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The Effects of Xbox Kinect Active Video Gaming on Executive Function, Inhibition, in Children with and without Autism Spectrum Disorder: A Pilot Study

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Abstract

The purpose of this study was to compare the effects of sedentary video gaming (SVG), active video gaming (AVG), and brisk walking (WLK) on inhibition and reaction time using the Flanker task in boys with and without autism spectrum disorder (ASD). We had 9 participants with ASD and 10 age-matched participants without ASD perform 20-minute bouts of each activity, and then had them take the Flanker test. Dependent measures were reaction time (RT) and accuracy (ACC). A Chi-Square analysis revealed that the ASD and TD groups significantly differed in the percent of participants who improved in both of these measures. Next, we looked at each of the conditions exclusively within the ASD group and compared congruent and incongruent trials. In the AVG condition, participants improved a significantly higher percentage on ACC. In the SVG condition, participants improved a significantly higher percentage on incongruent in RT; for ACC, a higher percentage improved on the congruent trials. In WLK, participants improved a significantly higher percentage in RT in the congruent condition.

Keywords

Autism Spectrum Disorder, Exergaming, Physical Activity, Cognitive Function

1. Introduction

The identification of children with autism spectrum disorder (ASD) has grown

rapidly from 1 in 88 [1] to now surveillance showing 1 in 44 in 2018 [2]. The maladaptive behaviors associated with this disorder have far-reaching effects in areas such as functional skills, caregiving, education, healthcare, and ultimately society. It has been suggested that executive function (EF), a common deficit in the population, can explain the trajectory of functional outcomes, such as the completion of tasks, school readiness, academic success, adaptive behaviors, and socialization [3] [4] [5]. Researchers have found a deficit in response inhibition in children with ASD [6]. Imaging studies using functional connectivity MRI (fcMRI) have shown changes in brain function during testing of inhibition. fcMRI found neuroconnectivity related changes with more response inhibition error with decreased IFC within a group of child aged [7]. fMRI increased brain activation in the left insula with interference [8] and inhibition and fNIRS showed more commission errors on Go No Go and a weaker prefrontal cortex [9]. Also, a greater number of reaction errors on the Stroop task compared to typical [10]. The Flanker task is commonly used to examine inhibitory function [11]. Individuals with ASD seem to have difficulty ignoring distracting visual information based on the results using the Flanker task [12]. Special education services are often required by school-aged individuals with ASD, and they often require special education for their dysfunctional behaviors related to EF deficits. Education is the highest contributor to costs associated with ASD care, costing $8610 more than neurotypical children per year [13]. The estimated cost of caring is rising and is estimated to increase from 368 billion in 2015 to 462 million in 2025 [14].

Developing cost-effective and time-minimized intervention which can influence academic performance and life skill function, therefore, has far-reaching implications. Videogames have been used for children with ASD [15] making Kinects a promising tool. Research exists that indicates PA has positive effects on cognitive function, academic performance, attention, and EF in a variety of populations [16] [17] [18] [19] [20]. Stroop showed improvement from pretest to retention [21]. More recently, children with ASD have shown changes in inhibition and working memory during physical activity (PA) [22] [23] [24]. Research has shown a positive effect of PA with acute exercise resulting in short-lived transient changes in neurophysiologic arousal. In addition, chronic bouts of PA have long-term effects that lead to anatomical and neurophysiologic changes [19] [25]. Researchers have used multiple brain imaging methods, including functional near-infrared spectroscopy, functional magnetic resonance imaging and electroencephalogram, particularly in the pre-frontal cortex [26] [27] [28]. Previous studies found improvements in cognitive function, long-term memory, stabilization of representations and working memory changes post-PA [23] [29] [30].

Two characteristics of PA factor into the degree to which PA impacts EF: intensity of exercise and complexity of the motor task. Multiple studies indicate moderate-intensity alters cognitive function with an apparent specificity for higher-level EF process with some specifically [19] [22] [27] [31]-[36]. In addi-

tion to intensity level, complexity level and cognitive demands of a motor task can lead to differences in EF responses [37] [38]. Research using complex motor tasks and games has demonstrated improvements in inhibition, attention, memory, and memory recall even in low intensity activities such as yoga [21] [39] [40]. These results suggest that a PA intervention should provide moderate intensity levels in a complex motor task to reap the most improvement in EF. Limited home, school and community-based opportunities exist that provide effective and efficient exercise [41]. Another confounding factor is that individuals with ASD participate in less diverse types of recreational activities compared to their peers [42]. Virtual reality and active video games (AVG) provide a potential solution to both issues.

Virtual reality, an immersive, interactive 3D computer-generated environment in which interaction takes place over multiple sensory channels, is already being successfully used with ASD populations in clinical, educational and rehabilitation environments [39] [43] [44] [45]. Due to moderate cost and wide availability AVGs, present a new option for PA. Several studies have shown that AVG increases PA levels in populations with ASD [18] [37] [46] [47] [48]. AVG has the potential to provide a safe environment for PA participation. A variety of AVG games require complex motor skills, which allow players to engage in more vigorous activities. Additional benefits of AVG include perceived decreases in social anxiety, increases in efforts during individual exercise bouts, as well as motivation to participate repeatedly over time [45] [49] [50]. The purpose of the study is to determine the effects of Xbox Kinect AVGs on EF in boys with and without ASD. Specifically, we aimed to compare inhibition (as measured by the Flanker test) after 20-minute bouts of SVG, AVG and brisk walking. We made no a priori hypotheses related to the results.

2. Methods

2.1. Participants

Prior to beginning this research, approval was obtained through the University of Delaware internal review board to perform the study. Eleven male participants with mild to moderate ASD between the ages of 8 - 11 years old and 11 age-matched typically developed (TD) participants were recruited in this study. A total of 18 participants (8 in ASD and 10 in the typical group) were ultimately included in data analysis, as three participants in the ASD group and one from the TD group did not finish all experimental conditions. Participants with ASD were recruited either through an Autistic program within an inclusion public school environment or through advertisements available to parents of the ASD community. Participants were initially recruited according to two criteria: First, they had a prior diagnosis through medical or school psychologist; second, they were currently participating in an Autistic Program within a school system in the Mid-Atlantic region. Next, parents of potential participants were given the Social Responsiveness Scale, second edition (SRS-2) to determine the severity of

social deficits; only participants who scored within the mild to moderate range were included. We used the Wisconsin Card Sorting Test to confirm that participants could understand and respond to commands on a computer [51] [52]. The typically developing (TD) group were included if their SRS-2 score did not indicate the presence of Autistic behaviors. Exclusion criteria for all participants were diagnosis of Tourette's Syndrome, Intellectually Developmentally Delay (IDD) or other neurological disorders, disability or injury that impeded PA, and a Movement Assessment Battery for Children-2nd Edition (MABC-2) score at or below the 5th percentile.

Participant demographics are described in **Table 1**.

2.2. Experimental Design

We used a repeated measures design where both groups of participants performed three different activity conditions that were presented in a randomized sequence to avoid an order effect. This included a sedentary video game, active video game, and independent walking.

2.3. Equipment

2.3.1. Video Gaming System

For all gaming conditions, an Xbox 360 gaming system was used. For the sedentary gaming condition, participants played Bang Bang Racing with a handheld controller while in a seated position. For AVG, the Kinect infrared sensor was secured to the top of a 36" television and participants stood in front of it. Two games called "Crazy Sales" and "Save the hotdog" from Raving Rabbids Disc were selected to promote complex fast pace full body movement.

2.3.2. Inquisit Children's Modified Flanker

The Flanker task measured response inhibition using measures of speed (ms) and accuracy (% correct) to measure the ability to suppress an inappropriate response in a particular context. It has been used in the pediatric population with ASD during an exercise protocol [53] Eriksen and Schultz (1979). The Inquisit Children Flanker program was based on past research involving similar tasks [12] in children with ASD (see **Figure 1**).

Figure 1. Inquisit children' flanker test. Participants are presented with yellow fish in either (a) Congruent or (b) Incongruent order. Participant had to identify the direction of the middle fish using the "<" or ">" keys as quickly and accurately as possible within a trial.

Table 1. Participant demographics.

	Age (months)	Weight (kg)	Height (cm)	BMI[a]
ASD	126.0 ± 10.52	34.42 ± 8.94	144.93 ± 7.98	18.22 ± 3.80
TD	125.5 ± 14.57	45.55 ± 10.60	138.71 ± 8.48	22.56 ± 4.66

a. BMI = Body Mass Index.

Two types of trials were administered: congruent and incongruent. On congruent trials, all five fish in the stimulus array pointed in the same direction. On incongruent trials, the center fish pointed in a position independent of the other four fish (See **Figure 1**). The center fish was the target and the direction it was facing determines correct response: pressing a right arrow for right facing and a left arrow for the left facing. The child was given feedback based on the time and accuracy (ACC) of response. A tone was given on an error and reason for error was flashed on the screen Directions were printed on the computer screen, additionally researcher again explained verbally and with gestures. Gestures primarily included pointing and nodding for visual feedback

An 18-inch laptop was used for all computerized tests, and interaction with the keyboard was limited to use of the "<" and ">" keys. Yellow stickers with a black arrow pointing left and right was placed on the "<" and ">" keys, respectively, to provide additional feedback.

2.4. Measures

2.4.1. Response Time

Response time (RT) of the Flanker task was collected in milliseconds. Trials with response times shorter than 250 ms were eliminated as the response time was faster than reaction time, which indicates an anticipatory response. Those longer than 1500 ms were also removed due to the likelihood of influence of other confounding variables such as distraction, resulted in participants not focused on task. Change was defined as an increase of more than 25 ms from baseline.

2.4.2. Accuracy

Accuracy of the Flanker task was counted as the number of trials correctly identified as 1) overall number correct, 2) number of congruent correct, and 3) number of incongruent correct. Change was defined as an increase of more than 3 correct from baseline.

2.5. Procedures

After parents completed SRS-2 to confirm eligibility, all participants came to an initial session where they performed the Berg card sorting task determine eligibility. After these tests, participants played the videogames for approximately 10 minutes per game to become familiar with them prior to data collection. At the second session, the MABC-2 was administered, and after a five-minute rest period, a baseline Flanker test was collected. In sessions 3 - 5, each participant per-

formed one of the conditions in a randomized order. They performed 2O minutes of each condition followed by a 10-minute sitting rest period. A posttest Flanker was administered after each session. For the walking condition, participants walked back and forth along a designated 50-foot pathway. The researcher paced the participant at 4.5 METS using a stopwatch.

2.6. Statistical Analysis

First, we calculated descriptive statistics on the raw scores in order to visualize the data. Next, we calculated change scores for each participant within each condition by subtracting the pre-test score from the condition scores. We then performed a series of Chi Squared analyses to compare between groups and conditions. All statistical analyses were performed using JASP version 0.16 using alpha = 0.05.

3. Results

3.1. Descriptive Statistics

Table 2 contains reaction time means and standard deviations and Table 3 contains the accuracy results for both groups.

3.2. Chi Square Analyses

3.2.1. Comparisons between Groups

First, we wanted to determine if the groups differed in the conditions where participants had the greatest percentage of change from pre-test. We compared

Table 2. Means and standard deviations of reaction time for ASD and TD in each condition.

Condition	ASD (M ± SD)	TD (M ± SD)
PRE	804.65 ± 207.6	661.71 ± 162.8
SVG	606.33 ± 102.5	745.81 ± 180.8
AVG	746.42 ± 222.6	745.78 ± 189.9
WLK	698.09 ± 120.5	725.83 ± 164.6

PRE = Pretest, SVG = Sedentary videogame, AVG = Active Videogame, WLK = Walking. Reaction time is in ms; lower values represent faster times.

Table 3. Means and standard deviations of accuracy for ASD and TD in each condition.

Condition	ASD (M ± SD)	TD (M ± SD)
PRE	103.36 ± 20.7	115.40 ± 3.84
SVG	109.89 ± 9.5	114.00 ± 4.64
AVG	105.00 ± 21.69	113.33 ± 5.4
WLK	110.00 ± 14.0	114.8 ± 5.5

PRE = Pretest, SVG = Sedentary videogame, AVG = Active Videogame, WLK = Walking. Accuracy is in (units); higher values represent greater accuracy.

change scores for each participant across conditions to determine the percentage of participants performing best within each category, then compared these percentages using Chi Squared analyses. We found significant differences between groups in both RT ($X^2(2, 18) = 18.33$, $p < 0.001$; Figure 2) and ACC ($X^2(2, 18) = 8.42$, $p = 0.015$; Figure 3), indicating that differences in the percentages of improvement in each condition within each group.

3.2.2. Congruent vs. Incongruent within Each Condition

For the next analyses, we focused exclusively on the ASD group. We wanted to see if the percentage of trials showing improvement differed based on type (congruent or incongruent) within a condition in each group. For the AVG condition, there were no significant differences percentage of improvement in congruent vs incongruent trials in RT ($X^2(1, 18) = 1.44$, $p > 0.05$). However, there was a significant difference in ACC ($X^2(1, 18) = 19.36$, $p < 0.0001$; see Figure 4.

For the SVG condition, both RT and ACC were significant. A significant difference existed in RT ($X^2(1, 18) = 19.36$, $p < 0.0001$) and in ACC ($X^2(1, 18) = 11.56$, $p < 0.0001$ (Figure 5).

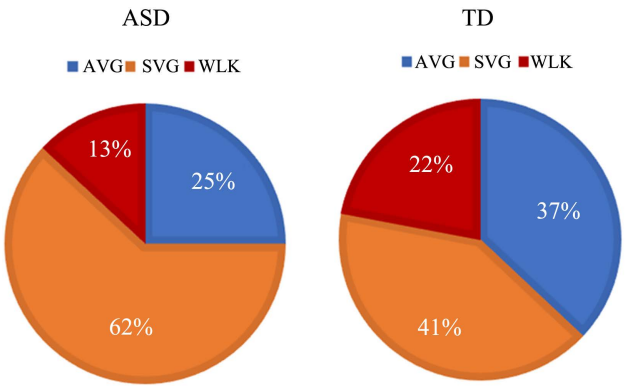

Figure 2. Percentage of participants who had a greatest improvement in RT within each condition for ASD and TD groups. Chi Square analysis indicated the percentages were significantly different between the groups ($p < 0.001$).

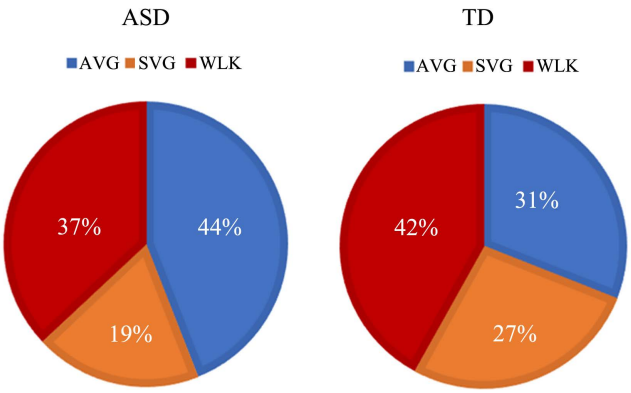

Figure 3. Percentage of participants who had a greatest improvement in accuracy within each condition for ASD and TD groups. Chi Square analysis indicated the percentages were significantly different between the groups ($p = 0.015$).

In the WLK condition, a significant difference existed in RT ($X^2(1, 18) = 31.36$, $p < 0.0001$), but not in ACC ($X^2(1, 18) = 1.31$, $p > 0.05$; see Figure 6).

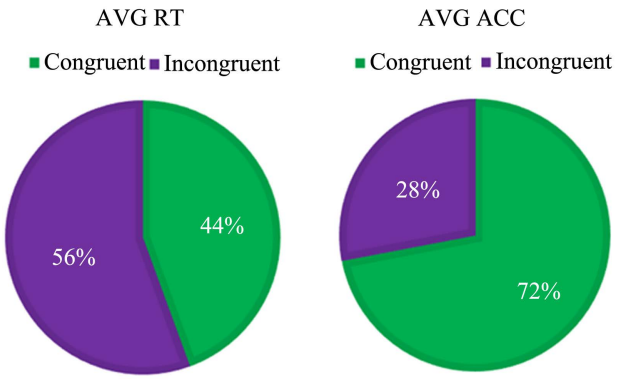

Figure 4. Pie charts of the distribution of RT and ACC improvement in the Active Video gaming (AVG) condition in the ASD group. Chi Square analyses indicated that the percent improving on RT did not differ in RT but was significantly different in ACC ($p < 0.0001$).

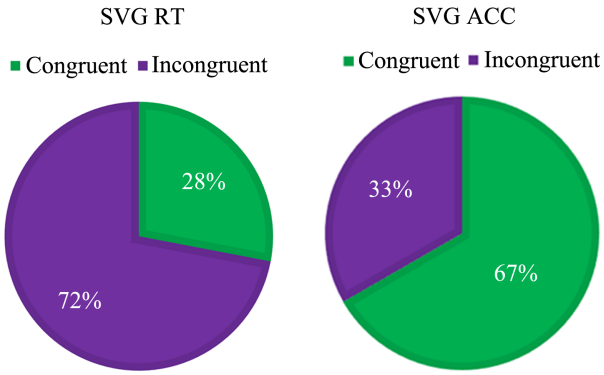

Figure 5. Pie charts of the distribution of RT and ACC improvement in the Sedentary Video gaming (SVG) condition in in the ASD group. In the SVG condition, a significant difference existed in RT ($X^2(1, 18) = 100$, $p < 0.0001$) and in ACC ($X^2(1,18) = 11.56$, $p < 0.0001$.

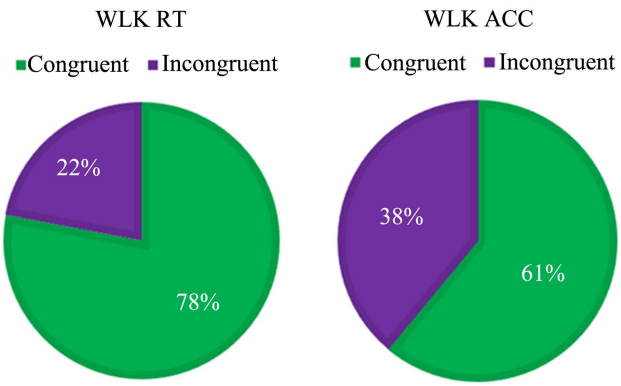

Figure 6. Pie charts of the distribution of RT and ACC improvement in the Walking condition in the ASD group. In the WLK condition, significant difference existed in RT ($X^2(1, 18) = 31.36$, $p < 0.0001$), but not in ACC ($X^2(1,18) = 1.31$, $p > 0.05$).

4. Discussion

The purpose of this study was to examine the effects of Xbox Kinect AVGs on EF in boys with and without ASD. We compared the performance of an inhibition task, the Flanker test, after three types of activities: AVG, SVG, and walking. Reaction time (RT) and accuracy (ACC) of the Flanker test were used to measure response inhibition. The effect of incongruent stimulus was also examined.

The results showed a trend of improvement in RT and ACC in ASD group, whereas there were no obvious changes of the Flanker test performance in TD group. SVG has been found to improve reaction time in an alphabet and numbers task in children with ASD but not TD group [54]. This might account for the absence of similar responses between children with and without ASD in the Flanker test.

The study found that types of activity affect children with ASD and TD differently. More than half of the participants with ASD had their best improvement in SVG. There was only about 40% of participants in TD groups had their best improvement in SVG. Nonetheless, there was more participants had improvement in SVG compared to AVG and Walk conditions in TD group. While a significant difference in the percentages of improvement in each condition within each group, both groups had most participants had their best improvement in SVG, and least participants had their best improvement in RT in walking condition.

Research has shown that moderate activity improves reaction time due to changes in arousal level [55]. Moderate activity increases arousal level and hence facilitates information processing speed, results in a faster reaction time. Studies also found that playing video games improves cognitive functions including visual skills and selective attention [56]. Children who were exposed to video games had a faster reaction time [57] [58]. Video game experience also increases efficiency of sensory information processing and improves probabilistic inference [59]. These results are consistent with our finding that most participants in both ASD and TD groups had a best improvement of RT in SVG conditions.

The trend of difference between groups showed in the improvement of RT was not observed in the improvement of accuracy. Forty-four percent of participants with ASD had their best improvement of accuracy in AVG condition, which was greater than the other two conditions. However, most participants in TD group had their best improvement of accuracy in Walk condition rather than AVG, as observed in ASD group. Both reaction time and accuracy are commonly used measures in cognitive tests. Changes in reaction time after exercise appeared to depend on the intensity of activity. However, exercise intensity appeared to have little effect on changes in accuracy of cognitive tests [60]. This may explain why the results of accuracy in our study was less consistent compared the changes in response time.

In ASD group, participants had improvement of ACC in more congruent trials compared to incongruent trials in both SVG and AVG. However, the im-

provement of RT was observed in more congruent trials in WLK alone. Studies have shown that reaction time of flanker test improved after moderate exercise [61]. The improvement was not dependent on the type of tasks (congruent or incongruent). The finding might explain why there is no consistent trend in the improvement of RT based on the type of task (congruent vs. incongruent).

There were some limitations in the current study. The sample size was small with a total of 18 participants. Only children between 8 to 11 years old were included in the study. Both factors limit interpretation and application of the results. In addition, the effects of severity of ASD and screen time of the participants were not addressed, which may have impacted the results of current study.

5. Conclusion

In our exploratory research, children with and without ASD responded differently on the Flanker test following a short intervention of sedentary Video gaming, active video gaming, and walking. Both groups improved reaction time the most after the SVG condition; however, the ASD group showed the greatest accuracy improvement after the AVG condition, whereas the TD group showed greater improvement after the WLK condition. When comparing improvement, specifically in the more challenging incongruent task, there appeared to be a speed-accuracy trade-off, where improvements in RT were matched with deterioration in ACC.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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