Effects of Visual Cluttering in Virtual Reality on Visuomotor Integration in Autistic Individuals

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ABSTRACT

Goal-directed throwing is ubiquitous in virtual reality (VR) games, demanding spatial and temporal accuracy to perceive position and motion, as well as to plan, and execute movement. Autistic individuals often show superior local visual sensitivity, which may paradoxically delay global visual processing, leading to incongruent visuomotor integration (VMI). Understanding VMI in VR and exploring supportive designs are vital for enhancing accessibility. We assessed VMI in VR with different levels of visual cluttering with autistic (n = 10) and non-autistic (n = 10) adults using overhand throwing with eye and hand tracking, comparing VR to identical physical environments and VR to visually simplified VR. In VR, all participants exhibited decreased throwing accuracy, increased visual scanning, and prolonged hand preparation phases. These differences were more significant in autistic individuals. However, our study highlighted an important effect: simplifying visual information in VR throwing resulted in autistic individuals outperforming non-autistic peers.

CCS CONCEPTS

• **Human-centered computing** → **HCI design and evaluation methods**; **Empirical studies in accessibility**; • **Computing methodologies** → **Virtual reality**.

KEYWORDS

Eye tracking, visual behavior, visuomotor integration, virtual reality

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1 INTRODUCTION

In both the physical environment (PE) and virtual reality (VR), visuomotor integration (VMI) is crucial for effective motor execution. VMI relies on co-registered visual and proprioceptive information [Palmer et al. 2017] in the same spatial-temporal window [Murray et al. 2016] with the corresponding motor output [Baldassarre et al. 2018]. However, individuals with autism often show incongruent VMI during movement [Mache and Todd 2016]. Autism is a prevalent neurodevelopmental disorder that affects 1 in 45 children [Maenner et al. 2021] and adults [Dietz et al. 2020] in the United States. As compared to non-autistic peers, autistic children aged 8-13 years have significantly lower scores in standardized tests of common ball skills [Ament et al. 2015], which demands concurrent VMI. Individuals with higher throwing accuracy search for task-relevant visual information more efficiently than their less-skilled counterparts [Williams et al. 2004]. Autistic individuals often have superior low-level visual sensitivity [Kovarski et al. 2019] and frequently notice features that are overlooked by others but may struggle to filter out task-irrelevant visual information [Townsend et al. 1996][Wilson et al. 2018], resulting in delays in perceiving global motion stimuli [Spencer et al. 2000] and integrating visual information into movement execution [Morris et al. 2015]. VR may naturally be supportive for VMI in autistic individuals because visual information can be rapidly manipulated to reduce clutter. However, there is a lack of systematic study on the way that real-world VMI impacts the use of VR by autistic individuals. In the current study, we used overhand throwing with eye and hand movement tracking to evaluate the real-time VMI process and the impact of visual clutter on VMI in VR. The insights gained may inform future designs of accessible and supportive VR environments for autistic individuals.

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2 RELATED WORK

2.1 Visuomotor Integration and Overhand Throwing Performance in VR

Visual information in VR may impact VMI processes and overhand throwing performance. Non-autistic adults showed reduced overhand ball-throwing accuracy in VR and presented uncertainty during the throw preparation phase, revealed as increased hand release velocity with higher variance [Butkus and Čeponis 2019]. Kinematic patterns during dart-throwing in VR are altered in non-autistic individuals as compared to PE, shown as less elbow extension and lower throwing velocities [Drew et al. 2020].

Little research exists on VMI performance and throwing accuracy in autistic individuals. Lauretti et al. 2021 evaluated the kinematic patterns of autistic individuals with an overhand ball-throwing task in PE with varying goal distances. Autistic participants demonstrated lower success rates as compared to matched control peers, exhibiting atypically consistent kinematic patterns across all throwing distances. In VR, Arthur et al. 2021 used a racquetball paradigm to systematically vary environmental volatility over time and showed that autistic individuals had difficulties in interpreting visual information from the ball motion, as evidenced by movement and gaze strategies that are irrespective of the ball movement. Rane et al. 2023 evaluated eye and hand movements during a virtual dart-throwing task using a flatscreen display system. Autistic participants exhibited larger endpoint errors, shorter proportions of fixation durations toward the target, and reduced quiet-eye duration (i.e., the last fixation on the target prior to the initiation of the movement [Vickers 2000]). Longer quiet eye duration is positively correlated to overhand throwing performance [Vine et al. 2014].

2.2 Visual Clutter and Visuomotor Integration Challenges in Autism

Autistic visual information processing appears to be intact or enhanced with local visual sensitivity driven by visual details in the environment [Morris et al. 2015]. However, inefficient filtering of task-irrelevant visual information [Mottron et al. 2006] may lead to inferior performance in dynamic VMI tasks [Bertone et al. 2005]. Reducing visual clutter in may support global-level visual information processing in autistic individuals. Visual clutter refers to the presence of excessive items, and/or their representation or organization (e.g., color, light, and texture), which can degrade visual processing performance [Rosenholtz et al. 2007]. Visually cluttered home and classroom environments can cause anxiety, poorer learning outcomes and more off-task behavior in autistic children [Fisher et al. 2014][Kahveci et al. 2024]. Reducing visual clutter in VR classrooms for autistic individuals resulted in inconsistent preferences and engagement with both less [Konstantinidis et al. 2009] and more [Wallace et al. 2010] detailed virtual avatars. The impact of reducing visual clutter on VMI and motor performance in autistic individuals remains underexplored. Stables and Reid 2010 suggested that lower performance on overhand throwing and inflexible movement strategies typically observed in autistic individuals are linked to VMI challenges rather than a lack of understanding of task demands. Allen et al. 2017 implemented a visual support protocol in the Test of Gross Motor Development (3rd edition) [Ulrich 2016], the visual aids improved the overhand throwing task performance of autistic individuals compared to their peers without visual aids.

3 STUDY DESIGN AND DATA COLLECTION

3.1 Experimental Setup

The overhand throwing tasks were programmed in Unity®. In VR, HTC Vive Pro Eye (HTC, New Taipei, Taiwan) was used; hand movements were tracked using a Vive tracker 2.0 mounted on a Manus Glove Prime II (Manus VR, Geldrop, Netherlands) VR glove. Eye movements were recorded via the embedded eye tracker in HTC Vive Pro (90Hz). In PE, five VICON Vero motion cameras (Vicon Motion Systems, Centennial, CO) with 250Hz frame rate were used to capture hand and ball movement. A Pupil Pro eye tracker (Pupil Labs, Berlin, Germany) was used to record eye movement (120 Hz) and world-view video (720 x 1280; 24-bit color, 60 Hz).

Participants were required to perform overhand throwing using their dominant hands with the goal of throwing a ball (diameter = 18cm, weight = 120g) to a hoop (diameter = 32cm, height = 122cm) in PE, a regular VR condition with the same parameters as PE (Figure 1A), and a visually simplified VR condition (VR Simple) with the same lighting, color, and texture as the regular VR condition but reduced cluttered objects using a black screen (Figure 1B). Participants were instructed to perform overhand throwing only and did not receive any extra endpoint feedback beyond what was visually evident to them in either PE or VR conditions. A researcher assisted participants to ensure safety and helped to replace the ball in the PE condition. In VR conditions, a new ball was replaced automatically after each trial.

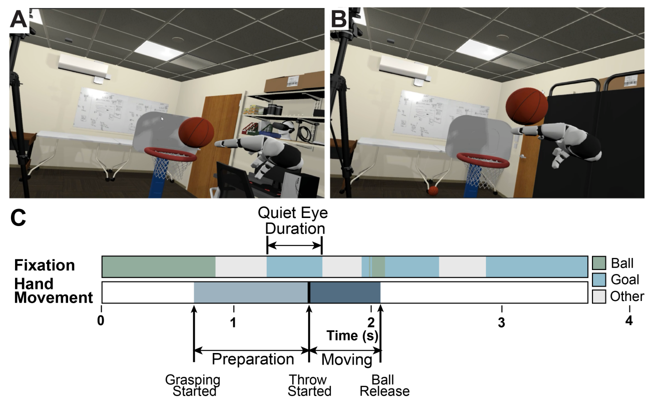

Figure 1: Experimental setup and VMI during overhand throwing. A: The overhand throwing task in VR that 1:1 replicated the physical environment. B: The VR Simple condition. C: Eye and hand movement during an example trial in VR from a non-autistic participant.

3.2 Participants

Ten non-autistic and ten autistic adults participated in the study. Non-autistic participants were recruited by word-of-mouth; autistic participants were recruited via a neurodiverse internship program hosted at Northeastern University. Autistic participants had community diagnosis (a formal diagnosis from a medical professional). Exclusion criteria were visual, cognitive, or auditory impairments that would interfere with task instruction, and unstable cardiovascular, orthopedic, or neurological conditions preventing participation in moderate exercise. Participants provided written informed consent. The study took place in the Rehabilitation Games and Extended Reality Lab at Northeastern University. All procedures were approved by Northeastern University's Institutional Review Board.

3.3 Experimental Procedure

All participants reported demographic information at the beginning of the study session and finished a self-report autism screening tool (Social Responsiveness Scale, Second Edition (SRS-2) [Constantino and Gruber 2012]) and a verbal and nonverbal intelligence assessment (Kaufman Brief Intelligence Test, Second Edition (K-BIT-2) [Kaufman 2004]), administered by trained lab personnel. The unbalanced sex ratio in the current study is based on the overall estimated gender ratio of autism, with an estimated male-to-female ratio of 4.2 [Zeidan et al. 2022]. During the overhand throwing, the basket was first set at 1.5m away from the standing position (15 trials), and

Table 1: Participants Demographic

Group	Sex	N	Age	SRS-2 T Score[a]	K-BIT-2 Standard Score[b]		
					Verbal	Nonverbal	Composite
			Mean(SD)	*Mean(SD)*	*Mean(SD)*	*Mean(SD)*	*Mean(SD)*
Autistic	Female	$n = 3$	21.20 (3.32)	75.33 (2.49)	104.67 (2.49)	110.67 (10.53)	109.33 (7.13)
	Male	$n = 7$	22.99 (5.35)	64.14 (10.05)	101.14 (18.01)	113.29 (17.65)	108.71 (18.75)
Non-autistic[c]	Female	$n = 3$	27.60 (4.75)	48.50 (9.19)	112.37 (7.72)	111.35 (5.78)	114.36 (8.45)
	Male	$n = 7$	25.25 (10.69)	49.12 (8.89)	103.59 (9.29)	110.67 (8.23)	111.25 (7.86)

[a]SRS T scores ≥ 75 and 60-65 indicate moderate to severe and mild differences in reciprocal social behavior respectively; <59 is designated as the normal range. [b]K-BIT scores within 85-115 fall in the average category. [c]We chose to use 'non-autistic' instead of 'neurotypical' because we did not conduct general screening for other neurodivergence.

then the difficulty progressed to 2m (15 trials), and 2.5m (15 trials). The order of conditions was counterbalanced across participants. Eye-tracking calibrations were conducted before the study session in each condition using the calibration program provided by the HTC Vive Pro Eye embedded eye tracker and Pupil Labs.

3.4 Evaluation Metrics

3.4.1 Task Performance. We defined throwing error as the distance between the center of the hoop and the ball in the hoop's horizontal plane. Success rate and throwing error were used to compare task performance between environments.

3.4.2 Hand Movement. Hand tracking data were lowpass filtered at 3Hz with a second-order Butterworth filter. The grasping phase was divided into a preparation phase, defined as the period from the ball being held to the start of throwing, and a moving phase, defined as the period from the start of throwing to the departure of the ball. The initiation of throwing was determined as the increase in hand velocity that exceeded three times of standard deviation.

3.4.3 Eye Movement. Areas of interest (AOIs) were recorded in VR as the combined gaze 'ray' collided with a virtual object and were manually coded for PE using Pupil Labs' annotation software with the video recorded from the world camera (30Hz). The ball and the goal were labeled as task-relevant AOIs. To evaluate participants' scanning patterns, we calculated the number of gaze shifts from one AOI to another and the percentage of shifts between task-relevant AOIs. A fixation was determined when the participant's gaze dwelled on an object for a minimum of 100ms (3 frames of video in PE). The percentage of fixation duration was calculated as the total fixation duration on an AOI divided by the total fixation duration. Quiet eye duration was determined as the final fixation at the goal during hand movement before ball release. Figure 1C illustrates the temporal relationship between the eye and hand movements during a trial.

3.5 Statistical Method

Descriptive measures were calculated for each outcome measure. Shapiro-Wilk tests were used to verify the normality of data distribution; none of the outcome measures met the expectations of a normal distribution. Friedman tests were used to compare outcome measures across different goal distances in overhand throwing, followed by post hoc analysis with Wilcoxon signed-rank tests with Bonferroni correction. Within each group (autistic and non-autistic), Wilcoxon signed-rank tests were used to compare differences in each measure between conditions. Within each condition, Wilcoxon rank-sum tests were used to compare differences between groups. The threshold for statistical significance was set as $p < 0.05$. All statistical analyses were performed using R (v. 4.0.2).

4 RESULTS

4.1 Influence of VR on Overhand Throwing Performance

In VR, both groups had lower overall success rates (Figure 2A. Autistic: $v = 354$, $p = 0.013$; non-autistic: $v = 279$, $p = 0.021$) and throwing accuracy (Figure 2B. Autistic: $v = 295$, $p = 0.023$; non-autistic: $v = 295$, $p = 0.023$), and at each distance (all ps ≤ 0.043). No between-group differences were observed in either PE or VR.

4.2 Influence of VR on the Visuomotor Integration Process

Within each condition, participants increased hand velocity as the goal moved farther away in both VR (Autistic: $\chi^2(2) = 50.259$, $p < 0.0001$; non-autistic: $\chi^2(2) =19.393$, $p < 0.0001$) and PE (Autistic: $\chi^2(2) = 45.156$, $p < 0.0001$; non-autistic: $\chi^2(2) = 12.463$, $p < 0.0001$), meaning all participants were able to interpret the task demand. There were no other differences in any hand and eye movement measures across different distances for either group in each condition. Therefore, except for hand release velocity, trials at different distances within each condition were combined for further analysis.

4.2.1 Eye Movement. All participants increased visual scanning and spent less time looking at the task-relevant AOIs in VR. Figure 2C illustrates the eye gaze distribution in PE and VR for each group. Each vertex in Figure 2C represents an AOI; the sizes of the colored areas represent the average number of gaze shifts between AOIs. In VR, all participants showed more shifts between any pair of AOIs (Autistic: $v = 2593$, $p < 0.0001$; non-autistic: $v = 2341$, $p < 0.0001$) and fewer gaze shifts between task-relevant AOIs (Autistic: $v = 5342$, $p < 0.0001$; non-autistic: $v = 3451$, $p < 0.0001$). As shown in Figure 2D, in VR, all participants had shorter relative fixation durations for task-relevant AOIs (Autistic: $v = 1982$, $p < 0.0001$; non-autistic: $v = 1384$, $p = 0.004$), and separately for the ball (Autistic: $v = 3484$,

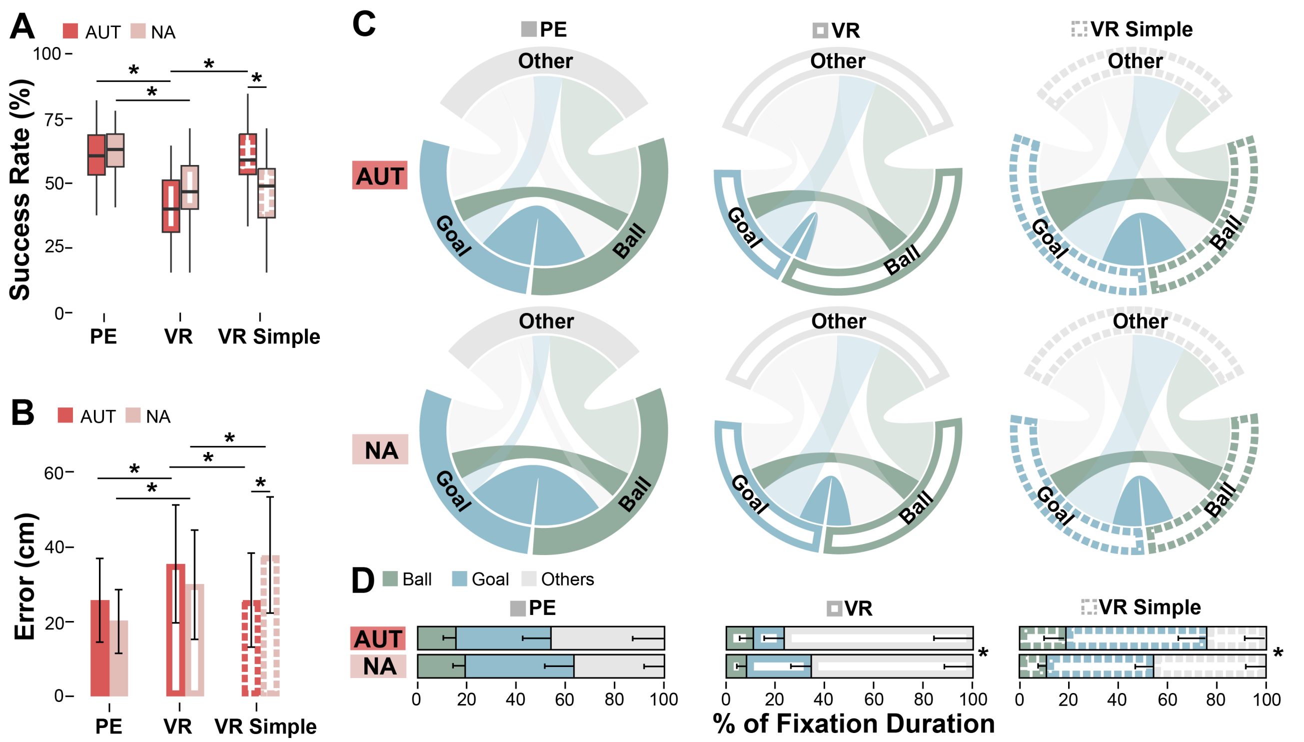

Figure 2: Task performance and gaze distribution during overhand throwing. Error bars represent ±1 standard error. A: Mean success rates. B: Mean throwing errors. C: Transition between each pair of AOIs. The size of each colored area denotes the proportion of gaze shift between AOIs. D: The percentage of fixation time on each AOI.

$p = 0.021$; non-autistic: $v = 2456$, $p < 0.0001$) and the goal (Autistic: $v = 2456$, $p < 0.0001$; non-autistic: $v = 2034$, $p < 0.0001$).

Autistic participants were more active in scanning the entire environment in both PE and VR. In PE, autistic participants made more gaze shifts between any pair of AOIs ($w = 7445$, $p = 0.007$) but fewer between task-relevant AOIs ($w = 2342$, $p = 0.045$), and had shorter quiet eye durations (Figure 3A. $w = 3569$, $p = 0.0002$) as compared to non-autistic peers. Similarly, in VR, autistic participants made more gaze shifts between any pair of AOIs ($w = 4052$, $p < 0.0001$) and fewer between task-relevant AOIs ($w = 6074$, $p < 0.0001$). As shown in Figure 2D, autistic participants had shorter relative fixation durations at both task-relevant AOIs ($w = 8830$, $p < 0.0001$), at the ball ($w = 1959$, $p < 0.0001$), and the goal ($w = 7558$, $p = 0.001$) individually. Autistic participants reduced quiet eye duration in VR (Figure 3A. $w = 6231$, $p = 0.023$); no differences were observed between PE and VR in non-autistic participants. Autistic participants also had shorter quiet eye durations in VR compared to non-autistic peers (Figure 3A. $w = 1642.5$, $p < 0.0001$).

4.2.2 Hand Movement. In VR, all participants increased overall hand release velocity (Figure 3B. Autistic: $v = 3753$, $p < 0.0001$; non-autistic: $v = 2512$, $p < 0.0001$), at each distance (All $ps < 0.002$), had a longer grasping duration (Figure 3C. Autistic: $v = 3528$, $p = 0.001$; non-autistic: $v = 4341$, $p = 0.002$), and had longer hand preparation time (Autistic: $v = 4552$, $p < 0.0001$; non-autistic: $v = 5341$, $p < 0.0001$). The hand preparation phase also took a larger proportion during the entire grasping phase in VR (Figure 3D. Autistic: $v = 3469$, $p < 0.0001$; non-autistic: $v = 5433$, $p < 0.0001$).

There were no between-group differences in release velocity (Figure 3B). Autistic participants had shorter grasping durations (VR: $w = 4957$, $p < 0.0001$; PE: $w = 4623$, $p = 0.002$), shorter hand preparation duration (VR: $w = 5150$, $p < 0.0001$; PE: $w = 3342$, $p = 0.037$), and proportions (VR: $w = 5730$, $p < 0.0001$; PE: $w = 4129$, $p = 0.013$) in both conditions.

4.3 Influence of Visual Clutter in VR on Overhand Throwing Performance

Similar to PE and VR, in the VR Simple condition, there were no differences in any hand or eye movement measures across different distances for either group, except hand release velocity increased as the goal moved farther away (Autistic: $\chi^2(2) = 55.799$, $p < 0.0001$; non-autistic: $\chi^2(2) = 20.019$, $p < 0.0001$). Therefore, other than comparisons with hand release velocity, all trials at different distances within VR and VR Simple were combined.

4.3.1 Overhand Throwing Performance. Compared to the regular VR condition, autistic participants significantly improved throwing performance in the VR Simple condition, showing improved success rates (Figure 2A. $v = 1538$, $p = 0.045$) and throwing accuracy (Figure 2B. $v = 2016$, $p = 0.001$) in the VR Simple condition. Non-autistic

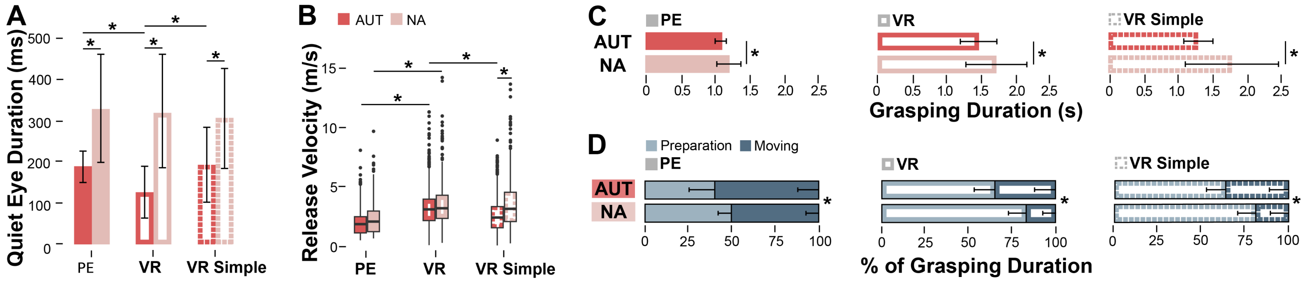

Figure 3: Quiet eye duration and hand movement during overhand throwing. Error bars represent ±1 standard error. A: Mean quiet eye duration. B: Mean hand release velocity. C: Mean grasping duration. D: Mean percentage of hand preparation time.

participants also improved throwing accuracy ($v = 2339$, $p = 0.012$) in VR Simple but the overall success rates were not improved.

Autistic participants outperformed non-autistic peers in VR Simple. Autistic participants had higher overall success rates ($w = 405$, $p = 0.046$) and at each distance (1.5m: $w = 425$, $p = 0.012$; 2m: $w = 385$, $p = 0.027$; 2.5m: $w = 356$, $p = 0.045$); and higher overall throwing accuracy ($w = 675$, $p < 0.0001$) and at each distance (1.5m: $w = 648$, $p = 0.0003$; 2m: $w = 415$, $p = 0.005$; 2.5m: $w = 425$, $p = 0.007$).

4.3.2 Eye Movement. All participants significantly reduced scanning in the VR Simple condition and increased relative fixation duration on task-relevant areas. In VR Simple, all participants reduced the total number of gaze shifts (Autistic: $v = 4378$, $p < 0.0001$; non-autistic: $v = 7054$, $p < 0.0001$) and increased the proportion of shifts between task-relevant AOIs (Autistic: $v = 1064$, $p = 0.019$; non-autistic: $v = 939$, $p = 0.015$) as compared to regular VR. As shown in Figure 3F, all participants increased the overall relative fixation duration on the task-relevant AOIs (Autistic: $v = 7162$, $p = 0.0002$; non-autistic: $v = 1189$, $p < 0.0001$) and for the ball (Autistic: $v = 2596$, $p < 0.0001$; non-autistic: $v = 1945$, $p < 0.0001$) in VR Simple. Non-autistic participants also increased the relative fixation duration at the goal ($v = 564$, $p = 0.012$) in VR Simple but autistic participants did not show differences as compared to the regular VR condition. Autistic participants increased quiet eye duration in VR Simple as compared to the regular VR condition (Figure 3A. $v = 4660$, $p = 0.019$), while non-autistic participants did not show any between-condition differences.

Similar to the other conditions, autistic participants had shorter quiet eye duration in VR Simple as compared to the non-autistic group (Figure 3A. $w = 5460$, $p = 0.019$). However, in contrast to PE and regular VR, in VR Simple, no between-group differences were observed on the number of overall gaze shifts and shifts between task-relevant AOIs. Also, unlike the other conditions, autistic participants had longer fixation duration at both the ball and goal (Figure 2D. $w = 4532$, $p = 0.019$) and at the ball ($w = 6380$, $p = 0.020$) and the goal ($w = 7778$, $p = 0.027$) individually.

4.3.3 Hand Movement. Compared to the regular VR condition, autistic participants reduced hand release velocity in VR Simple (Figure 3B. $v = 2028$, $p < 0.0001$). Autistic participants reduced grasping duration (Figure 3C. $v = 2154$, $p < 0.0001$) and hand preparation duration ($v = 8602$, $p = 0.026$) in VR Simple as compared to the regular VR condition. The relative proportions of the hand preparation were not impacted. For non-autistic participants, no differences on any hand movement measures were observed in VR Simple as compared to the regular VR condition.

Autistic participants had lower hand release velocity in the VR simple condition as compared to the non-autistic peers (Figure 3B. $w = 6378$, $p < 0.0001$). This effect was also observed at each distance (All ps < 0.001). Autistic participants had a shorter grasping duration (Figure 3C. $w = 2766$, $p < 0.0001$), shorter hand preparation time ($w = 5965$, $p < 0.0001$), and smaller portion of the hand preparation phase (Figure 3D. $w = 5662$, $p < 0.0001$) in VR Simple.

5 DISCUSSION

This study aims to answer our research question "How does visual clutter in VR impact visuomotor integration in autistic individuals?" This study compared visuomotor integration process and overhand throwing performance using an overhand throwing task in PE, VR that was identical to PE, and visually simplified VR (VR Simple) conditions with autistic and non-autistic individuals.

VR altered the VMI process during overhand throwing. All participants demonstrated heightened visual scanning activity and shorter quiet eye duration in VR, especially in autistic individuals. The increased gaze shifting in autistic individuals should not be attributed to the difficulty in maintaining stable fixation because gross control of fixation appears to be intact in autistic participants [Frey et al. 2013]. Previous studies with non-autistic individuals suggested that the disparity of efficiency and robustness of the visual information in VR may lead to rapid focus changes and divergence in visual attention [Banstola et al. 2022]. VR resulted in reduced overhand throwing accuracy, increased hand release velocity, and prolonged hand preparation phases compared to the physical environment. These findings may reflect the uncertainty associated with throwing in VR, similar to previous research [Butkus and Čeponis 2019].

All participants, especially in the autistic group, exhibited reduced throwing accuracy in VR. Head-mounted displays have the potential to disrupt accommodation and vergence [Renner et al. 2013], as well as distort visual features that contribute to binocular perception such as motion parallax, occlusion, shadows, and texture gradients [Robert and Levin 2018]. More than estimating the static position of the goal, overhand throwing also requires accurate perception of motion in depth. fMRI studies in autistic adults revealed diminished activation in frontal regions of the brain, resulting in diminished top-down control of pursuit eye movements to update the velocity and trajectory of moving objects and predict future positions [Johnson et al. 2016]. Additionally, visual artifacts in VR may also impact motion perception. VR displays have discontinuous illuminating pixels with a particular frequency (refresh rate) and period of illumination (duty cycle). With each eye movement, pixel illuminations are smeared across photoreceptors, causing phantom array or strobing effects when the duty cycle is low, and blurry objects when the duty cycle is high [Murdison et al. 2019] that may impact dynamic visual acuity [Regan and Miller 2017].

Reduced visual clutter had no significant impact on non-autistic individuals but notably improved the overall success rate and throwing accuracy in autistic individuals, surpassing the performance of non-autistic peers and enhancing visuomotor integration. Previous studies with non-autistic individuals found that higher visual complexity, including clutter, dynamism, and textural fidelity in VR reduced performance in visual scanning tasks [Ragan et al. 2015]. While the direct impact of visual clutter on overhand throwing performance in autistic individuals was not investigated, previous research has highlighted the preferences of autistic individuals for visually simplified environments, with reduced distractions, visual clutter, and physical clutter [Martin 2016][Nagib and Williams 2017] in everyday environments and classroom settings [Mostafa 2014][Rafiei Milajerdi et al. 2021]. While this small study cannot provide definitive conclusions, the VR Simple condition does show promising results that could be used to improve visuomotor integration performance in autistic individuals, particularly in eye movement measures.

Besides the small sample size, the main limitation of this study was the constrained physical space for ball throwing in PE. To comprehensively explore eye and hand movement strategies and assess motion perception efficiency, a broader range of throwing distances is essential. Another limitation of this experiment is the absence of haptic information in VR, potentially contributing to the overall increase in hand release velocity in VR. While previous studies have shown that the absence of haptic feedback does not affect movement coordination in VR [Furmanek et al. 2021], passive haptic feedback has been found to increase performance on Fitts's law tasks [Joyce and Robinson 2017] that also require spatial and temporal accuracy, which are crucial for VMI. Incorporating a physical ball in VR could be a valuable enhancement for future studies.

6 CONCLUSION

This study examined the impact of visual clutter in VR on visuomotor integration for autistic and non-autistic individuals. We evaluated the visuomotor integration performance with an overhand throwing task with real-time eye and hand movement data. Autistic participants showed lower performance in both VR and the physical environments as compared to their non-autistic peers. However, reducing visual clutter in VR led to a notable improvement in overhand throwing accuracy and visuomotor integration measures in autistic individuals. Our study highlights the understudied area of how visual information features in VR affects visuomotor integration in autistic individuals. The findings pave the way for further investigations into various aspects of visual information in VR, aiming to tailor visual design to enhance visuomotor integration performance for autistic individuals.

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