Directional Anisotropy in the Neural Representation of Human Movement Kinematics and Its Relationship to Autistic Features in Children: Results from the Autism Biomarkers Consortium for Clinical Trials (ABC-CT)

Jacob P. Momsen[1], Adam Naples[1], Susan Faja[2], Shafali Jeste[3], Natalia Kleinhans[4,5], Geraldine Dawson[6], James Dziura[7], Frederick Shic[8,9], Sara Webb[9,10], Catherine Sugar[11], April Levin[12,13],James McPartland[1,14]

[1]Yale Child Study Center, Yale University School of Medicine; [2]Department of Pediatrics, Boston Children's Hospital; [3]Department of Pediatrics, Children's Hospital Los Angeles; [4]Department of Radiology, University of Washington School of Medicine; [5]Center On Human Development and Disability, University of Washington; [6]Duke Center for Autism and Brain Development, Duke University; [7]Emergency Medicine, Yale University School of Medicine; [8]Department of General Pediatrics, University of Washington School of Medicine; [9]Center for Child Health, Behavior, and Development, Seattle Children's Research Institute; [10]Department of Psychiatry and Behavioral Science, University of Washington School of Medicine; [11]Department of Biostatistics, University of California Los Angeles; [12]Department of Neurology, Boston Children's Hospital; [13]Department of Neurology, Harvard Medical School; [14]Center for Brain and Mind Health, Yale University School of Medicine

Background

- Gravity is a ubiquitous (though often overlooked) constraint that dictates the nature of real-life, physical events.
- Through experience, developing an internal "model" of gravity facilitates action and perception by organizing *predictions* about the "where" and "when" of event dynamics subject to downward gravitational force, i.e., in the earth-vertical plane [1,2].
- By tuning perception into the physics of real, gravity-affected movement, neurocognitive mechanisms associated with this predictive model are critical for many things, including the interpretation of others' movements [3].
- These mechanisms could offer a mechanistic explanation for behavioral and neurophysiological differences associated with autism in the context of biological motion perception.
- We examine how biological motion information is represented in the brains of autistic and age-matched non-autistic children.
- By decomposing motion dynamics according to their direction in space, i.e., horizontal (orthogonal to gravity) vs vertical (subject to gravity), we test the **hypothesis** that *predictive processing of vertical motion associated with human moveent is especially relevant to the neurocognitive profile of autism.*

Methods

- EEG was recorded as 205 autistic (49 females; μ age=8.57; 1.62) and 91 non-autistic (26 females; μ age=8.46; 1.64) participants passively watched videos of point-light walkers that either preserved the human form or were spatially and temporally scrambled (total # trials=112)[4,5].

Figure 1 Trial Design

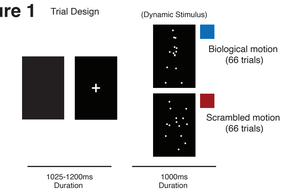
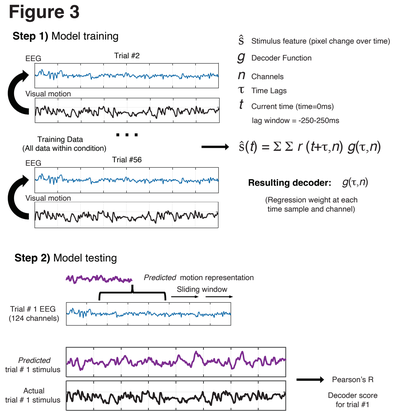


Table 1

	Diagnosis	
	Autism (n=205)	No Autism (n=91)
Age	8.58 (1.62)	8.46 (1.64)
IQ	2.30 (1.32)	1.02 (0.15)
SRS total (raw)	89.98(27.06)	15.19 (12.95)
CASI-5	68.22(16.03)	47.63(6.56)
ADOS-2 (SA)	7.25(1.86)	1.95(1.38)
ADOS-2 (RRB)	8.00 (1.83)	3.09 (2.49)
		mean (std. dev.)

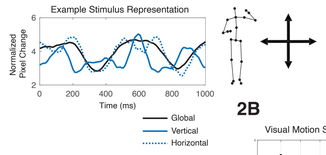
- To assess how visual motion was represented in the EEG, a multivariate linear model (***g***) was used to reconstruct the pixel change trajectory (ŝ) from the neural data (***r***) [6].

Figure 3

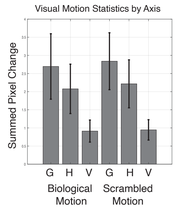


- Visual motion trajectories were calculated using matrix subtraction of pixel values between consecutive frames.
- To represent motion change strictly within each directional axis, pixel values were summed across rows (Vertical) or columns (Horizontal) before computing the frame gradient (See Figure 2).

Figure 2A



2B

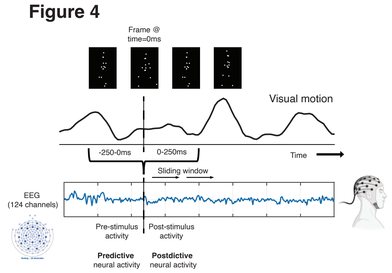


- Within each participant and type of video, a rotating leave-one-out training procedure was used to generate decoders designed to transform EEG data into predicted motion representations [6]. Predicted stimulus features were generated by applying the test-set EEG to the corresponding decoder model.
- Decoder performance was then quantified using correlations between the predicted motion representation against the corresponding veridical motion trajectory associated with the same test-set trial.
- Decoder "scores" generated for each participant reflect how well the computer could learn something about the videos they watched from their brain activity alone (!)—higher scores indicate stronger tracking, or a more precise reflection of that feature in the brain. These scores populate the y-axis in all bar charts seen in the results section.

Analysis

- Decoders learned directly from brain activity recorded shortly before and shortly after the time a particular video frame was witnessed (-250-250ms); where current time=0ms).
- Critically, to probe the engagement of predictive mechanisms for visual motion processing, separate decoders were trained using only activity that occurred in response to a change in the video (i.e., postdictive time lags: 0-250ms), or strictly in anticipation of a change (predictive time lags: -250-0ms).
- Conditional comparisons were performed using random permutation tests on mean decoder scores.
- Individual differences in the temporal distribution of decoders was assessed by summing the absolute value of each set of decoder weights at each channel and iteratively computing Spearman correlations with clinical measures (see Table 1).

Figure 4

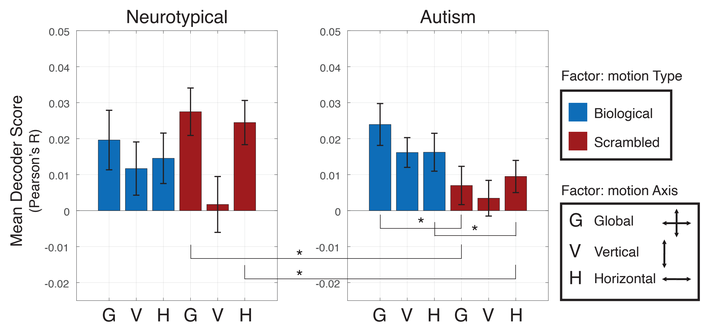


Time lags by decoder type:

"Full" decoder models: -250-250ms of EEG data
"Predictive" decoder models: -250-0ms
"Postdictive" decoder models: 0-250ms

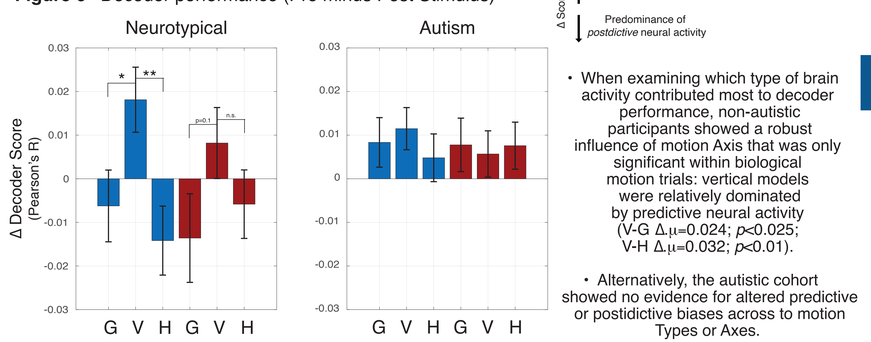
Results

Figure 5 Baseline decoder performance (all time lags)



- No effects of diagnostic Group emerged on decoder scores when full models were trained on biological motion data. By contrast, autistic participants displayed reduced decoder performance relative to non-autistic peers for models trained on scrambled motion trials, both for global (Δ.μ=0.021; $p<0.05$) and horizontal (Δ.μ=0.015; $p<0.05$) motion.
- Futhermore, an effect of motion Axis was only present in the autistic cohort for global and vertical motion models, such that reconstruction performance was significantly diminished for models trained on scrambled motion (GΔ.μ=0.017; $p<0.05$; VΔ.μ=0.013; $p<0.05$).

Figure 6 Decoder performance (Pre minus Post Stimulus)***

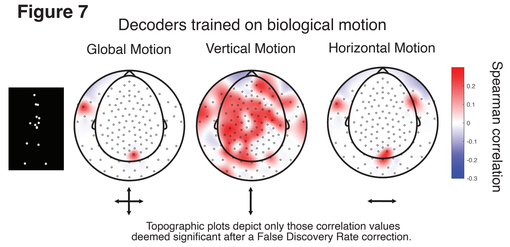


- When examining which type of brain activity contributed most to decoder performance, non-autistic participants showed a robust influence of motion Axis that was only significant within biological motion trials: vertical models were relatively dominated by predictive neural activity (V-G Δ.μ=0.024; $p<0.025$; V-H Δ.μ=0.032; $p<0.01$).
- Alternatively, the autistic cohort showed no evidence for altered predictive or postidictive biases across to motion Types or Axes.

Results

- Participant-level weights from decoders trained on biological motion revealed positive associations with Social Affect subdomain scores of the ADOS-2 (post-stimulus lags; autistic cohort only).
- This provides further support for the hypothesis that perceiving kinetic details about human movement and their relationship to gravity is tied to core attributes of the autistic phenotype.

Figure 7



Conclusions

- By comparing decoder scores across conditions, we found that children with autism were most distinguished from their non-autistic peers when quantifying the engagement of predictive brain activity that was reliably associated with information about the visual content in our video stimuli.
- ***Unlike their non-autistic peers, autistic children did not show evidence for the selective engagement of predictive mechanisms during the apprehension of vertical movement dynamics in biological motion.***
- Atypical engagement of neural mechanisms tuned to predict the consequences of gravity may underlie perceptual differences in autism.

Discussion

- These findings are in line with work showing that the brain's internal model of gravity helps structure visual perception primarily by issuing predictions about natural movement trajectories in space (those associated with earth-vertical dynamics) [7,8].
- Numerous previous reports of reduced ***"inversion effects"*** during the perception of static or dynamic faces and bodies in autism may feasibly be ***(re-)interpreted as a consequence of divergent functioning associated with these gravity-sensitive brain mechanisms***—which are largely managed by the vestibular system [9,10].
- Future work should pursue this underexplored hypothesis, both in the context of biological motion perception, but also in non-social contexts.
- This implicates the vestibular system as a potential target for diagnostic biomarkers and intervention strategies aimed at improving real-world movement interpretation and social communication.

References

[1] Wang, Y., Zhang, X., Wang, C., Huang, W., Xu, Q., Liu, D., ... & Jiang, Y. (2022). Modulation of biological motion perception in humans by gravity. Nature Communications, 13(1), 2765.
[2] Troje, N. F. (2004). Inverted gravity, not inverted shape impairs biological motion perception. Journal of Vision, 4(8), 227-227.
[3] Momsen, J. P., & Coulson, S. (2025). Sensorimotor Account of Multimodal Prosody. Cambridge University Press.
[4] Webb SJ, Naples AJ, Levin AR, et al.The Autism Biomarkers Consortium for Clinical Trials: Initial Evaluation of a Battery of Candidate EEG Biomarkers. American Journal of Psychiatry. 2022;0(0):appi.ajp.21050485.
[5] Faja S, Sabatos-DeVito M, Sridhar A, et al.Evaluation of clinical assessments of social abilities for use in autism clinical trials by the autism biomarkers consortium for clinical trials. Autism Res. May 2023;16(5):981-996.
[6] Crosse MJ, Di Liberto GM, Bednar A, Lalor EC (2016) The Multivariate Temporal Response Function (mTRF) Toolbox: A MATLAB Toolbox for Relating Neural Signals to Continuous Stimuli. Frontiers in Human Neuroscience 10:604.
[7] Jörges, B., & López-Moliner, J. (2017). Gravity as a strong prior: implications for perception and action. Frontiers in Human Neuroscience, 11, 259425.
[8] Takehana, A., Uehara, T., & Sakaguchi, Y. (2019). Audiovisual synchrony perception in observing human motion to music. Plos one, 14(8), e0221584.
[9] Delle Monache, S., Indovina, I., Zago, M., Daprati, E., Lacquaniti, F., & Bosco, G. (2021). Watching the effects of gravity. Vestibular cortex and the neural representation of "visual" gravity. Frontiers in Integrative Neuroscience, 15, 793634.
[10] Barra, J., Senot, P., & Auclair, L. (2017). Internal model of gravity influences configural body processing. Cognition, 158, 208-214.

Funding Sources

The Autism Biomarkers Consortium for Clinical Trials is funded through NIH U19 MH108206 (McPartland); NIMH R01 MH100173 (McPartland)

McPartland Lab
mcp-lab.org
mcp.lab@yale.edu
mcpartland.lab on Instagram

YALE CHILD STUDY CENTER
Where discovery inspires care