising that play behavior and EF development are related in some ways. Our results support the hypothesis that types of games can support the development of EFs.

A closer examination of the interrelationship of EF components that enhance the development of other components is crucial for developing richer theoretical models of EF development. For instance, even if updating was not significantly predicted by any game type, and we observed a negative effect of puzzle games on switching, the enhancement of inhibition and switching through other game types may enhance the development of other components thatcompensate for these negative effects.

3.1. Future research direction

More research is needed to confirm and elaborate our findings. A similar longitudinal study assessing play behavior and EF at all measurement points, preferably including more measurement points, would allow for a better control of extraneous variables and a more stable estimation of children's play behavior. Future research would benefit from greater parental involvement with the assessment of habitual, naturalistic use of video games and board games in preschoolers (e.g., by time tracking; writing down different games for a given time). Finally, due to the observational nature of this study, causality cannot be established. Experimental evidence to identify mechanistic pathways would be needed.

3.2. Strengths and limitations

A strength of this study is that it utilized a naturalistic, observational, longitudinal design to discover the effects that habitually occurring play behavior has on the development of EF in children. In addition, we were able to control EF skills in kindergarten in order to examine the difference in the development of EF and the effect that play behavior had on it. At the same time, the study had some limitations that reduced the power of our analysis, as we detail below.

Since play behavior was only assessed at T1, we could not control for the autoregression but only assume that it remained stable over time. This may be problematic, because the interest in exergames could have increased in those 18 months, as could have the interest in any other game, depending on the video game market. However, research suggests that key aspects of interest–including positive affect, sustained attention with relative ease, and persistence–tend to remain stable [36, 12] when someone finds interest in a type of game. Consequently, it may be reasonable to assume that, despite changing interests for particular games, at least the interest in a game *type* tends to remain relatively stable. Moreover, video game statistics show that the most common and popular game consoles and games remain popular on the market (e.g. PlayStation 2 is still the best-selling console of all time, while Wii Sports, an exergame, is the best-selling console game; [66]). Thus, numerous games that were highly influential a few years ago are likely to exert some influence today (e.g., Minecraft), with children potentially remaining interested in the same highly influential game(s) for years. For future research, we nonetheless recommend including more measurement points to assess both EF and play behavior.

Another limitation of the study is the sample size. It was not large enough to compare specific game types to each other concerning their effect on EF skills at T2. It is possible that different game types have different effects on EF, and may vary in their effectiveness in promoting EF development. This should be explored in future work.

Board games were categorized into one type of game (traditional media) and the duration of this type of game was not assessed. Including this information might have provided additional insights into these types of games and their effect on EF, yet might also have distributed relevant variance into several groups.

Furthermore, the sample size did not allow for the comparison of children playing one type of game with children who play various types of games. However, given the existing data, we have to acknowledge that children seem to be interested in multiple kinds of games and, moreover, that some games do not seem to be easily categorized into any one group. Thus, future studies should include a more experimental approach to find more precise effects of specific game types on EF.

Finally, questionnaire-based assessment has the limitation of being less objective, as it might be biased by social desirability, memory retrieval issues, interpretation as well as judgment formation, which might be a challenge when estimating the frequency, duration, and the game type that was played. However, questionnaires have the advantages that they can offer more detailed information on the type of game played, and are superior for larger sample longitudinal studies compared to experimental designs. More specifically, by using questionnaires we acquired additional information on the games the children were playing, and on parents' management strategy for how their children spend time on games. Lastly, compared to experiments or intervention studies, our sample was larger, approaching 100 children.

4. Conclusion

The present study points to a need for future work to more closely examine the interaction between various types of games and EF development. While our results are not conclusive, they indicate that the development of EF could be enhanced by seeking a balance between exergames and more traditional board games. Parents might be relieved to know that video games did not appear to pose harm for most domains of children's EF development. At the same time, parents should be attentive that children engage in a variety of games that pose different cognitive demands in order to train a variety of skills. While puzzle games were negatively related to switching, we note that puzzle games enhance a variety of other skills, such as spatial reasoning. In line with previous intervention studies, our research supports the notion that playing board and video games in groups, as well as adding a physical component to the activity, might be a playful, enjoyable, and effective means of training children's EF with lasting effects.

Declaration of competing interest

We wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

Ethical Statement

I agree with the above statements and declare that this submission follows the policies of Solid State Ionics as outlined in the Guide for Authors and in the Ethical Statement.

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