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Adaptations of Executive Function and Prefrontal Cortex Connectivity Following Exergame Play in 4- to 5-year old Children

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Abstract

This study examined the separate and combined effects of exercise and cognitive training on children's executive function (EF) and associated neural substrates. Sixty-two children were recruited and randomly assigned to an Exergame (exercise + cognitive activity), Exercise (physical activity), Sedentary (cognitive activity), or Control (no-play) Condition. The training consisted of 20 min sessions 2x/week and was completed by 49 children 4- to 5-years-old. Resting-state prefrontal cortex (PFC) connectivity utilizing functional near-infrared spectroscopy, behavioral assessments of EF, and teacher ratings of EF were assessed pre- and posttest. Exergame training significantly improved performance on transfer EF assessments compared to the other conditions and increased PFC connectivity. The changes in PFC connectivity were positively associated with EF improvement. These findings suggest that the combination of cognitive and exercise training modulates the effects on EF and elucidates the neural mechanisms underlying the changes in EF induced from exergame play.

Keywords: educational technology; executive function; exergames; prefrontal cortex, fNIRS

Introduction

Exergames are a generation of video games that stimulate cognitive and motor functions simultaneously: the digital interface requires participants to interact with the virtual environment through body movements. Existing research on exergames has primarily focused on health outcomes and found that exergames enhance physical activity in children and adults (Sween et al., 2014). A more recent body of research has focused on whether exergames exhibit not only physical health benefits, but cognitive health benefits as well.

The majority of research on the effects of exergames on cognition have primarily focused on elderly populations. Prior findings suggest exergame training is more effective than exercise or cognitive training alone (Bruderer-Hofstetter et al., 2018) and within individual domains of cognition, exergames specifically benefit executive function (EF), theorizing the combination of exercise and cognitive training may affect neuroplasticity additively and improve EF over and above single component cognitive or exercise training alone (Monteiro-Junior et al., 2016).

EF is an umbrella term for cognitive processes that subserve goal-directed behavior (Best & Miller, 2010). The ecological account of EF by Werchan and Amso (2017) emphasizes that environmental enrichment is critical in shaping the development of EF by providing increased quantity and quality of multimodal input to the prefrontal cortex (PFC). The combination of exercise and cognitive stimulation through multisensory exergame play could potentially foster EF by providing an enriching environment that promotes increased quantity (kinesthetic, auditory, visual) and quality (increasing challenge, continuously adapting difficulty based on individual performance, matching feedback) of multimodal input.

EF longitudinally predicts academic achievement and learning-related classroom behaviors (Blair & Razza, 2007). Children with lower initial performance on EF tasks tend to benefit most; thus, early intervention is crucial and may avert widening achievement gaps later (Diamond & Lee, 2011). Exergames are widely available, require little space, adapt to performance, and are enjoyed by children (Best, 2010).

Despite the practical applications of exergames in youth, few studies examine the efficacy of exergame training on EF with children. Those that do found exergames improve EF in children diagnosed with attention-deficit/hyperactivity disorder and with autism spectrum disorder, as well as low-income adolescents compared to no-play control groups (Anderson-Hanley et al., 2011, Benzing & Schmidt, 2019; Staiano et al., 2012). A limitation to these studies was that there were no cognitive or exercise training groups; therefore, conclusions could not be drawn as to whether the effects were driven by the exercise, cognitive, or combined cognitive and physical components of the exergames.

Studies that have compared exergames to exercise training found improved cognitive flexibility in adolescents and enhanced EF in preschool children from exergaming compared to exercise training (Benzing et al., 2016; Xiong Xiong, Zhang, & Gao, 2019). The limitation of these studies was that there was no cognitive control conditions; therefore, conclusions could not be made on whether the cognitive component alone from the exergame without the exercise component would be enough to induce changes in EF.

While there is evidence of exergames demonstrating advantages over control and exercise groups, evidence is mixed when comparing exergame training to cognitive training with children. Best (2012) found that children's EF improved after participating in an exergame and an exercise condition compared to both cognitive and no-play control conditions. These findings suggest that the exercise component of exergames—not the cognitive component—enhances EF. A limitation of this study was that participants in each condition played different video games, and the type of motor movements differed between the exergame (i.e., moving from side to side, jumping to avoid obstacles) and exercise (i.e., running) conditions.

Flynn and Richert (2018) worked towards resolving these limitations by ensuring children in the exercise group executed motor movements similar to the exergame group, and children in the cognitive and exergame groups played the same game. The researchers found that the exergame and cognitive groups improved performance on EF compared to the exercise and control groups. Contrary to Best (2012), findings from this study indicated that the cognitive component of exergames—not the exercise component—enhanced EF. Although the type of physical activity between the exergame and exercise groups were similar, a limitation to the exercise condition was that it was not in a virtual environment, making the context between the exergame and exercise interventions a potential confound. Additionally, while the participants in the exercise group exerted similar motor movements as the exergame group, these children did not have to inhibit or receive feedback to modify their responses, making the features of the exergame and cognitive conditions different from those of the exercise condition.

While these studies are foundational to broadening our understanding of exergames and EF in youth, more carefully controlled studies with additional EF assessments and the supplementation of neuroimaging techniques are needed to clarify the unique efficacy of exergames on EF in children, and the neural mechanisms underlying these changes. A concern of EF training more generally is how the skills transfer to real-world contexts. This study aims to fill these gaps by (1) assessing the efficacy of exergames on EF with children by comparing exergame training to cognitive training, exercise training, and a control group, (2) including teacher ratings of children's EF to assess if skills children learn from training transfer to EF-related behavior in a real-world educational context, and (3) elucidating the potential neural mechanisms of exergame-induced EF changes with neuroimaging. Studies using functional near-infrared spectroscopy (fNIRS) have shown that PFC connectivity is developmentally correlated with EF in young children (Moriguchi & Hiraki, 2013); and more recently, resting-state functional connectivity (rsFC)—correlated activity in the absence of a task—has specifically been found to predict cognitive performance, educational attainment, and even household income (Shen et al., 2018). We hypothesized that exergame training would improve children's performance on behavioral EF tasks, EF-related behaviors in the classroom, and rsFC in the PFC compared to the control groups.

Method

Participants 62 children were recruited from a pre-primary school on the campus of a Mid-Atlantic city in the United States. Of the 62 children, 5 children were excluded due to noncompliance on the EF assessments at pretest, 5 children did not return to the laboratory to complete the full intervention, 2 children lacked motor skills necessary for training, and 1 child from the control group was unwilling to participate in the posttest. The remaining 49 participants were ages 4 to 5 (*M*=4.89, *SD*=.42 years). The school environment represents local racial and economic diversity with children being 54% White, 24% Asian or Pacific Islander, 5% African American, 12% Middle-Eastern, 5% Hispanic, and 28% of children attending with financial aid. The experimental protocol was approved by the Institutional Review Board. Signed consent was obtained from the parents of participants. Verbal assent was secured from all participants and children were given stickers for their participation. This study utilized a randomized block design by classroom, age, and sex. Then, within each block, subjects were randomly assigned to one of the four conditions: Exergame (*n*=13), Exercise (*n*=12), Sedentary (*n*=11), or Control (*n*=13).

Procedure and Measures

Predictions and analyses were preregistered on the Open Science Framework in advance, where the materials and protocols utilized in this study are available (Eng, 2018). A between-subjects design was used with two testing phases: pretest and posttest. PFC functional connectivity utilizing fNIRS, EF task performance, and teacher ratings of EF were assessed at pretest. The day after pretest, children in the Exergame, Sedentary, and Exercise Conditions trained for 2 consecutive days, 20 mins/day, for 40 mins total. Participants returned to the laboratory the following day after training and PFC connectivity, EF task performance, and teacher ratings of EF were reassessed at posttest. Teachers were condition-blind. Children in the No-play Control Condition continued their typical activities and just participated in the pre- and posttest assessments.

Resting State-Prefrontal Cortex Connectivity fNIRS is a neuroimaging technique that uses low-levels of light to measure changes in cerebral blood volume and oxygenation. Optical imaging was collected with a continuous wave real-time fNIRS system (TechEn, Inc.). There were 4 light sources, each containing 690-nm and 830-nm laser light and

8 detectors, with a source-detector distance of 3.0 cm to give oxygenation measures in 10 channels. Probes were positioned referenced to the 10–20 EEG international coordinate system covering areas Fp1-F8 on the PFC. Sensors were mounted on a probe strip and secured with a child-friendly Neoprene Cap. fNIRS is ideal for neuroimaging studies with children because it is noninvasive and does not require participants to remain relatively immobile. Inscapes (Vanderwal et al., 2015)—a movie paradigm designed to measure rsFC—has been found to be a useful condition between task-free rest and movies for children. It features abstract shapes without a social narrative and has been associated with patterns of connectivity that most closely resembles those obtained during rest.

Behavioral Executive Function Assessments

Modified Flanker Task (Rueda et al., 2004): A modified version of the Flanker Task appropriate for children was utilized in which a computer screen presented 5 fish in a row facing either right or left. The task goal was to make a response in accordance with the direction of the middle fish while ignoring the surrounding fish, which either faced the opposite or same direction of the target fish for incongruent and congruent trials, respectively. This task involves multiple EF skills: following rules, paying attention, and inhibiting distraction from the flanking fish. Children completed 8 practice trials to ensure directions were understood, followed by 42 test trials. Children were given encouragement during the practice trials to respond as quickly and accurately as possible. No encouragement or correction was given during the testing block. The primary outcome measure was accuracy for the incongruent trials.

Day-Night (Gerstadt, Hong, & Diamond, 1994): The Day-Night Task presented children with cards with either a moon or a sun on them. A block of congruent trials was shown first in which children were instructed to say "day" or "night" when shown a sun or moon card, respectively. A block of incongruent trials was shown next in which children were told to do the opposite and say "day" when shown a moon card and "night" when shown a sun card. Children completed 2 sets of practice trials to ensure directions were understood, followed by 2 sets of 16 test trials for a total of 36 trials. This task also involves multiple EF skills: following rules, switching, and inhibiting prepotent responses. The main outcome measure was accuracy for the incongruent trials.

Behavior Rating Inventory of Executive Function-Preschool Version (BRIEF; Gioia et al., 2002): This questionnaire assessed EF as manifested in the everyday behavior of preschool-aged children. Teachers completed items assessing Inhibitory Control, Flexibility, Working Memory, and Planning/ Organizing with response options ranging from "never" to "often" a problem for the child (e.g., "Is impulsive"). Questionnaires were scored and entered by condition-blind trained research assistants.

Training Sessions

Each condition was programmed in Unity Technologies: a game software permitting customization of condition features. Each condition was projected onto a wall with a connected non-slip game step mat (144 x 96 x 48 in) and was a "gamified" version of the Flanker Task while maintaining the goals of the standard task. The game features included a narrative, player feedback, and a computational algorithm to provide incremental challenge by continuously adapting the difficulty level based on performance. For correct trials, difficulty advanced by decreasing the allotted response time by 500 ms. For incorrect trials, difficulty decreased by increasing the allotted response time by 500 ms. Children played 20 mins/day, for 2 consecutive days. Training was administered to participants in the same room each day, with a hypothesis-blind experimenter present to ensure directions were understood and followed.

Enjoyment Post-training, an *Again-Again* question, a valid measure of children's enjoyment assessed whether children would play an activity again, with answers of "no", "maybe", or "yes" (Read & MacFarlane, 2006).

Exergame Condition (combined exercise + cognitive training): Identical to the Flanker Task, but instead of pressing left and right arrows on a computer keyboard, children responded by stepping left or right on the physical game mat's arrows depending on the direction that the central target was facing (Fig. 1A). The surrounding fish faced the opposite or same direction of the central fish for incongruent and congruent trials, respectively. To ensure stimuli were projected in a systematic visual angle so the distractor fish were not in far peripheral vision, the visual angle was calculated as 2 x inverse tangent of S/2D, where S = the screen width and D = the distance from the eye pupil.

Sedentary Condition (cognitive training): was identical to the Exergame except participants sat on the mat and pressed left or right with their hands, rather than stepping (Fig. 1B).

Exercise Condition (exercise training) was identical to the Exergame except that the central target fish was not surrounded by distractor fish (Fig. 1C).

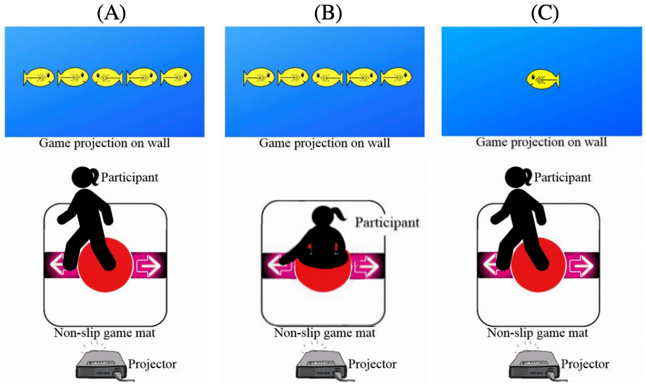

Figure 1: (A) Exergame (B) Sedentary (C) Exercise Condition

Results

Preliminary analyses examined condition differences of age, sex, training enjoyment, and pretest assessments. Neither age, sex, nor training enjoyment differed significantly between the groups (*p*s>0.11). At pretest, there were no significant differences between groups on the Flanker Task, the Day-Night Task, BRIEF, or mean PFC rsFC (*p*s>0.41).

fNIRS Data Acquisition and Analysis Preprocessing and rsFC analyses were carried out using the NIRS Brain AnalyzIR toolbox (Santosa, Zhai, Fishburn, & Huppert, 2018). Raw fNIRS intensity signals were first converted to changes in optical density. The data were then corrected for motion artifacts using the Temporal Derivative Distribution Repair method. This uses a motion correction procedure based on robust regression that effectively reduces the magnitude of large fluctuations (i.e., motion) in the signal, while leaving small fluctuations (i.e., hemodynamics) intact to prevent physiological artifacts from biasing the results (Fishburn et al., 2019). Signals were then converted to oxygenated hemoglobin concentrations using the modified Beer Lambert relationship. rsFC was quantified by concatenating the individual block time courses, and the Pearson correlation coefficient was computed between all 45 channel-pairs at pre- and posttest.

A Fisher's r-to-Z transformation was then applied to normalize the variance of the correlation values. To account for variability in the hemodynamic response function, the temporal and dispersion derivatives were estimated and discarded. An autoregressive iteratively-reweighted least squares approach (Barker, Aarabi, & Huppert, 2013) was used to estimate the coefficients to account for serial correlations in the data. The estimated coefficients for both conditions were submitted to a robust weighted mixed effects model, with time modeled as a fixed effect and subject as a random effect. The response variable and design matrices were weighted using the inverse of the 1st-level coefficient covariance matrices, effectively weighting observations by the reliability of the estimate. To assess the changes in rsFC over time between conditions, a t-contrast of 'Posttest' versus 'Pretest' was carried out by group, and the false discovery rate (FDR) correction was used to control for multiple comparisons via multiple channel-pairs (Benjamini and Hochberg, 1995). The results from this analysis were used to assess the channel-pairs where there was a significant change in rsFC from pre- to posttest.

Prefrontal Cortex Connectivity

Out of 45 channel-pairs, PFC rsFC significantly changed from pre- to posttest in 26 channel-pairs for the Exergame group, 4 channel-pairs in the Exercise group, 3 channel-pairs in the Sedentary group, and 1 channel-pair in the Control group (Fig. 2). Exergame training elicited significantly greater rsFC than the control groups in the PFC ($p < .05$; FDR corrected).

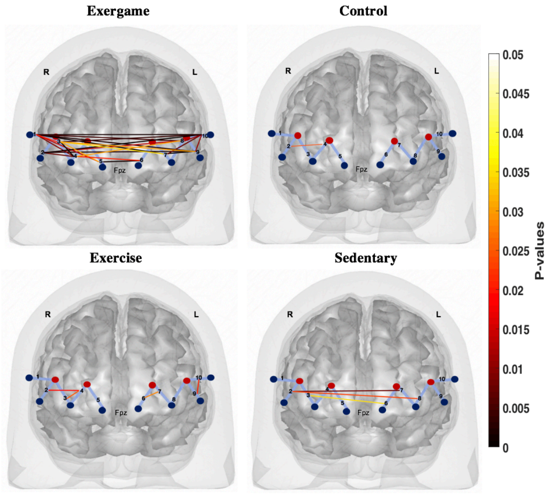

Figure 2. Changes in PFC functional connectivity ($p < .05$)

Effects on Behavioral EF Assessments

As per preregistered analyses, one-way ANOVAs were conducted with difference scores from pre- to posttest as dependent variables and Condition as the explanatory variable. Planned contrasts based on a priori hypotheses were run if a significant main effect of condition was found.

The Flanker Task Flanker Task accuracy changes from pre- to posttest revealed a significant effect of condition, $F(3, 45) = 4.03$, $p=.013$, $\eta_p^2=.21$. Planned contrast analyses revealed that gains in Flanker accuracy were significantly larger for the Exergame Condition ($M=29.67$; $SE=6.67$), $F(1, 45)= 9.63$ p=.003, $\eta_p^2=.18$, and for the Sedentary Condition ($M=25.97$; $SE=6.69$), $F(1, 45)= 6.52$, $p=.014$, $\eta_p^2=.13$ relative to the No-play Condition ($M=6.19$; $SE=4.58$) while gains for the Exercise Condition ($M=13.99$; $SE=5.16$; $p=.31$), did not differ from the No-play Condition (see Fig. 3A). Tukey's HSD Test showed Flanker Task accuracy gains did not differ between the Exergame, Sedentary, and Exercise Condition ($p=.20$). These results were not surprising, as the Sedentary and Exergame group directly practiced the ability to focus on a center target while ignoring distractors on the side during training, while the No-Play and Exercise Conditions did not.

Day-Night Task Day-Night Task accuracy changes from pre- to posttest revealed a significant effect of condition, $F(3, 45)=6.58$, $p<.001$, $\eta_p^2=.31$. The planned contrast analysis revealed that compared to the No-Play Condition ($M=1.33$; $SE=4.26$), gains in Day-Night accuracy were significantly larger for the Exergame condition ($M=25.52$; $SE=4.77$), $F(1, 45)=16.56$, $p<.001$, $\eta_p^2=.27$, but not for the Sedentary ($M= 10.23$; $SE=3.98$), or Exercise Conditions ($M=3.13$ $SE=4.12$), *p*s>0.15 (see Fig. 3B). Tukey's HSD Test showed gains in Day-Night accuracy significantly differed between the Exergame and all conditions ($p<.02$), but there were no significant differences between the other conditions ($p=.26$).

Teacher Ratings of EF BRIEF score changes from pre- to posttest revealed a significant effect of condition, *F*(3, 45)= 4.86, *p*=.006, η_p^2=.27. The planned contrast analysis revealed that compared to the No-Play Condition (*M*=.69; *SE*=1.70), BRIEF scores gains were significantly larger for the Exergame condition (*M*=9.00; *SE*=1.68), *F*(1, 45)=14.30, *p*< .001, η_p^2=.26, but not for the Sedentary (*M*=3.12; *SE*=4.09) or Exercise Conditions (*M*=2.80; *SE*=1.04), *ps*>0.19 (see Fig. 3C). Teachers were blind to the hypotheses and condition assignments, ensuring no expectancy effect bias. Tukey's HSD Test showed gains in BRIEF scores significantly differed between the Exergame condition and all other conditions (*p*<.05), but there were no significant differences comparing the other conditions to each other (*p*=0.92).

Effects on EF and Associated Neural Substrates

After the group-level analysis, subject-level rsFC correlation coefficients were extracted from all 45 channel-pairs and standardized using *z*-scores. *Z*-scores were averaged for each time point, resulting in a single global rsFC score at pre- and posttest. To quantify the mean change in rsFC, a difference score for each child was calculated by subtracting the mean pretest rsFC from the mean posttest rsFC. Scores estimated changes in rsFC, such that higher scores indexed greater changes in connectivity strength in the PFC. rsFC changes from pre- to posttest revealed a significant effect of condition, *F*(3, 45)=2.86, *p*=.04, η_p^2=.16. The planned contrast analysis revealed that compared to the No-Play Condition (*M*=-.05; *SE*=.16), gains in global PFC rsFC were significantly larger for the Exergame condition (*M* =.46; *SE* =.10), *F*(1,45)=5.79, *p*=.02, η_p^2=.11, but not for the Sedentary (*M*=.09; *SE*=.19) or Exercise Conditions (*M*=-.13; *SE*=.16), *ps*>0.74 (see Fig. 3D). Tukey's HSD Test showed gains in PFC rsFC significantly differed between the Exergame condition and all other conditions (*p*<.05), but no significant differences between the other conditions (*p*>.51).

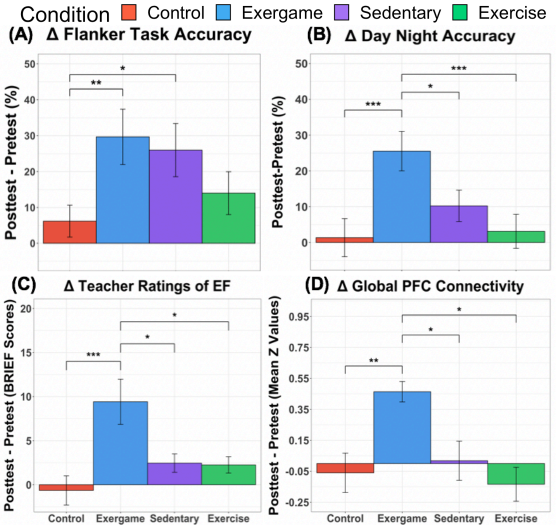

Figure 3: Changes in (A) Flanker (B) Day-Night (C) BRIEF (D) PFC Connectivity. ***$p < .001$ **$p < .01$ *$p < .05$.

Association of EF and PFC Connectivity Changes in behavioral EF assessments were positively and significantly associated (all *ps*<.009, *r*=0.37-0.42). Therefore, to examine the association between the behavioral EF assessments and PFC rsFC changes, changes in Flanker Task (*M*=18.29%) and Day-Night Task performance (*M*=9.69%), and BRIEF scores (*M*=3.53) were standardized using Z-scores and averaged together to create an EF composite variable (*M*=-.002; *SD*=.79). Global PFC rsFC difference scores ranged from -1.31 to 2.34 (*M*=.07; *SD*= .58). The changes in PFC rsFC were associated with children's EF composite scores, *r*(48)=.41, 95%CI [.17, .98], *p*=.004 (see Fig. 4).

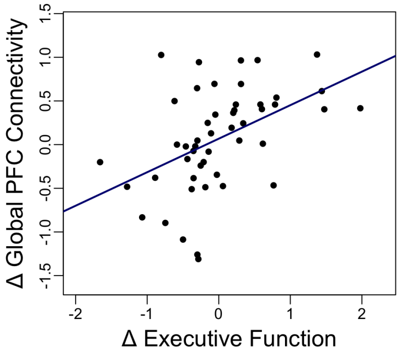

Figure 4: Greater changes in EF were associated with higher PFC connectivity difference scores

Discussion

The results of this study provide the first systematic analysis to determine whether cognitive training without the exercise component, or exercise training with less cognitive stimulation more greatly impact EF via comparing an exergame to: 1) a sedentary version of the same game 2) an exercise version using the same motor movements as the exergame and 3) an age-matched control group. Although conservative interpretations should be drawn due to the small sample size, the present findings extend the literature in several ways. First, the Exergame Condition had the strongest effect on EF and associated PFC rsFC, suggesting that the interaction of exercise and cognitive training drives the effects on EF. Second, the Exergame and Sedentary Conditions had equivalent effects on the trained EF skill of resolving visuospatial conflict on the Flanker Task, suggesting that the cognitive component of game play—whether physical or sedentary—provides a context to improve targeted EF processes. Third, only children in the Exergame Condition exhibited improvement on Day-Night Task performance and EF-related behaviors in the classroom.

Children's everyday environments at school are important venues for observing routine manifestations of EF. This study extends previous findings by demonstrating that improvements generalize to teacher ratings of EF in addition to a novel EF task. Furthermore, changes in EF were associated with changes in PFC rsFC, supporting the neuroplasticity hypothesis of exergames. An important question is whether exergames transiently facilitate EF, or whether they have a more fundamental impact on development, resulting in long-term changes. Future research should follow children longitudinally to examine whether the effects of exergames are sustained over time.

During exergame play, the physical effort imposed by exergames could produce the already known neurological mechanisms of exercise: the increased synthesis and release of trophic factors such as brain-derived neurotrophic factor (BDNF) subsequently stimulates neuroplasticity—the ability of the brain to form and grow connections—especially in response to learning and experiences (Ding et al., 2006). The cognitive effort imposed by exergames could produce the growing evidence of neuroplasticity induced from action videogame: game features such as adaptability, challenges, rules, and the feedback system (positive rewards and anticipating competitors) require participants to inhibit and initiate actions, pay attention, plan, and make decisions quickly and accurately, which subsequently fosters EF development and brain plasticity (Bavelier et al., 2012). Therefore, the combination of exercise and cognitive stimulation through multicomponent exergame play may provide an enriching environment that affects neuroplasticity additively, and may be more effective in improving EF than single component cognitive or exercise training alone (Monteiro-Junior et al., 2016).

Exergames may be ideal for children from low income backgrounds who may not have access to safe recreational equipment, and also for children with low physical activity self-efficacy because they include computational algorithms for continuously adapting the difficulty level based on children's individual performance capabilities (Best, 2010). Therefore, the outcomes of this study are promising in support of Exergame training as a means to enhance EF development in children as young as 4 to 5-years old. Exergames can potentially be used as educational tools so that children enter formal schooling equipped with the EF skills to facilitate learning at par with their peers.

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References

Anderson-Hanley, C., Tureck, K., & Schneiderman, R. L. (2011). Autism and exergaming: effects on repetitive behaviors and cognition. *Psychology research and behavior management*, *4*, 129. https://doi.org/10.2147/PRBM.S24016

Barker, J. W., Aarabi, A., & Huppert, T. J. (2013). Autoregressive model based algorithm for correcting motion and serially correlated errors in fNIRS. *Biomedical Optics Express*, *4*(8), 1366. https://doi.org/10.1364/boe.4.001366

Bavelier, D., Green, C. S., Pouget, A., & Schrater, P. (2012) Brain plasticity through the life span: learning to learn and action video games. *Annual review of neuroscience*, *35*, 391-416. https://doi.org/10.1146/annurev-neuro-060909-152832

Benjamini, Y., & Hochberg, Y. (1995). Controlling the false discovery rate: a practical and powerful approach to multiple testing. *Journal of the Royal statistical society: series B (Methodological)*, *57*(1), 289-300. https://doi.org/10.1111/j.2517-6161.1995.tb02031.x

Benzing, V., Heinks, T., Eggenberger, N., & Schmidt, M. (2016). Acute cognitively engaging exergame-based physical activity enhances executive functions in adolescents. *PLoS ONE*, *11*(12). https://doi.org/10.1371/journal.pone.0167501

Benzing, V., & Schmidt, M. (2019). The effect of exergaming on executive functions in children with ADHD: A randomized clinical trial. *Scandinavian journal of medicine & science in sports*, *29*(8), 1243-1253. https://doi.org/10.1111/sms.13446

Best, J. R. (2012). Exergaming immediately enhances children's executive function. *Developmental Psychology psychology*, *48*(5), 1501. https://doi.org/10.1371/journal.pone.0167501

Best, J. R. (2010). Effects of physical activity on children's executive function: Contributions of experimental research on aerobic exercise. *Developmental Review* *30*(4), 331-351. https://doi.org/10.1016/j.dr.2010.08.001

Best, J. R., & Miller, P. H. (2010). A developmental perspective on executive function. *Child development, 81* (6), 1641-1660. https://doi.org/10.1111/j.1467-8624.201001499.x

Blair, C., & Razza, R. P. (2007). Relating effortful control, executive function, and false belief understanding to emerging math and literacy ability in kindergarten. Child development, *78*(2), 647-663. https://doi.org/10.1111/j.1467-8624.2007.01019.x

Bruderer-Hofstetter, M., Rausch-Osthoff, A. K., Meichtry, A., Münzer, T., & Niedermann, K. (2018). Effective multicomponent interventions in comparison to active control and no interventions on physical capacity, cognitive function and instrumental activities of daily living in elderly people with and without mild impaired cognition–a systematic review and network meta-analysis. *Ageing research reviews*, *45*, 1-14. https://doi.org/10.1016/j.arr.2018.04.002

Diamond, A., & Lee, K. (2011). Interventions shown to aid executive function development in children 4 to 12 years old. *Science*, *333*(6045), 959-964. https://doi.org/10.1126/science.1204529

Ding, Q., Vaynman, S., Akhavan, M., Ying, Z., & Gomez Pinilla, F. (2006). Insulin-like growth factor I interfaces with brain-derived neurotrophic factor-mediated synaptic plasticity to modulate aspects of exercise-induced cognitive function. *Neuroscience*, *140*(3),823-833. http://doi.org/10.1016/j.neuroscience.2006.02.084

Eng, C. (2018). The Effects of an Exercise-based Interactive Game on Executive Function in Preschool Children. Retrieved from https://osf.io/mf3rp/?view_only=19168e1b145e45e49f73be38ea62a86f.

Fishburn, F. A., Ludlum, R. S., Vaidya, C. J., & Medvedev, A. V. (2019). Temporal Derivative Distribution Repair (TDDR): A motion correction method for fNIRS. *NeuroImage*, *184*, 171–179. https://doi.org/10.1016/j.neuroimage.2018.09.025

Flynn, R. M., & Richert, R. A. (2018). Cognitive, not physical, engagement in video gaming influences executive functioning. *Journal of Cognition and Development*, *19*(1), 1–20. https://doi.org/10.1080/15248372.2017.1419246

Gerstadt, C. L., Hong, Y. J., & Diamond, A. (1994). The relationship between cognition and action: performance of children 3 ½-7 years old on a stroop- like day-night test. *Cognition*, *53*(2), 129–153. https://doi.org/10.1016/0010-0277(94)90068-x

Gioia, G., Andrwes, K., & Isquith, P. (1996). *Behavior rating inventory of executive function-preschool version (BRIEF-P). Psychological Assessment Resources*. https://doi.org/10.32388/h92o5c

Monteiro-Junior, R. S., Vaghetti, C. A. O., Nascimento, O. J. M., Laks, J., & Deslandes, A. C. (2016). Exergames: neuroplastic hypothesis about cognitive improvement and biological effects on physical function of institutionalized older persons. *Neural regeneration research*, *11*(2), 201. https://doi.org/10.4103/1673-5374.177709

Moriguchi, Y., & Hiraki, K. (2013). Prefrontal cortex and executive function in young children: a review of NIRS studies. *Frontiers in human neuroscience*, *7*, 867. https://doi.org/10.3389/fnhum.2013.00867

Read, J. C., & MacFarlane, S. (2006). Using the fun toolkit and other survey methods to gather opinions in Child Computer Interaction. *Proceeding of the 2006 Conference on Interaction Design and Children*, 81–88. https://doi.org/10.1145/1139073.1139096

Rueda, M. R., Fan, J., McCandliss, B. D., Halparin, J. D., Gruber, D. B., Lercari, L. P., & Posner, M. I. (2004). Development of attentional networks in childhood. *Neuropsychologia*, *42*(8), 1029–1040. https://doi.org/10.1016/j.neuropsychologia.2003.12.012

Santosa, H., Zhai, X., Fishburn, F., & Huppert, T. (2018). The NIRS Brain AnalyzIR toolbox. *Algorithms*, *11*(5). https://doi.org/10.3390/A11050073

Shen, X., Cox, S. R., Adams, M. J., Howard, D. M., Lawrie, S. M., Ritchie, S. J., ... & Whalley, H. C. (2018). Resting-state connectivity and its association with cognitive performance, educational attainment, and household income. *Biological Psychiatry: Cognitive Neuroscience and Neuroimaging*, *3*(10), 878-886. https://doi.org/10.1016/j.bpsc.2018.06.007

Staiano, A. E., Abraham, A. A., & Calvert, S. L. (2012). Competitive versus cooperative exergame play for african american adolescents' executive function skills: Short-term effects in a long-term training intervention. *Developmental Psychology*, *48*(2), 337–342. https://doi.org/10.1037/a0026938

Sween, J., Wallington, S. F., Sheppard, V., Taylor, T., Llanos, A. A., & Adams-Campbell, L. L. (2014). The role of exergaming in improving physical activity: a review *Journal of Physical Activity and Health*, *11*(4), 864-870. https://doi.org/10.1123/jpah.2011-0425

Werchan, D. M., & Amso, D. (2017). A novel ecological account of prefrontal cortex functional development. Psychological Review, 124(6), 720–739. https://doi.org/10.1037/rev0000078

Vanderwal, T., Kelly, C., Eilbott, J., Mayes, L. C., & Castellanos, F. X. (2015). Inscapes: A movie paradigm to improve compliance in functional magnetic resonance imaging. *NeuroImage*, *122*, 222–232. https://doi.org/10.1016/j.neuroimage.2015.07.069

Xiong, S., Zhang, P., & Gao, Z. (2019). Effects of Exergaming on Preschoolers' Executive Functions and Perceived Competence: A Pilot Randomized Trial. *Journal of Clinical Medicine*, *8*(4), 469. https://doi.org/10.3390/jcm8040469