NATURALISTIC VISUOMOTOR BEHAVIOURS REVEAL REDUCED HANDEDNESS LATERALIZATION IN AUTISM.

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Abstract

Autistic individuals often exhibit differences in perceptual and visuomotor functioning, potentially reflecting reduced cortical specialization. The current study investigates how handedness, a robust marker of cerebral lateralization, is modulated in autistic and non-autistic right-handed adults (n=27 per group) using a naturalistic LEGO® model-building task. Participants recreated five models from blocks placed on a standardized tabletop, enabling detailed analysis of real-world visuomotor behaviour. Autistic participants showed a lower proportion of right-hand grasps and more balanced cross-body reaches, indicating reduced lateralization. They also preferred blocks closer to their hands, suggesting larger safety margins in 3D space use. Movement trajectory analyses revealed more idiosyncratic action sequences and slower completion times compared to non-autistic participants, reflecting reduced motor efficiency. These findings demonstrate reduced specialization of hand use in autism, which may contribute to challenges and differences in visuomotor control.

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1. Introduction

Handedness is a distinctive aspect of human visuomotor integration and is crucial in various cognitive and motor functions. It is typically classified into three categories: right-handedness, left-handedness, and mixed-handedness, based on the dominant hand(s) used for performing tasks and skills (Cheng et al., 2020). Research has linked handedness to cerebral lateralization for language, a process where the brain's left and right hemispheres handle information differently and govern specific patterns of behaviour (Groen et al., 2013; Rogers, 2021). Notably, approximately 89.4% of the population is right-handed, underscoring the importance of studying factors that contribute to handedness, including cerebral lateralization (Papadatou-Pastou et al., 2020). This widespread preference for the right hand likely reflects left-hemisphere dominance in motor control, given that motor functions are mapped contralaterally (i.e., each hemisphere controls movements of the opposite side of the body), with the left hemisphere typically specialized for fine motor skills such as hand movements (Barber et al., 2012).

The idea that hand preference is localized to a specific cerebral hemisphere was first proposed by Liepmann (1908), building on earlier discoveries by Broca (1865) and Wernicke (1874) regarding the lateralization of language. More recent research has reinforced Liepmann's proposal. For example, Gonzalez et al. (2007) found that right-handed individuals prefer their dominant hand 82.2% of the time in a LEGO® building task, while left-handers use theirs only 44.4% of the time. This suggests stronger lateralization in right-handers, whereas left-handers exhibit greater ambidexterity, indicating less strict lateralization of motor control. Supporting this, Johnstone et al. (2021) used fMRI to measure cerebral asymmetries in verbal fluency, face perception, body perception, and scene perception. They found a strong link between

right-handedness and left-hemisphere dominance for language, while left-handed participants showed less pronounced lateralization across all tested functions. Furthermore, de Bruin et al. (2016) found that right-handed participants demonstrated a strong preference for using their right hand during grasping tasks. However, as task complexity increased, this preference slightly decreased, suggesting that hand dominance, while robust, can be influenced by visuospatial demands. This supports the notion that hand preference is deeply rooted in lateralized motor control mechanisms, but is also adaptable to situational factors. These findings collectively highlight handedness as a key marker for understanding the lateralization of brain functions and its implications for both typical and atypical developmental trajectories.

Handedness arises from a complex interplay of brain structure, genetics, and environmental influences. Key brain regions, including the motor cortex, basal ganglia, and cerebellum, play crucial roles in motor coordination and the execution of movement. The motor cortex, responsible for voluntary muscle movements, is shaped by genetic factors and environmental stimuli, such as physical activity levels and types. Meanwhile, the basal ganglia and cerebellum play a crucial role in movement and coordination (Jackson et al., 2003; Leisman et al., 2016). On the genetic front, multiple genes, including LRRTM1 and PCSK6, have been linked to handedness, indicating a polygenic rather than single-gene basis (Brandler & Paracchini, 2014). Additionally, cultural and societal pressures, particularly historical biases favouring right-handedness, have significantly shaped hand preference across populations (Fagard & Dahmen, 2004). This multifaceted perspective underscores the intricate interplay of internal and external factors that shape handedness, revealing its complexity despite its seemingly straightforward nature.

Visuomotor specialization, which integrates visual information with motor actions, develops primarily through experience-dependent neural plasticity (Widmer et al., 2022). Unlike innate reflexes, visuomotor coordination evolves gradually as infants interact with their environment, refining neural circuits postnatally (Contreras-Vidal et al., 2004). The brain develops significantly during infancy and early childhood, adapting to sensory and motor experiences. Children's visuomotor representations of hand movements become increasingly specialized and consistent by preschool age. This transition reflects the stabilization of visuomotor skills as neural circuits mature through practice and learning (Bo et al., 2006; Scharoun & Bryden, 2014). The refinement of visuomotor control highlights the remarkable neuroplasticity of the developing brain and its reliance on environmental stimuli.

In contrast to visuomotor control, the development of hand preference begins much earlier and appears to be driven by genetic and environmental factors. Studies of fetal behaviour have shown that hand preference emerges as early as 15 weeks of gestation, with fetuses often exhibiting a preference for thumb-sucking with one hand over the other (Hepper et al., 1991). This early manifestation of handedness suggests a strong biological underpinning. However, the consistent use of a dominant hand typically stabilizes during early childhood, influenced by environmental and experiential factors such as cultural norms, parental reinforcement, and task-specific practice (Scharoun & Bryden, 2014; Yancosek, 2010). While early hand preference appears to be innate, its development remains dynamic and is shaped by external influences throughout early childhood.

Despite their interconnectedness, the developmental trajectories of visuomotor control and handedness follow partially independent pathways. Hand preference emerges prenatally, reflecting early neural specialization, while visuomotor control requires postnatal experience for

refinement. This dissociation underscores the differing timelines and mechanisms underlying these processes. The development of handedness stabilizes relatively early, while visuomotor coordination continues to mature well into childhood, adapting through repeated practice and sensory input (Ritter & Haschke, 2015; Gonzalez et al., 2020). These developmental profiles highlight the interplay between innate biological predispositions and experience-driven neural plasticity, emphasizing the complex nature of human motor specialization.

However, the emergence of visuomotor functions, as well as handedness, can be altered in cases of neurodevelopmental disorders, such as autism spectrum disorder (ASD). ASD is a neurodevelopmental condition characterized by challenges in social communication, repetitive behaviours, and restricted interests (American Psychiatric Association, 2013). While ASD is primarily studied for its social and cognitive differences, it also involves broader neurodevelopmental differences, including motor planning and coordination deficits, which are intrinsically linked to handedness (Fournier et al., 2010; Marco et al., 2011; D'Cruz et al., 2013). The emergence of visuomotor functions, as well as handedness, can be altered in ASD, providing valuable insights into both typical and atypical neurodevelopmental trajectories. Research indicates that individuals with ASD exhibit a higher prevalence of non-right-handedness and weaker-handedness compared to neurotypical populations (Soper et al., 1986; Forrester et al., 2014). Supporting this, a meta-analysis by Markou et al. (2017) found that autistic individuals are significantly more likely to be non-right-handed, left-handed, or mixed-handed, reflecting atypical lateralization patterns. These findings highlight how variations in handedness may illuminate the unique neurodevelopmental pathways associated with autism.

The relationship between handedness and visuomotor specialization is critical in environmental interactions. Visuomotor specialization, which enhances efficiency in tasks such

as grasping, tool use, and feeding, is closely tied to lateralizing motor functions (Mutha et al., 2011). For example, handedness influences which hand is used for grasping tasks, guided by visual input to fine-tune movement precision. This seamless integration of sight and motion is essential for navigating the environment effectively. In conditions like ASD, impairments or notable differences in visuomotor skills, such as differences in handedness, highlight the profound effect of this relationship on daily life functioning (Fournier et al., 2010; Mostofsky et al., 2000). For example, autistic children often exhibit distinctive grasping and reaching patterns when interacting with their 3D spatial environments, characterized by less coordinated and less efficient movements compared to their typically developing peers (Sacrey et al., 2014).

The demonstrated relationship between handedness and visuomotor specialization highlights the importance of investigating how these processes are influenced by cerebral lateralization. Such insights can deepen our understanding of the brain's organization and functioning (Karapetsas & Vlachos, 1997; McGrath & Kantak, 2016). This is particularly relevant in neurodevelopmental conditions like ASD, where atypical handedness patterns may reflect and influence unique visuomotor profiles, potentially affecting functional abilities (Soper et al., 1986; Ozonoff et al., 2008). Despite its importance, research often relies on subjective questionnaires or simple grasping tasks that fail to capture the nuanced nature of handedness and its diagnostic potential. Also, much of the existing literature on visuomotor specialization in autism focuses on children. By focusing on adults, we can explore whether differences in handedness and visuomotor abilities represent delayed development or an altered system, thereby addressing gaps in our understanding of how these traits manifest after developmental processes have largely stabilized.

The current study addresses these gaps by exploring handedness and visuomotor skills in autistic and non-autistic individuals, using a naturalistic yet standardized task. This study employs a similar methodology based on Gonzalez et al.'s (2007) investigation of hand preference in neurotypical adults during a LEGO® building task. Participants will recreate various models using a standardized, symmetrical LEGO® board, providing a controlled setting to examine visuomotor tendencies across the different groups. By examining handedness and visuomotor behaviours in autistic adults through a controlled LEGO®-building task, this study aims to shed light on the relationship between autism, handedness and atypical visuomotor behaviours, providing insights into the unique patterns of neurodevelopmental diversity (Mostofsky et al., 2007).

2. Materials and Methods

Participants

The study included 27 autistic and 27 non-autistic participants tested in Haifa, Israel, and Toronto, Canada. All participants provided informed consent under a protocol approved by the York University Human Participants Review Committee (HPRC). The inclusion criteria required participants to be right-handed (i.e., write with their right hand) and have normal or corrected-to-normal vision.

Participants were age- and gender-matched within a ±5-year range to ensure comparable developmental contexts, except for one non-ASD participant, for whom the age was missing. Data from seven additional participants were not analyzed: five because they were predominantly left-handed (two autistic participants and three non-autistic participants), and two non-autistic participants because a single trial time exceeded 250 seconds.

Table 1

Demographic Characteristics of Participants

Variable	Autistic Group	Non-autistic Group
Gender	19 male (70.4%), 8 female (29.6%)	19 male (70.4%), 8 female (29.6%)
Age	27.6 ± 5.4	26.2 ± 5.1
AQ score	27 ± 7.53	17.83 ± 5.21
EHI score	72.26 ± 21.40	93.68 ± 7.75
TONI score	102.81 ± 12.62	101.83 ± 11.21

Materials and Apparatus

LEGO® Building Task: The primary task involved a standardized and symmetrical construction board (61 × 33.5 cm) comprising 26 LEGO® blocks (Figure 1A). At the center of the board, a LEGO® baseplate served as an anchoring point for the model display (Figure 1B). Participants were instructed to recreate five pre-displayed LEGO® models varying in colour and the number of blocks used (Figure 1C). One video camera, positioned to capture a bird's-eye view of the board, was used to record participant actions.

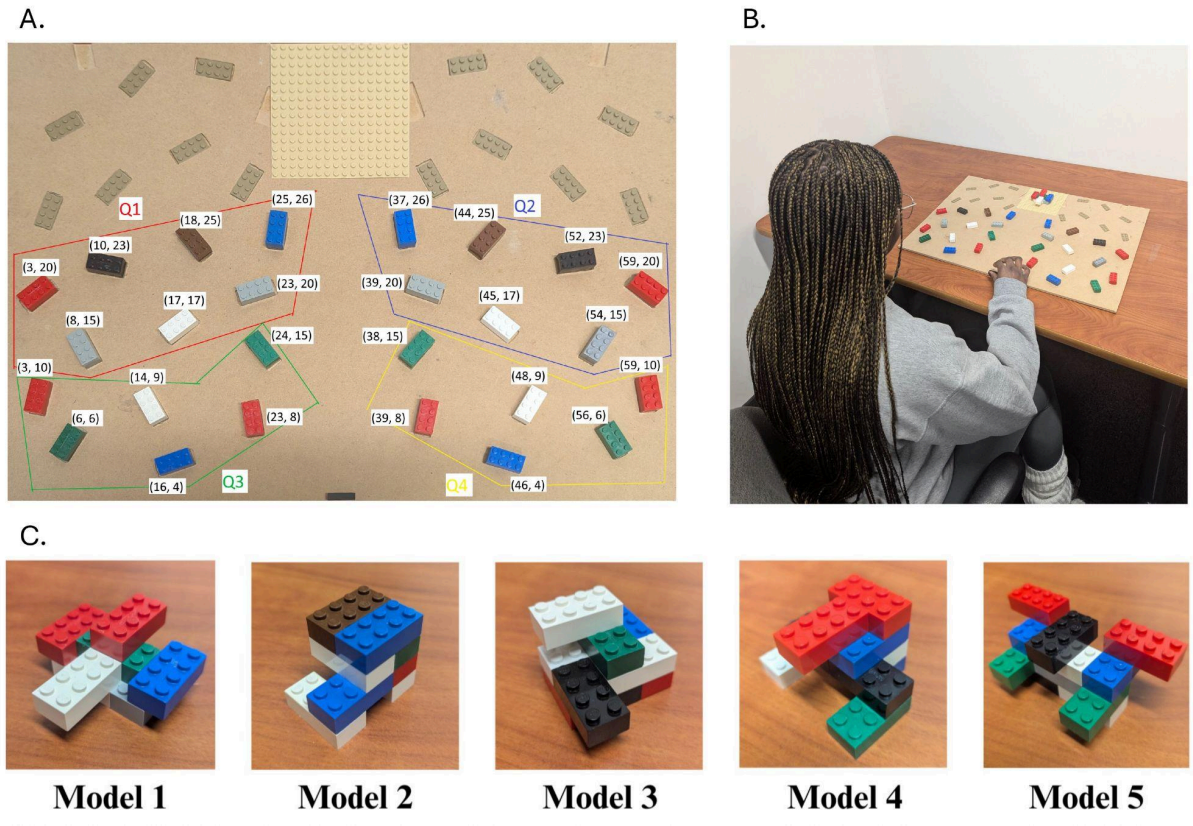

Figure 1. Experimental Design.
A: Experimental setup displaying the standardized construction board for LEGO® model assembly, including quadrant divisions and block coordinates. Coordinates (in centimetres) originate at (0,0), located at the bottom-left corner of the board.
B: Participant orientation to the experimental board, with Model 1 anchored on the baseplate.
C: The five LEGO® models used for the recreation task.

Autism Spectrum Quotient (AQ): The AQ is a 50-item self-report questionnaire developed by Baron-Cohen et al. (2001) to measure five domains associated with Autism Spectrum Disorder (ASD): social skills, attention switching, attention to detail, communication, and imagination. Each domain consists of 10 items, scored on a four-point Likert scale: definitely disagree, slightly disagree, slightly agree, definitely agree. Higher scores indicate a greater likelihood of neurodiverse traits. Responses in the "autistic" direction are scored 1, while non-autistic responses are scored 0.

Test Of Nonverbal Intelligence-4 (TONI-4): The TONI-4 (Brown et al., 2010) is a standardized assessment of nonverbal intelligence suitable for individuals aged 6 to 89 years and 11 months. Each item presents a sequence of abstract figures with a missing element, and participants must select the correct figure to complete the sequence. Item difficulty increases as attributes such as shape, rotation, and size are added. Responses are scored dichotomously: 1 for correct and 0 for incorrect answers.

Edenborough Handedness Inventory (EHI): The EHI (Oldfield, 1971) is a 10-item questionnaire that assesses handedness based on participants' preferences for using their left or right hand in various daily activities. Each item includes a follow-up question: "Do you ever use the other hand?". The EHI accounts for sociocultural differences by focusing on universally relevant activities and provides a standardized measure of handedness, with scores ranging from -100 (entirely left-handed) to +100 (entirely right-handed)

Procedure

Before data collection, written informed consent was obtained from all participants after they were informed of the study's nature and potential consequences. This ensured they fully comprehended the information before providing informed consent.

Participants completed the AQ questionnaire, the EHI, and the TONI-4. They then reconstructed five LEGO® models of varying complexity to evaluate naturalistic grasping patterns and handedness tendencies. Each model was positioned at the top center of the experimental board, and participants were instructed to reconstruct the LEGO® model using the appropriate blocks. Participants were allowed to use both hands but were asked to keep the original model stationary. Nevertheless, they were allowed to reposition themselves for optimal viewing of the model. The experimental board was reset between trials. Participants completed the task at their own pace. All trials were video-recorded for subsequent analysis.

Data Analysis

The AQ, EHI, and TONI-4 were scored according to each measure's standardized protocols, and independent-sample t-tests were used to examine group differences.

For the LEGO® task, at least two independent raters reviewed video footage. They recorded eleven dependent variables: model completion time, the number of grasps with the left and right hands, the number of blocks used from each of the four board quadrants, and reaches categorized as cross-body or same-side (for both right and left-handed reaches). Inter-rater discrepancies exceeding two units for model completion time, grasp counts, and reach classifications prompted a joint reexamination. Final ratings were then averaged across raters to derive model averages and overall proportions. Ratings for quadrant-specific block utilization required exact consistency; discrepancies led to joint reevaluation. Consistent ratings were used to calculate the proportions of blocks utilized from the right (quadrants 2 and 4) and the bottom (quadrants 3 and 4) of the board, which were then averaged for each participant. Independent-sample t-tests were used to assess group differences in model completion time, the proportion of right-hand grasps, and the frequency of block utilization from both the bottom and

right areas of the board. Group differences in reach type were analyzed using a repeated-measures analysis of variance (ANOVA) with two factors: group (ASD vs. non-ASD) and hand (left vs. right).

Independent raters also documented the coordinate trajectories for each participant by recording the precise sequential order in which blocks were utilized. Ratings required exact consistency; discrepancies triggered joint reexamination until consensus was achieved. Dynamic Time Warping (DTW) was applied due to its effectiveness as a distance metric for comparing sequential data, allowing flexible alignment of sequences to minimize overall distance. DTW distances were visualized using a Representational Dissimilarity Matrix (RDM), depicting pairwise comparisons of individual participant trajectories. Additionally, a bootstrap analysis with 1,000 resamples was conducted to statistically evaluate group differences, generating confidence intervals around the mean DTW values to determine the significance and robustness of the observed differences.

Alongside this bootstrap analysis, a permutation analysis was conducted on the participant-level mean DTW distances to further assess the statistical reliability of group differences. Group labels were randomly shuffled 10,000 times to simulate the null hypothesis that within-group similarity was independent of diagnostic status. For each permutation, the difference in mean DTW distance between the reshuffled groups was recalculated, generating a null distribution of difference scores. The observed group difference was then compared to this distribution to derive a two-tailed p-value, providing a non-parametric test of significance that does not rely on distributional assumptions.

Finally, a post hoc analysis was conducted to compare the number of incorrectly built LEGO® models between the autistic and non-autistic groups. Models were considered incorrect

if they were missing blocks or exhibited incorrect block placements. To determine the appropriate statistical test, the data was first assessed for normality and homogeneity of variance using the Shapiro–Wilk and Levene's tests, respectively. The Shapiro–Wilk test indicated significant deviations from normality in both groups (ASD: $W = 0.785$, $p = .000077$; non-ASD: $W = 0.690$, $p = .0000028$), violating the assumption of normality required for parametric testing. Additionally, Levene's test revealed a significant difference in variance between groups ($F = 6.59$, $p = .0132$), indicating heteroscedasticity. Given these violations of parametric assumptions, a non-parametric Mann–Whitney U test was conducted to compare group differences.

3. Results

An independent-sample Welch's t-test was conducted to examine differences between ASD and non-ASD groups on the Edinburgh Handedness Inventory (EHI) (Figure 2A). Two ASD and three non-ASD participants were excluded from this analysis due to missing data. Additionally, five autistic participants only had partial scores, which were rounded. Autistic participants had lower handedness scores than non-autistic participants, indicating weaker right-hand dominance, $t(31.26) = -4.44$, $p < .001$, 95% CI [-27.94, -10.35]. *Note: Welch's t-tests were used due to unequal group variances, resulting in non-integer degrees of freedom.* This finding is consistent with previous reports of atypical handedness patterns and reduced lateralization in ASD (Soper et al., 1986; Forrester et al., 2014).

A similar pattern was observed in the main LEGO® building task. The analysis demonstrated that the autistic participants exhibited a lower proportion of right-hand grasps than non-autistic participants, $t(50.80) = -2.68$, $p = .01$, 95% CI [-0.18, -0.03] (Figure 2B). Consistent with this result, we also observed a clear difference in the proportion of cross-body grasp movements, such as grasping a block on the left side of the table with the right hand. A 2 x 2 repeated-measures ANOVA revealed a significant Group x Hand interaction, $F(1, 52) = 12.72$, $p = .001$, $\eta^2 = 0.20$, 95% CI [0.06, 1.00], indicating that autistic participants exhibited a more balanced pattern of cross-body reaches, using both hands while non-autistic participants completed cross-body movements almost exclusively with the right hand (Figure 2C).

The naturalistic setting of the LEGO® task allowed us to explore other aspects of visuomotor behaviours. To examine spatial biases in block utilization, we analyzed the proportion of blocks used on the right side of the board. The analysis revealed no significant group differences, $t(50.77) = 0.51$, $p = .61$, 95% CI [-0.04, 0.07] (Figure 2D). This suggests that

while autistic and non-autistic participants may differ in hand preference during grasping, this difference does not translate into differences in the overall spatial allocation of blocks.

However, a different pattern was observed when we examined the proportion of blocks used in the bottom portion of the board. Results revealed that autistic individuals were more likely to rely on bottom-placed blocks (i.e., objects closer to their body) when constructing the models, $t(51.6) = 4.73$, $p < .001$, 95% CI [0.05, 0.11] (Figure 2E). This suggests potential differences in spatial processing or task strategy. One possible explanation is that autistic participants may adopt larger safety margins when engaging in dynamic or unfamiliar tasks, prioritizing more accessible or visually prominent areas on the board.

To measure the overall visuomotor efficiency, we examine the average completion time of the models. Results revealed that autistic participants took longer, on average, to complete the models compared to non-autistic participants, $t(41.98) = 2.44$, $p = .02$, 95% CI [2.62, 27.68] (Figure 2F). This finding replicates previous reports (Fournier et al., 2010; Marco et al., 2011; D'Cruz et al., 2013) that have demonstrated motor alterations and differences in task planning and execution in autistic individuals. However, despite autistic participants exhibiting longer model completion times compared to non-autistic participants, a bimodal distribution was observed among the autistic group. This indicates the presence of two distinct performance subgroups, suggesting heterogeneity in task execution strategies or processing speed in autism, consistent with prior evidence of heterogeneity in sensorimotor integration strategies (Haswell et al., 2009).

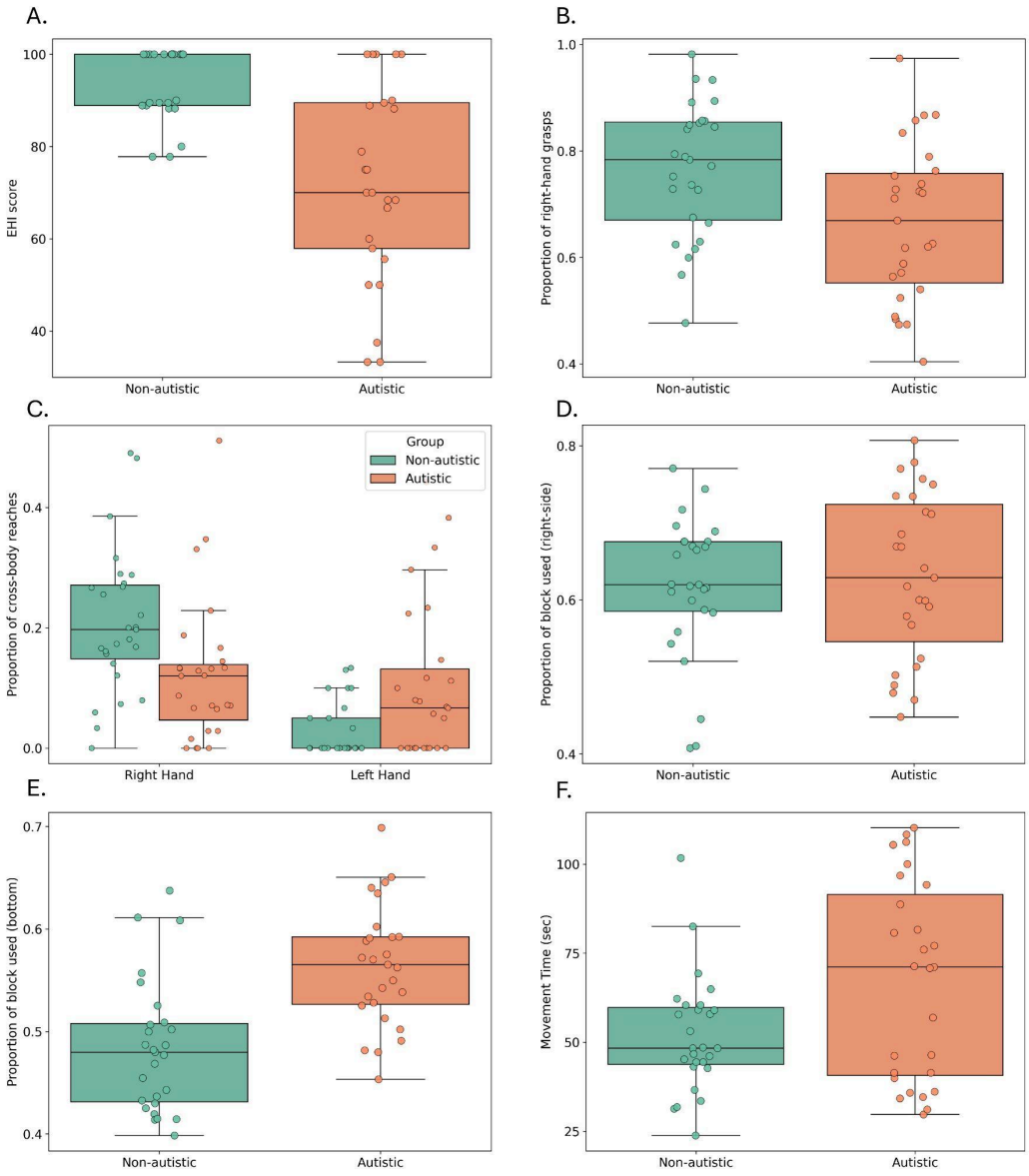

Figure 2. Results from Behavioural and Visuomotor Analyses.
Panels A-F display group medians (black horizontal lines), interquartile ranges (boxes), and the minimum and maximum values within 1.5 times the interquartile range (whiskers). Individual data points (dots) represent each participant within the Autistic and Non-autistic groups.
A: EHI scores by Group.
B: The average proportion of right-hand grasps by group. Higher values indicate a stronger preference for the right-hand during LEGO® model assembly.
C: The average proportion of cross-body reaches separated by group and hand used (left, right). Higher proportions reflect more frequent cross-body reaching movements during the task.
D: The average proportion of blocks utilized from the right side (quadrants 2 and 4) of the experimental board, displayed by group. Higher proportions indicate greater block use on the right side of the board.

E: The average proportion of blocks utilized from the board's bottom half (quadrants 3 and 4), displayed by group. Higher proportions suggest a preference for using blocks closer to the participant.
F: Average LEGO® model completion times (in seconds) by group. Lower values represent faster performance on the construction task.

The complex and continuous nature of the reconstructing task employed here also allowed us to track the sequence of blocks utilized in each trial. We measured participants' similarity in movement trajectories using Dynamic Time Warping (DTW). DTW distances were computed for all pairwise participant combinations, resulting in Representational Dissimilarity Matrices (RDMs) that depict the movement similarity structure within and between groups. Subsequently, we averaged these five model-specific RDMs to construct an overall similarity matrix representing consistent participant-level movement patterns across models.

Using this aggregated RDM, we calculated the mean DTW distance between each participant and all other participants within the same group, allowing us to quantify the average movement similarity per participant. We then compared the distributions of these per-participant means between the autistic and non-autistic groups. To statistically evaluate differences in within-group consistency, we conducted a bootstrap analysis (1,000 iterations) on the participant-level mean DTW distances within each group. This analysis provided confidence intervals for within-group DTW distances, allowing us to assess whether autistic participants showed significantly different movement consistency compared to their non-autistic counterparts.

The results showed a clear difference between the two groups, with greater distance (i.e., more variable movement patterns) within the autistic group than the non-autistic group (Figure 3A–B). Bootstrap resampling (1,000 iterations) yielded minimally overlapping 99% confidence intervals for the group means, indicating a statistically robust difference in within-group

consistency. Specifically, the mean DTW distance for autistic participants was M = 30.95, 99% CI [30.11, 31.91], while the non-autistic participants showed a lower mean distance of M = 29.36, 99% CI [28.63, 30.07].

To explore whether individual differences in lateralized motor behaviour were associated with movement trajectories, we examined the relationship between average DTW distance and two indices of lateralization: the proportion of right-hand grasps (Figure 3C) and handedness scores on the Edinburgh Handedness Inventory (EHI; Figure 3D).

A significant negative correlation was observed between the DTW distance and the proportion of right-hand grasps (r = -.33, p = .015), indicating that participants who relied more heavily on their right hand tended to produce movement trajectories that were more similar to those of other participants. Greater left-hand use was associated with more idiosyncratic movement patterns, reflecting distinct motor strategies. In contrast, there was no clear relationship between DTW distance and EHI scores (r = .10, p = .49), implying that self-reported handedness may not strongly predict actual movement consistency during this task.

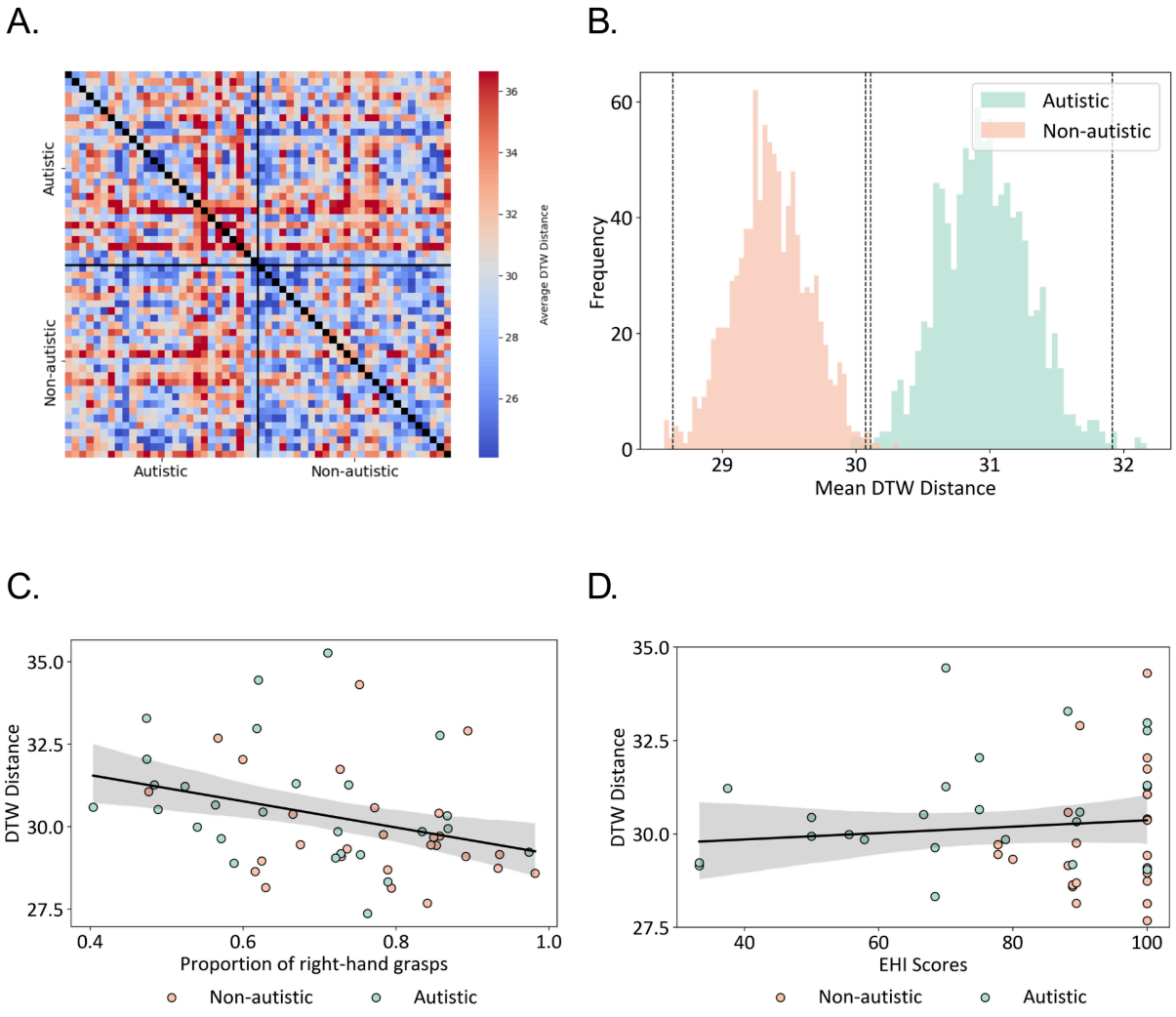

Figure 3. Results from Movement Trajectory Analyses.
Panels A–D visualize group-level and individual-level patterns in movement trajectory similarity across participants, as measured by Dynamic Time Warping (DTW).
A: Representational Dissimilarity Matrix (RDM) illustrating pairwise comparisons of movement trajectories between participants using Dynamic Time Warping (DTW). Each cell represents the dissimilarity between the movement trajectories of two participants, with cooler colours (blue) indicating greater similarity and warmer colours (red) indicating greater dissimilarity.
B: Bootstrap distributions illustrating group differences in mean DTW distances between participants' movement trajectories. Distributions represent the variability of these differences, with the vertical dashed line indicating the 99% confidence interval.
C: Scatterplot showing the relationship between the proportion of right-hand grasps and DTW distance. Each point represents an individual participant, with colour indicating group membership. A negative trend suggests that greater reliance on the right hand is associated with more consistent movement trajectories (lower DTW distance). The black line represents the line of best fit; the grey region shows the 95% confidence interval.

D: Scatterplot showing the relationship between handedness scores (EHI) and DTW distance. Each point represents an individual participant. No clear association was observed, suggesting that self-reported handedness may not reliably predict movement consistency in this task. The black line represents the line of best fit; the grey region shows the 95% confidence interval.

To further validate the reliability of this group difference, a permutation analysis was conducted using the full representational dissimilarity matrix (RDM) to preserve the pairwise structure of the data. Group labels were randomly reassigned 10,000 times, and for each permutation, participant-level within-group DTW means were recalculated. The resulting null distribution of group differences was compared to the observed difference between autistic and non-autistic participants ($\Delta M = 1.59$). Although the observed difference fell near the extreme of the null distribution, it did not exceed the conventional threshold for statistical significance, yielding a two-tailed p-value of .099. This suggests a trend toward greater within-group variability in the autistic group, though the result should be interpreted with caution (Figure 4).

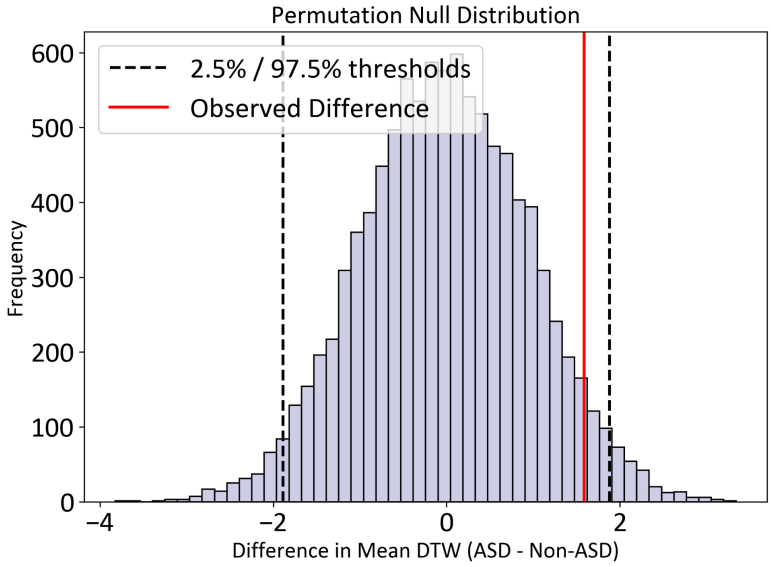

Figure 4. Revised Permutation Test of Group Differences in Movement Consistency. Histogram showing the null distribution of differences in mean DTW distances generated by 10,000 random permutations of group labels. Dashed black lines indicate the 2.5th and 97.5th percentile thresholds of the null distribution. The solid red line marks the observed group difference ($\Delta M = 1.59$).

Finally, a Mann–Whitney U test was conducted to compare the number of incorrectly built LEGO® models between the ASD and non-ASD groups. This non-parametric test was selected due to violations of normality and homogeneity of variance. The analysis revealed no statistically significant difference in incorrect model counts between groups ($U = 441.5$, $p = .146$), suggesting that the accuracy of LEGO® model construction was comparable for participants in the autistic and non-autistic groups.

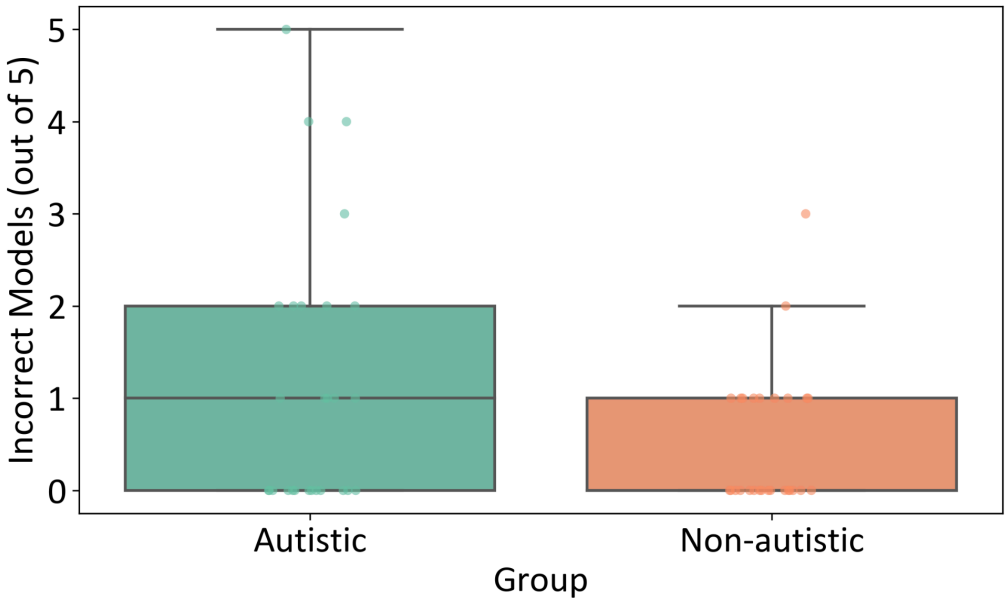

Figure 5. Group Differences in Model Construction Accuracy.
Boxplot showing the number of incorrectly built LEGO® models (out of 5) by group. Individual data points are overlaid and coloured by group. The median and interquartile range are displayed within each box, with whiskers extending to 1.5 times the IQR. No significant difference was found between groups (Mann–Whitney $U = 441.5$, $p = .146$).

4. Discussion

The current study aimed to explore visuomotor behaviours and handedness in autistic individuals, using a naturalistic LEGO® model reconstruction task. Our findings make a significant contribution to the literature by demonstrating reduced lateralization and distinct spatial utilization patterns among autistic adults, which supports theories linking visuomotor efficiency to cerebral lateralization.

Firstly, our primary finding of a lower proportion of right-hand grasps among autistic participants, despite all participants reporting themselves as right-handed, supports theoretical frameworks suggesting atypical cerebral lateralization in autism. According to Geschwind and Galaburda's (1985) theory, atypical hemispheric specialization may result from differential neural development influenced by genetic and environmental factors. Reduced motor lateralization observed in autism may thus reflect underlying atypical neural connectivity, particularly affecting the left hemisphere, which is typically dominant for precise and goal-directed motor actions. This aligns closely with more recent literature (see meta-analysis by Markou et al., 2017), indicating higher rates of mixed-handedness in autistic populations. The observation that autistic individuals use their left hand more frequently supports earlier studies suggesting a weaker lateralized motor preference, even among those who identify as right-handed (Knaus et al., 2016; Forrester et al., 2014). Notably, this study employed a dynamic observational approach, contrasting the previous reliance on self-reporting or simple performance tasks (Soper et al., 1986). While handedness questionnaires are practical, they have limitations due to their subjective nature and potential inconsistencies in self-perception (Oldfield, 1971). In contrast, our observational task captured real-world motor behaviours, providing a more accurate and objective assessment of handedness.

Second, we observed significant differences in spatial utilization, with autistic participants preferentially selecting blocks closer to their bodies. This behaviour may reflect larger visuomotor safety margins, suggesting that autistic individuals adopt spatial strategies prioritizing motor precision and stability (Sacrey et al., 2014). Prior research supports this interpretation, indicating that autistic individuals often exhibit atypical motor planning and execution, characterized here by cautious and deliberate movements closer to the midline of their bodies (Glazebrook et al., 2006). These adjustments have been linked to underlying differences in proprioceptive processing and sensorimotor integration, potentially compensating for reduced motor efficiency or increased motor variability observed in autism (Dowd et al., 2012; Whyatt & Craig, 2013). Specifically, autistic individuals have been reported to demonstrate a greater reliance on visual feedback and a more conservative spatial strategy, which likely helps mitigate uncertainty in motor execution (Mosconi et al., 2015; Sharer et al., 2016). Thus, our findings align with a growing body of evidence suggesting that spatial strategies employed by autistic individuals during visuomotor tasks may reflect adaptations aimed at enhancing motor control in response to underlying sensorimotor challenges.

Our results also demonstrated that autistic participants took significantly longer to complete tasks, consistent with evidence that autistic individuals experience prolonged movement initiation and execution phases (Zheng et al., 2019; Fournier et al., 2010). Increased task completion time in autism likely reflects challenges in motor planning, sensory integration, and the execution of movement. Motor delays in autism, including slower and less fluid movement trajectories, have been frequently reported (Cook et al., 2013; Gowen & Hamilton, 2013). The observed slower performance in our task supports theories suggesting that motor

control deficits in autism might stem from broader neural inefficiencies, including reduced specialization and atypical lateralization (Barber et al., 2012; Markou et al., 2017).

Additionally, trajectory analyses revealed that autistic participants exhibited more idiosyncratic movement patterns than neurotypical controls. This between-subjects variability suggests potential challenges in developing consistent motor plans, aligning with previous research that indicates increased movement variability and atypical feedback use during motor tasks in autism (Zheng et al., 2019; Ziv et al., 2024). Specifically, Cavallo et al. (2018) demonstrated that autistic individuals exhibit prospective motor control strategies which vary markedly from one individual to another, even though their overall level of anticipatory movement modulation is comparable to that of neurotypical peers. In their study, autistic participants adjusted their initial grasp patterns to accommodate subsequent actions, but did so with highly individualized strategies. This finding underscores the heterogeneity of motor planning in autism, suggesting that rather than lacking anticipatory capabilities altogether, autistic individuals differ substantially in how they implement these prospective motor adjustments. In line with our findings, such individualized strategies may reflect underlying variability in cerebral connectivity and integration of visual-spatial information (Floris et al., 2013). Therefore, the idiosyncratic visuomotor patterns observed in our task may also represent adaptive or compensatory responses to subtle inefficiencies or differences in the predictive mechanisms that drive motor planning.

Collectively, these findings underscore the interconnection between motor lateralization, spatial strategy, and motor efficiency in autism. Our data align with previous reports, which emphasize that autism involves differences in motor planning, execution, and spatial utilization,

manifesting as reduced lateralization of handedness (Markou et al., 2017; Knaus et al., 2016; Forrester et al., 2014).

The current study has several limitations that should be acknowledged when interpreting the findings. Firstly, although the naturalistic LEGO® building task provides a standardized yet ecologically valid setting, its complexity and the specific skills required may not fully generalize to other motor tasks encountered in daily life. Therefore, it remains unclear whether the observed patterns of reduced lateralization and spatial strategies in autism would manifest similarly across diverse visuomotor tasks. Furthermore, this study examined only a subset of relevant variables, including the proportion of right-hand grasps, cross-body reaching behaviours, spatial block utilization, movement trajectories, and movement time. However, this unique methodology could have captured additional metrics, such as block drops, grasping errors, hand-switching frequency, and gazing patterns, by incorporating eye-tracking technology. Future research using this approach should consider capturing a broader range of visuomotor behaviours and integrating tools like eye tracking or motion capture to gain deeper insights into visuomotor specialization in autism. Despite this being a limitation of the current study, this also highlights the versatility and strength of this methodology for elucidating visuomotor behaviours. Lastly, while Dynamic Time Warping (DTW) effectively quantifies movement variability, this approach is sensitive to variations in movement speed and sequence order, which can potentially confuse the temporal and spatial aspects of motor planning. Additional metrics that independently assess spatial and temporal motor components could provide a more comprehensive understanding of motor planning differences in autism spectrum disorder.

In conclusion, the present study provides robust support and expands upon existing knowledge regarding visuomotor behaviours in autism. The demonstrated reduced handedness

lateralization, unique spatial utilization, and extended task completion times provide valuable evidence of the nuanced and complex motor profiles characteristic of autism spectrum disorder. These findings underscore the importance of accounting for motor and lateralization differences in clinical assessments and interventions for individuals with autism, which may lead to more targeted support strategies and improved functional outcomes.

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