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**ORIGINAL ARTICLE**

# Atypical Gaze Behavior in Children with High Functioning Autism During an Active Balance Task

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## ABSTRACT

**Background.** Unusual gaze behavior in children with autism spectrum disorder (ASD) was reported very early in the literature. **Objectives.** The current study examined gaze behavior in children with ASD and typically developing (TD) children while performing an active balance task on the Wii balance board. **Methods.** 8 children (male) diagnosed with high-functioning ASD and 9 TD children (3 female, 6 male) were recruited for the study. Eye movements were recorded at 60 Hz during the soccer game on Wii balance board. **Results.** There was no significant difference in the game scores between the two groups ($p > 0.05$). However, evidence indicates differences in gaze behavior, particularly total fixation durations on the main area of interest (center AOI) ($p < 0.05$). While performing the active balance task, children with ASD spent less time looking at the center of the screen than typically developing children. Shorter fixation durations in ASD compared to the TD group could indicate how our ASD group had enhanced perceptual processing. The second possibility for shorter total fixation duration in ASD is that they are more scattered in their fixations. **Conclusion.** Shorter fixation durations in children with ASD while performing the active balance task could be because of enhanced perceptual processing or a deficiency in their ability to plan. However, no advantage or disadvantage was observed in the Wii-fit game's performance.

**KEYWORDS:** ***Autism, Gaze, Eye-Tracking, Motor Control, High-Functioning, Children, Vision, Motor-Development, Balance, Perception.***

## INTRODUCTION

Unusual gaze behavior in children with Autism Spectrum Disorder (ASD) was reported very early in the literature (1). This feature was considered fundamental to the disorder and is consistent with a more general pattern of unusual responsiveness to sensory stimulation (1).

Consistent with previous reports, recent work has repeatedly shown atypical visual-spatial perception associated with ASD by enhancing performance on various experimental tasks (2). In particular, individuals with ASD have been shown to excel at the embedded figures test (EFT) (3). EFT is a visual search task that involves identifying a target item among an array of distractors and responding with a quick action indicating whether the target is present or not. Although superior EFT performance in ASD is well replicated, the underlying mechanisms remain uncertain.

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According to the Weak Central Coherence (WCC) theory, individuals with ASD have a local processing bias that impedes the processing of global features and thus fails to integrate parts to form a global whole (3). Alternatively, one study proposed that enhanced perceptual functioning in ASD accelerates their EFT performance compared to that in typically developing (TD) children (4). Keehn and colleagues examined gaze variables such as fixation frequency and fixation duration during an EFT in ASD and TD children. Even though children with ASD displayed a superior performance and significantly different fixation durations, their findings did not offer support for either WCC or EPF models (5). Several questions remain. Among the most central is how these atypicalities in gaze in ASD contribute to superior performance in EFT.

This pattern of superior performance in ASD in certain tasks may not be advantageous in other tasks, such as motor skills. With the trend toward conceptualizing Autism as a cognitive, social disorder, and a movement disorder, the role of atypical eye gaze in motor abnormalities in children with ASD has been substantiated by an increasing body of research. Using standardized tests such as Movement Assessment Battery for Children (M-ABC), clinicians and researchers have shown deficits in a broad range of movement abilities across the Autism Spectrum (6–8). Notable impairments were observed in the sub-category of 'ball skills'(6, 7, 9, 10). Difficulties in performing ball skills among children with ASD may involve impairments in visual perception-action coupling due to atypical eye gaze observed in Autism. (11). Perception-action coupling in this context can be described as the relationship between the perception of spatial and temporal characteristics of a moving ball and the control of moving limbs to intercept the ball successfully. Deficits with perception-action coupling may lead to difficulty with the spatial-temporal control of movement, particularly movements that require coupling onto externally imposed spatial and temporal constraints, such as intercepting a moving ball. A limitation of these studies related to motor issues in ASD is that existing data preclude firm conclusions about the exact role of gaze abnormalities.

This study aimed to characterize gaze behavior in children with ASD and TD while performing an active balance task (Wii Fit soccer game) using Wii Fit balance board. Performing a motor skill on Wii balance board is conducive to using eye-tracking technology to record various gaze variables. Wii Fit games (basic balance test and soccer heading game) have been reported to relate to functional health measures. The Wii balance board used to play Wii Fit games has been determined to be a comparable measure of the static center of pressure. A study implemented with fitness-based video games on the Wii balance board showed that adolescents with ASD expended more energy than age-matched typically developing children (12). Another study using the Wii fit with a randomized control design showed significant fitness gains across the Autistic spectrum (13). Even in other pediatric groups, such as cerebral palsy Wii gaming led to improved postural stability (14), suggesting that video game-based training is a key area to explore. Balance challenges in children diagnosed with ASD were also improved by using Wii Fit (15). Another advantage of using the Wii fit with children with ASD is that children with ASD are drawn to screen-based media such as video games (16). Hence, we used Wii Fit in our study to investigate gaze behavior in children with ASD.

We hypothesized that: The performance on Wii Fit soccer games will be significantly lower in children with ASD compared to typically developing children because children with Autism cannot adapt the temporal characteristics of their movement to conform to external spatial constraints. Gaze variables Fixation duration, fixation count, time to the first fixation, and first fixation duration will be significantly different in children with ASD compared to typically developing children while performing the active balance task.

## MATERIALS AND METHODS

**Participants.** Eight children (male) diagnosed with high-functioning ASD with an average age of 14±1.6 years were recruited from the Center for Autism Spectrum Disorders at Southern Illinois University (SIU) Carbondale. Children with high-functioning Autism recruited for our study were highly verbal and had an IQ of 85 or higher. We used these inclusion criteria because it was important that the participants could follow instructions to use the Wii balance board to play Wii soccer games. Children received a diagnosis of Autism before they were admitted to any intervention at the center.

Parents of children receiving therapy were referred to our study by the therapists at the center.

Nine typically developing children (3 female, 6 male) with an average age of 13±1 years) and no neurological disorders were recruited by posting fliers on SIU Carbondale campus.

**Protocol.** Before data collection, all parents signed informed consent, and the child's assent was obtained using a minor assent form. These forms were approved by SIU Carbondale human subjects committee. The study was performed under the ethical standards of the 1975 Declaration of Helsinki. After receiving the parent's consent and the child's assent to participate in the study, subjects were given instructions for participation.

Subjects were familiarized with the soccer heading game on Wii Balance Board. The game requires the participant to adapt the temporal characteristics of their movement to external spatial constraints. Like 'ball skills,' the soccer game in WiiFit requires the participants to intercept soccer balls. The participants performed this task by controlling an on-screen avatar via their lower body center of pressure (COP) postural adjustments on the balance board. The participants were required to successfully couple their movements, i.e., on-screen avatar, onto externally imposed spatial and temporal constraints, i.e., soccer balls. Subjects received points by successfully intercepting and heading a soccer ball while dodging distracting objects. Instructions to all subjects included fixating vision on the center of the screen and adjusting posture via the lower body to control the on-screen avatar. Subjects performed a practice trial followed by three experimental trials. Each trial lasted for about 3 minutes. They received adequate rest between the trials (17).

To assess visual perception, we examined gaze metrics via an eye tracker in the two groups (ASD and TD) while they performed the task. They were fitted with an eye tracking device (Tobii Pro glasses) before performing the task using the Wii balance board. Eye movements were recorded at 60 Hz during the soccer game. The eye tracking system consists of a pair of glasses with 2 cameras per eye, a gyroscope, an accelerometer to track head movement, and a full HD wide-angle scene out camera. Due to the robust setup, the system records the gaze point of interest with outstanding precision with minimum gaze data loss. Tobii Pro Glasses were calibrated for each participant to collect accurate eye tracking data. During the calibration process, the participant must wear the head unit while focusing on the center of the calibration target. The calibration target is printed on the supplied calibration cards and calibration stickers. Animated graphics illustrate the progress of the calibration process.

**Analysis**. The recordings are made with scene out camera in the eye tracker while the participants perform the video game task used for analysis. A still image from the recording, known as a snapshot, is used to identify areas of interest (AOI) and obtain metrics. Recordings from the eye tracker are mapped onto a snapshot through the automatic mapping function available when replaying the recording. AOIs enable numerical and statistical analysis based on regions of interest in the recording. Several AOIs were created on the snapshot (see Figure 1), and the video recording data were mapped onto the snapshot to export using Tobii Pro lab software. The export file contained data on whether the subject's gaze point was inside or outside the AOIs. The software provided metrics based on AOIs for further analysis: fixation duration, fixation count, time to the first fixation, and first fixation duration. Since the participants were instructed to fixate on the center of the screen during the game, we analyzed fixation duration, count, time to the first fixation, and first fixation for the central AOI for typically developing and high-functioning children with Autism. A 4 (Group: Typically Developing Children vs. Children with ASD) x 3 (Trial: 1$^{st}$ vs. 2$^{nd}$ vs. 3$^{rd}$) mixed-design was used, with the group varying between participants and the trial varying within participants. Wii soccer game scores served as a dependent variable, as were three eye gaze metrics from the center AOI: Total visit duration, total visit count, and first fixation duration.

## RESULTS

Mean visit duration, total visit count, first fixation duration, and Wii soccer game scores were calculated for each participant and trial. These means were submitted to separate 2 (Group: Typically Developing Children vs. Children with ASD) x 3 (Trial: 1$^{st}$ vs. 2$^{nd}$ vs. 3$^{rd}$) mixed-design ANOVAs. An alpha level of .05 was adopted for all statistical tests. For performance on the Wii soccer game, neither the Group x Trial interaction (see Figure 2) nor the

main effect of the group was significant (both *F*s < 1). However, a marginally significant main effect of trial was found, $F(2, 30) = 2.80$, $MSE = 228.87$, $p = 0.08$. Post hoc tests revealed that performance was significantly better in trial 2 ($M = 64.3$, $SD = 70.4$) than trial 1 ($M = 44.5$, $SD = 39.2$), but neither was different than trial 3 (see Figure 2). With the total visit duration data, the Group x Trial interaction was not significant, $F(2, 30) = 1.34$, $MSE = 53.13$, $p > 0.27$ (see Figure 3), nor was the main effect of trial, $F < 1$. Critically, however, a significant main effect of group was found, $F(1, 15) = 5.14$, $MSE = 228.87$, $p < 0.05$, $\eta^2_p = .26$, with the ASD group ($M = 45.1$ s, $SD = 8.7$) spending less time fixated in the center AOI than the group of typically developing children ($M = 54.7$ s, $SD = 8.7$) (see Figure 3). For total visit count, the Group x Trial interaction, $F(2, 30) = 1.51$, $MSE = 371.0$, $p > 0.23$, was not significant, nor were the main effects of trial, $F(2, 30) = 2.03$, $MSE = 371.0$, $p > 0.14$, or group, $F < 1$ (see Figure 4). This same pattern was found with the first fixation duration data ($F[2, 24] = 1.34$, $MSE = 0.17$, $p > .28$; $F[2, 24] = 1.25$, $MSE = 0.17$, $p > 0.30$; and $F < 1$, for the Group x Trial interaction, main of effect of trial, and main effect of group, respectively) (see Figure 5).

These results demonstrate that while overall performance on the soccer task was comparable between the two groups of children, an important difference was found in the eye gaze behavior of each group. Specifically, children with ASD spent significantly less time fixated on the center AOI than typically developing children across all three task trials.

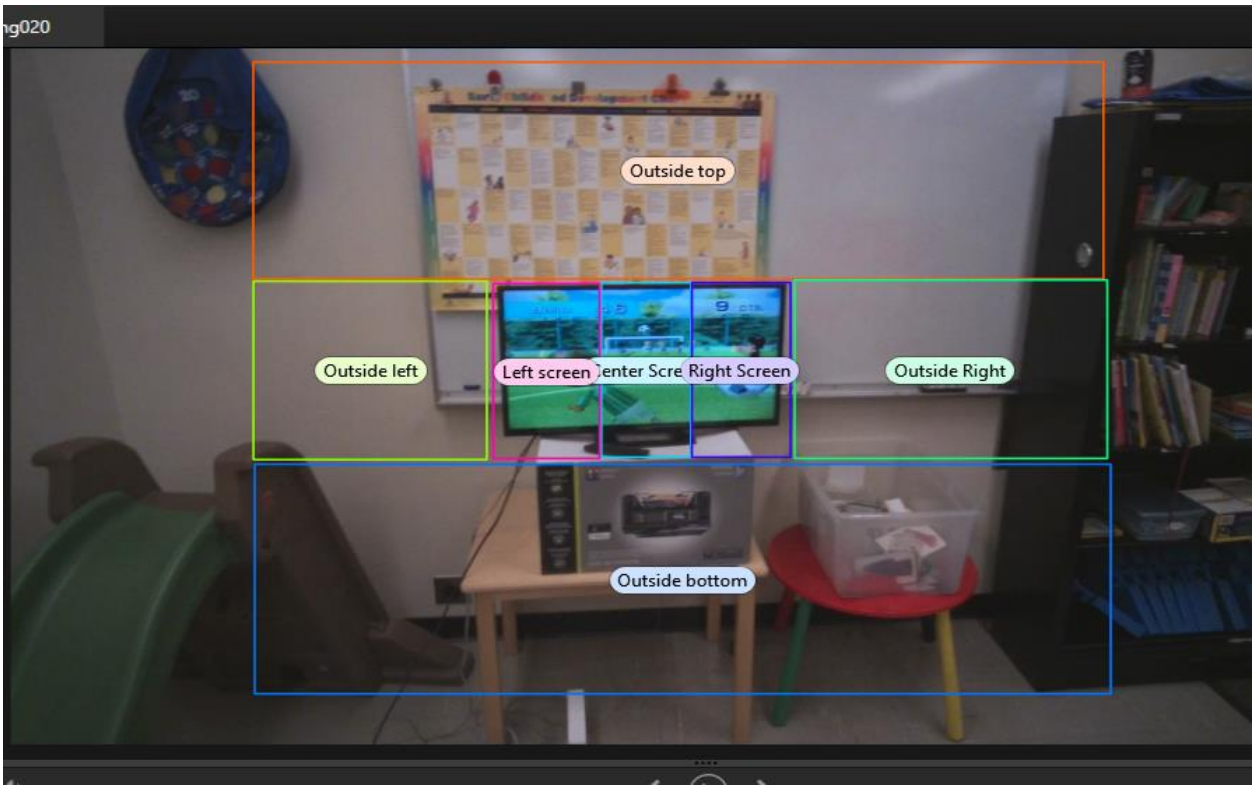


**Figure 1.** Example of AOIs created in a snapshot of the video recording used to map eye-tracking data and determine various fixation variables.

## DISCUSSION

The purpose of this study was to record gaze behavior in children with ASD and TD children during an active balance task to examine the hypothesis that kids with ASD will display atypical gaze behavior. We also hypothesized that kids with ASD will underperform in the Wii Fit game. For this purpose, we used an active balance task on Wii balance board that requires the participant to adapt the temporal characteristics of their movement to the external spatial constraints. We used eye-tracking technology to examine visual attention in participants while performing the active balance task. There was no significant

difference in the game scores between the two groups. However, evidence indicates differences in gaze behavior, particularly total fixation durations on the main area of interest (center AOI). While performing the active balance task, children with ASD spent relatively less time looking at the center of the screen than typically developing children.

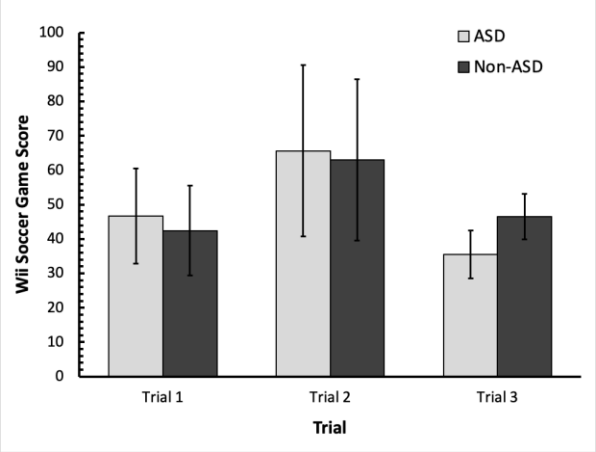


**Figure 2.** Mean soccer game scores for trials 1, 2, and 3 for ASD and TD groups.

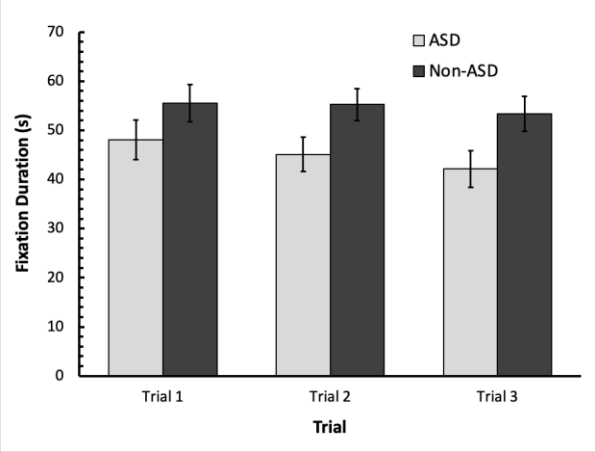


**Figure 3.** Mean fixation duration at center AOI for trials 1, 2, and 3 for ASD and TD groups.

Even though the total fixation duration at the center AOI in ASD was shorter than that in the TD group, no differences were observed in other gaze variables, such as time to first fixation and total fixation count. Two possible reasons could potentially explain shorter fixation durations in kids with ASD.

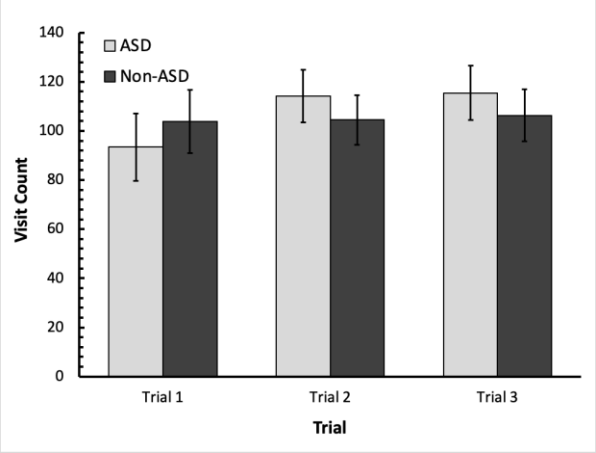


**Figure 4.** Mean gaze visit count for trials 1, 2 and 3 for ASD and TD groups.

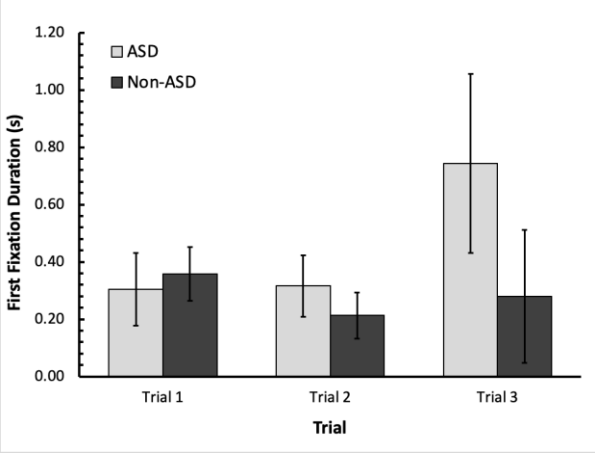


**Figure 5.** Mean first fixation count for trials 1,2 and 3 for ASD and TD groups.

First, shorter fixation durations in ASD compared to the TD group could indicate how our ASD group had enhanced perceptual processing. Enhanced perceptual processing in ASD has been exemplified in numerous studies involving visual search tasks such as embedded figures tests (3). A visual search task involves looking for a target item among an array of distractors and responding with a quick action indicating whether the target is present or not. In the current study, the visually driven task is more dynamic. It involves perceiving a moving target and responding with quick postural adjustments. In the weak central coherence (WCC) theory proposed by Happe and Firth, individuals with ASD outperform TD individuals in visual search tasks due to differences in processing style (3). In ASD, there is a processing bias toward local elements failing to integrate parts to extract global meaning. The

superior performance of ASD in visual search tasks such as embedded figures tests is a consequence of this local processing bias. Another model proposed by Mottron and colleagues titled "Enhanced Perceptual Functioning" suggests increased perceptual functioning in ASD results from superior low-level perceptual processing (4). Therefore, this model does not support deficits in global processing in ASD but an enhanced perception of local parts leading to shorter fixation durations in visual search tasks. It is consistent with previous studies that reported shorter fixation durations in individuals with ASD while performing visual search tasks such as the Embedded Figures Test (5, 18). Keehn and colleagues reported superior performance in the Embedded Figures Test in children with ASD arises from processing bias toward local information and enhanced perceptual functioning particularly superior low-level perceptual processes (5). Shorter fixation durations in ASD were observed even when the nature of the visual search task was varied. Joseph and colleagues compared reaction times and gaze variables in children with ASD and TD children for a standard static search task and a dynamic search task. Children with ASD exhibited faster reaction times and shorter fixation durations, suggesting enhanced perceptual processing in static and dynamic search tasks (18).

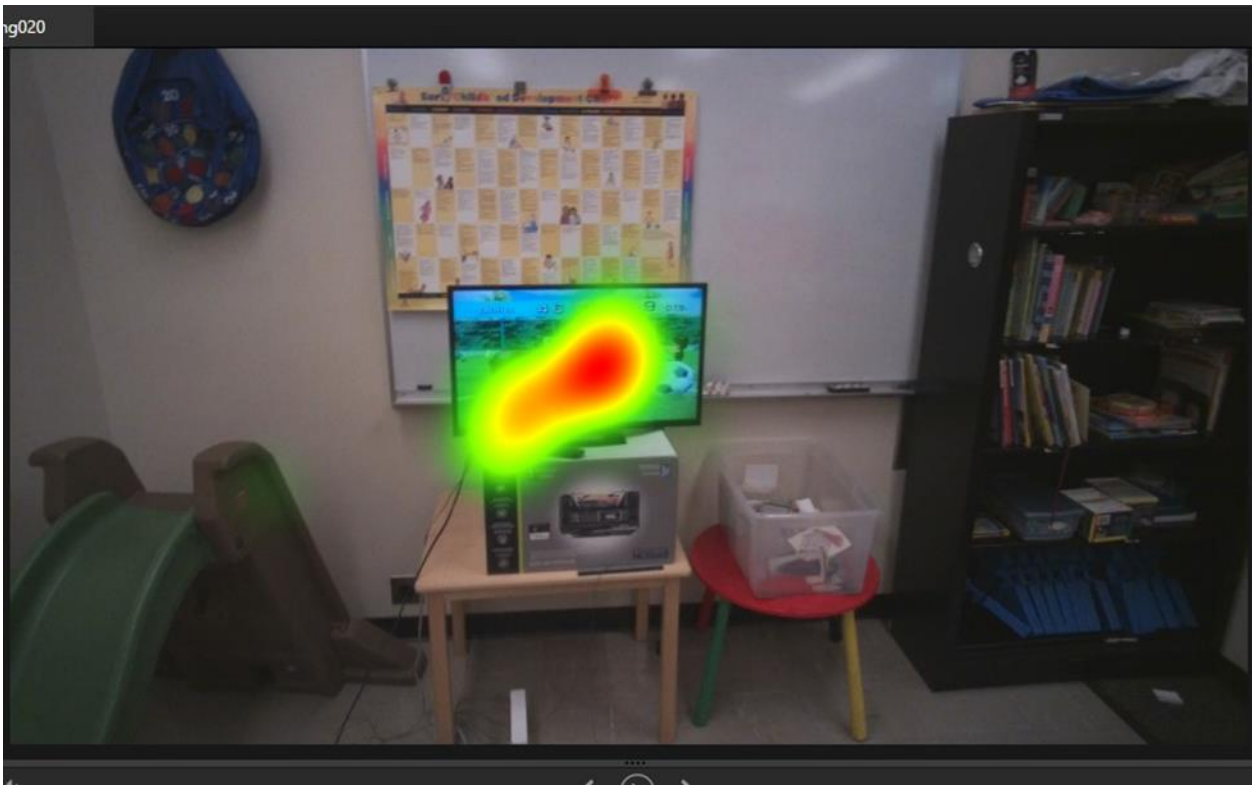


**Figure 6.** Sample heat map of a child with ASD

The dynamic search task used in this previous study (18) is comparable to the visually driven Wii fit game used in our current study. Eye-movement analysis from our current study also indicates shorter fixation durations in ASD compared to TD. We also did not find any significant differences in other gaze variables, such as total fixation count at the center AOI for ASD and TD groups. Thus, our results are consistent with prior evidence reported by Joseph and colleagues (18). It is indicative of the possibility that enhanced perceptual processing in ASD underlies shorter fixation durations while playing Wii Fit soccer game.

The second possibility for shorter total fixation duration in ASD is that they are more scattered in their fixations, as seen in sample figure 6 (sample heat map of ASD). TD kids focused very much on the center AOI (see Figure 7, sample heat map for TD), while the children with ASD looked elsewhere. Several studies have found evidence that children with ASD lack a plan for what to look at next. For instance, von Hofsten and colleagues presented a videotaped conversation with

preschool children with ASD and TD children (19). Children with ASD had shorter fixation durations on the speakers and did not predict the onset of the next turn in the conversation. It seemed like the scattered fixation pattern observed in children with ASD is not just because of their aversion to faces (20) or enhanced perceptual processing (5) but rather a deficiency in their ability to plan where to look. However, the differences in fixation durations between children with ASD and TD children became insignificant when the speakers in the video were replaced by objects that alternated sounds while moving up and down (19). Children with ASD fixated on the moving objects in the video, like TD children. Therefore, they concluded that the social component of conversation in the video likely caused scattered fixations in ASD. Since our study did not involve social interactions, it becomes difficult to interpret scattered fixations and shorter fixation durations in ASD in this context. One way to address this difference in fixation duration at the center of AOI is by looking into previous studies that examined the orienting network of attention in ASD (21, 22). Landry and Bryson report that children with ASD were less likely to rapidly shift attention from central to peripheral stimulus and vice versa (22). Since the task in the current study involves rapidly shifting attention between the center and periphery of the screen, children with ASD must have had difficulty shifting attention between the two areas of interest.

**Figure 7.** Sample heat map of a TD child from the study.

Whether shorter fixation durations were because of enhanced perceptual processing or a deficiency in their ability to plan, there was no advantage or disadvantage observed in the performance of the Wii-fit game. Kids with ASD and TD children showed no significant differences in game scores. However, previous studies have presented evidence for significant motor dysfunctions in children with ASD (8, 23). For instance, Green and colleagues tested children with ASD using a prominent motor test for children called the Movement ABC (MABC-2). Results showed that children with ASD had significant difficulties performing everyday actions such as throwing and catching an object, standing on one leg, and walking in a line (8). Siaperas and colleagues used MABC-2 in a large group of boys with ASD and TD groups between the ages of 7 and 14. Difficulty in movement tasks that involve timing and accuracy stood out in

ASD group (23). They also observed deficits with balance in ASD when children were asked to stand on one leg with open and closed eyes. Although several studies have identified deficits in the control of action in children with ASD, there is still no clear indication of the specific problems. Did the kids with ASD in our study have problems with action control? Does having enhanced perceptual processing in ASD help them compensate for deficits in action control and maintain similar Wii-fit game scores as TD children? It can be addressed by measuring kinematics and kinetics in sync with eye tracking.

Our preliminary study has several limitations that should be addressed in future research. Due to the explorative nature of this preliminary study, we did not use motion capture technology to record the kinematics of motor skill performance. Using motion capture and force plate synchronized with an eye tracking device could indicate perceptual and motor dysfunctions in children with ASD. In future studies, we would also like to investigate executive functioning in children with autism spectrum disorder. It has been reported in the current autism literature that there is a relationship between executive functions and sensory processing in children with autism spectrum disorder (24, 25). Another limitation of our study is the small sample size which limits the generalizability of our results. Lastly, our ASD group only comprised males, whereas the TD children group comprised males and females. Therefore, the lack of gender variation in ASD group should be addressed in future studies.

## CONCLUSION

Our results demonstrate no significant difference in the performance outcome of the active balance task between the two groups, albeit evidence indicates differences in gaze behavior, particularly total fixation durations on the main area of interest (center AOI). While performing the active balance task, children with ASD spent relatively less time looking at the center of the screen than typically developing children. Shorter fixation durations in ASD compared to the TD group could indicate how our ASD group had enhanced perceptual processing. It may indicate the processing bias according to WCC theory and may also be considered as evidence for EPF model. Shorter fixation duration in ASD may also indicate that they are more scattered in their fixations, as seen in the sample heat map of ASD. Children with ASD displayed no advantage or disadvantage in their motor skill performance, as observed in the soccer game scores, regardless of shorter fixation durations. Further research using motion capture and eye tracking may provide stronger support for WCC or EPF models.

## APPLICABLE REMARKS

- Gaze behavior in children with Autism is atypical and is likely to affect early-life development and social learning.
- Characterizing gaze behavior using quantifiable variables could pave the way for newer behavioral therapies.

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## AUTHORS' CONTRIBUTIONS

Study concept and design: Venkata Naga Pradeep Ambati. Acquisition of data: Venkata Naga Pradeep Ambati. Analysis and interpretation of data: Venkata Naga Pradeep Ambati, Jason Reimer, Fabricio Saucedo. Drafting the manuscript: Venkata Naga Pradeep Ambati, Jason Reimer, Guillermo Escalante, Fabricio Saucedo. Critical revision of the manuscript for important intellectual content: Venkata Naga Pradeep, Jason Reimer, Guillermo Escalante, Fabricio Saucedo. Statistical analysis: Venkata Naga Pradeep Ambati, Jason Reimer. Administrative, technical, and material support: Venkata Naga Pradeep. Study supervision: Venkata Naga Pradeep Ambati.

## CONFLICT OF INTEREST

The authors mention that there is no "Conflict of Interest" in this study.

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