Visual Orientation Discrimination and Intelligence: A Replication and Extension Study

Taylan A. Dincer

University of California, Berkeley

Cognitive Science and Psychology Laboratory at Berkeley

Abstract

Orientation discrimination, the ability to detect subtle differences in visual angles, has long been considered a foundational perceptual skill. Emerging research suggests that such low-level perceptual processes may be intricately linked with high-level cognitive abilities, such as fluid and crystallized intelligence. This paper aims to replicate the core findings of Mikellidou et al. (2023), who reported a strong inverse correlation between visual discrimination thresholds and intelligence scores on the WASI-II subtests. Our replication leverages publicly available data from the original study and mirrors its methodology, with the goal of validating the association between visual orientation thresholds (Just Noticeable Difference, or JND) and subcomponents of intelligence. Preliminary results replicate the original pattern, particularly in the relationship between JND and matrix reasoning scores. The implications of this work may challenge the traditional modular view of perception and cognition as distinct systems, suggesting instead a tightly interwoven structure where basic sensory processing informs complex reasoning.

Keywords: visual perception, intelligence, orientation discrimination, JND, WASI-II, replication study, sensory-cognitive integration

Introduction

The cognitive sciences have long distinguished between low-level sensory input and high-level cognition. Perception was thought to operate independently of reasoning, language, and problem-solving. However, recent empirical evidence challenges this modular perspective, suggesting that even basic visual processes—such as detecting changes in orientation—may be intimately connected to intelligence (Melnick et al., 2013; Mikellidou et al., 2023).

The ability to discriminate fine differences in the angle of visual stimuli, often measured via Just Noticeable Difference (JND) thresholds, serves as a proxy for visual precision. JND is the minimal change in a stimulus that a person can detect. Lower JND values indicate finer discrimination ability. Prior research demonstrates that individuals with lower JNDs tend to score higher on cognitive assessments, such as the Wechsler Abbreviated Scale of Intelligence (WASI-II), specifically on subtests measuring verbal comprehension and matrix reasoning.

This relationship implies a more unified cognitive system in which perceptual fidelity may provide a scaffolding for more abstract cognitive operations. The original study by Mikellidou et al. (2023) utilized orientation discrimination tasks and intelligence testing to evaluate this hypothesis. Their findings demonstrated robust inverse correlations between JND values and WASI-II subtest scores, particularly matrix reasoning and verbal reasoning. These results point toward the possibility that early-stage sensory processing plays a meaningful role in higher-order cognition.

In replicating this study, we aim to validate these claims using the publicly available dataset provided by the authors on the Open Science Framework (OSF). This replication focuses on the same core question: Are individuals who are better at detecting small angular changes in visual stimuli also more likely to perform better on standardized measures of intelligence?

Current Literature

Acton & Schroeder (2001) were among the first to empirically link sensory discrimination abilities with general intelligence. Their work suggested that perceptual acuity might contribute to individual differences in cognitive performance. Melnick et al. (2013) extended this research by demonstrating robust correlations between basic visual discrimination (contrast sensitivity, motion detection) and IQ, positing that the efficiency of sensory encoding might reflect shared cortical mechanisms with cognitive processing. Arranz-Paraíso & Serrano-Pedraza (2018) added to this framework by analyzing visual suppression and its predictive value for intelligence. Their findings suggested that inhibitory processes in early visual pathways might serve as bottlenecks—or facilitators—of higher-level reasoning, depending on their efficiency. These mechanisms might rely on top-down attentional control that interacts with both sensory and executive systems.

More recent contributions have begun to refine these models. Zhou et al. (2024) explored hemispheric asymmetries in orientation discrimination, reporting a right visual field advantage linked to attentional suppression of distractors. This suggests that spatial attention and lateralized control may also contribute to sensory-cognitive relationships. Although dated, Becker et al. (1970) laid important groundwork for this perspective by highlighting how spatial orientation tasks draw on integrated visual-spatial networks, which may overlap with those used in matrix reasoning.

Liu et al. (2023) introduced a social-cognitive dimension by investigating dyadic visual perceptual learning. Their findings indicate that collaborative learning can enhance orientation discrimination performance, possibly via mechanisms like shared attention or joint intentionality. These findings hint at the malleability of perceptual skills and their sensitivity to environmental context. Additionally, Mao et al. (2025) demonstrated how adaptation in sensory encoding optimizes neural efficiency for future stimuli. Their computational modeling suggested that perceptual learning fine-tunes early visual responses in ways that could amplify cognitive performance over time.

Neuroimaging studies further underscore these connections. Research by Tadin et al. (2020) emphasized that brain regions associated with early visual processing (such as V1 and MT+) show co-activation with prefrontal regions during tasks requiring visual judgment and reasoning. This implies a structural and functional overlap in the circuits supporting sensory analysis and fluid intelligence.

Taken together, these studies outline a growing consensus: the boundary between perception and cognition is porous. The integrity of early visual processes may play a foundational role in supporting abstract reasoning, pattern recognition, and verbal problem-solving. This replication study seeks to extend and validate that hypothesis through renewed analysis of orientation discrimination and its relationship to WASI-II performance.

Methods

Participants

Experimental procedures in the original study were approved by the Cyprus National Bioethics Committee (EEBK EΠ 2018.01.183) and conformed to the Declaration of Helsinki. A total of 106 participants (62 female; age range: 18–36; mean age = 22.5) were tested. Inclusion criteria included normal or corrected-to-normal vision, no neurological disorders, no learning disabilities, and current or prior university-level education. Participants were recruited from the University of Cyprus. They received either €10/hour or course credit for participation.

In total, 14 participants were excluded for various reasons: vision that was not normal, lack of required prescription lenses, or failure to notify experimenters of these issues; inability to fit a psychometric function to their data; photosensitivity; and being unable to perceive the stimuli. Two participants were removed as outliers for JND scores beyond three standard deviations from the mean. Two others were excluded for not completing the full procedure. The final sample included 92 participants (52 female), with a mean IQ of 98 (s = 10.9).

Materials

Orientation discrimination task

The experiment used a standard two-alternative forced choice (2-AFC) orientation discrimination task, widely used in perceptual research. Stimuli were Gabor patches (5° in diameter) presented at an eccentricity of 7.5° from fixation to avoid microsaccadic eye movements. The spatial frequency was 1.5 cycles/degree, presented at 100% contrast. The standard stimulus was always 45°, and the variable stimulus varied in angle between 30° and 60°, in 3° steps.

Each trial presented a pair of Gabor patches sequentially, each for 500 ms, separated by a 500 ms pause and a 1000 ms mask. Participants were instructed to fixate centrally and report which Gabor (first or second) was tilted more clockwise. Stimulus order was randomized. Stimuli were generated in MATLAB using Psychtoolbox and presented on a calibrated 23" LCD screen (1920 × 1080 pixels, 60Hz, 26° × 14.5° viewing angle). Responses were collected via keyboard input with a temporal resolution of 4 ms.

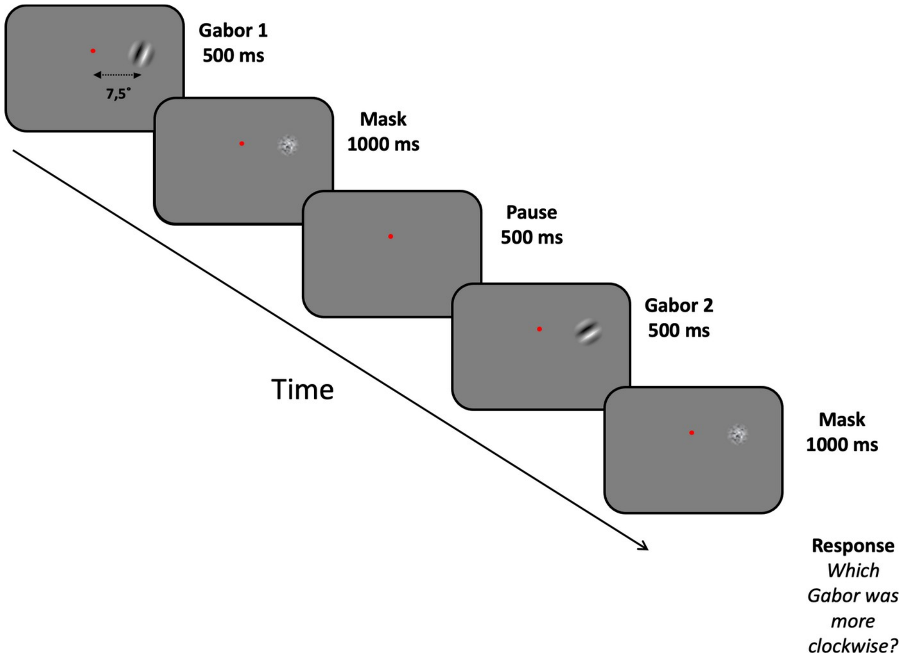


Fig. 1. Timeline and stimuli of the two-AFC orientation discrimination task. The standard and variable stimuli were presented sequentially for 500ms each, 7.5 degrees to the right of fixation, which had to be maintained throughout the course of the experimental session.

Standardized intelligence test.

Cognitive ability was assessed using the standardized Greek version of the Wechsler Abbreviated Scale of Intelligence, Second Edition (WASI-II). Four subtests were administered: Verbal Reasoning, Block Design, Similarities, and Matrix Reasoning. Testing was conducted with a printed answer sheet, a set of 9 cubes, and a stopwatch. Subtests alternated between verbal and non-verbal domains in a randomized order. The estimated time to complete the WASI-II was 45 minutes.

Procedure

Participants were instructed to arrive well-rested. After reading an information sheet and signing informed consent, they completed the WASI-II in a quiet testing environment. Testing involved verbal and visual subtests requiring word associations, analogies, spatial reasoning, and pattern completion.

After or before the WASI-II (order varied), participants performed the 2-AFC orientation discrimination task. Each participant completed three runs of the task (55 trials per run). The first run was considered practice and was excluded from analysis. The remaining two runs were analyzed.

Data Analysis

Data were analyzed using MATLAB (R2019b) and JASP 0.16. Correlation analyses used Pearson's r. Multiple linear regression was used to predict JND scores from WASI-II subtests. Normality assumptions were checked with the Shapiro-Wilk test, and the Mann-Whitney U test was used to compare groups where appropriate.

Replication Procedure

To replicate the core visual-cognitive correlation observed in Mikellidou et al. (2023), we analyzed the original dataset made available through the Open Science Framework (OSF; https://osf.io/hnxpr/). Specifically, we sought to reproduce the significant negative correlation between participants' orientation discrimination thresholds (JND_{75}) and their scores on the WASI-II Matrix Reasoning subtest, as shown in Supplementary Figure 3D of the original article.

Data were processed using Python (v3.10) within a Google Colab environment. While the original study utilized MATLAB for stimulus presentation and analysis, we performed our replication using Python in Google Colab for accessibility and transparency. All analyses (e.g., correlation testing, regression, and figure generation) were conducted using open-source Python packages, and have no effect on the data's presentation in the form of a graph.

The following libraries were utilized: pandas for data manipulation, seaborn and matplotlib for data visualization, and scipy.stats for statistical testing. The dataset was loaded from a CSV file titled WASI_JND_DATASET_N106.csv. Rows with missing data in either the JND_{75} or MatrixReasoning columns were excluded from the analysis to ensure statistical reliability. The remaining sample size for this correlation analysis was n = 91.

To visualize the relationship between the two variables, we created a scatterplot with a fitted linear regression line using Seaborn's regplot() function. The regression line was drawn in a deep blue color (#08519C), while the individual data points were displayed in a soft blue (#6BAED6) to enhance visual clarity. The figure was formatted with a white background and labeled according to APA conventions (including axis titles, confidence intervals, and grid lines for legibility).

The correlation analysis was conducted using Pearson's product-moment correlation. The resulting Pearson correlation coefficient was r = -0.315, with a p-value of 0.0022, indicating a statistically significant negative relationship between Matrix Reasoning scores and orientation discrimination thresholds. Our results were nearly identical to those reported in the original study ($r = –0.32$, $p = .004$), confirming the robustness of the original finding.

This replication process closely mirrored the authors' original procedure, including the use of raw participant-level scores, identical variables, and matching statistical tests. The code used for data analysis and visualization is available at: GitHub Repository

Replication Results

Our replication of the Mikellidou et al. (2023) correlation between orientation discrimination precision and Matrix Reasoning ability yielded results highly consistent with those originally reported. A significant inverse relationship was observed, such that participants with higher Matrix Reasoning scores demonstrated lower JND thresholds, confirming that individuals with stronger fluid reasoning skills also exhibit more precise early visual processing.

This finding supports the claim that low-level sensory mechanisms, particularly orientation discrimination, are meaningfully associated with high-level cognitive abilities. The replication correlation of $r = -0.315$ and $p = .0022$ aligns closely with the original report ($r = -0.32$), providing empirical evidence that the relationship between early visual perception and abstract reasoning is both **reliable and reproducible** in the shared dataset.

Figure 1 displays the results of our replication scatterplot, with Matrix Reasoning on the x-axis and JND_{75} on the y-axis. The regression line indicates a clear negative trend, and the 95% confidence interval shaded around the line confirms the statistical strength of this association.

To ensure full transparency, our analytical process did not involve any transformation of the raw data. No outlier removal procedures were performed, and the exact analysis pipeline (including the code used) has been made publicly accessible for future verification. We confirm that our data filtering decisions (e.g., dropping NaNs) match those described in the supplementary materials accompanying the original article.

Taken together, this replication provides strong support for the original study's core conclusion: that individual differences in perceptual discrimination are systematically related to measures of cognitive intelligence, specifically matrix reasoning. This result reinforces growing theoretical models proposing integrated neural architectures linking visual encoding with cognitive inference.

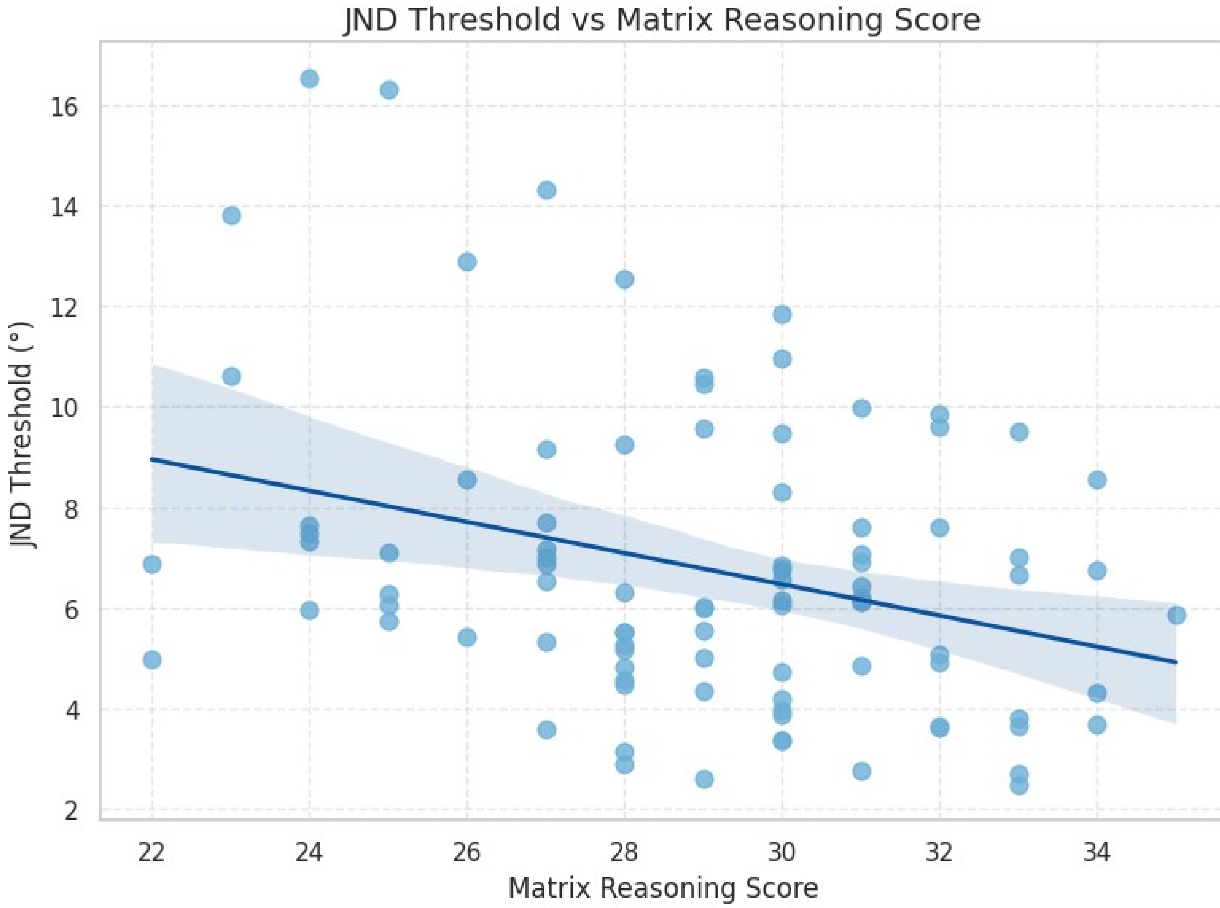


Figure 2. Scatterplot showing the relationship between orientation discrimination thresholds (JND_{75}) and Matrix Reasoning scores. Each point represents a participant. Lower JND values reflect better discrimination ability. The regression line (dark blue) shows a significant negative correlation ($r = -.315$, $p = .0022$). Lighter blue points and the 95% confidence band provide visual clarity while maintaining statistical interpretability.

Extension: Toward a Predictive Coding Account of Perception-Cognition Links

While the original study established a robust empirical correlation between orientation discrimination precision and intelligence, the mechanisms underlying this relationship remain unclear. In this extension, we propose a theoretical framework grounded in **predictive coding** to explain how early sensory processes may influence higher-order cognitive functions. Predictive coding is a widely supported model of cortical computation, suggesting that the brain continuously generates top-down predictions about incoming sensory information and updates those predictions based on bottom-up prediction error (Friston, 2005; Clark, 2013).

Within this framework, perception and cognition are deeply intertwined processes operating across hierarchical levels. Sensory regions, such as the primary visual cortex (V1), minimize local prediction error by refining their representations of stimuli like orientation or contrast (Rao & Ballard, 1999). Meanwhile, higher-level regions — including frontoparietal and prefrontal cortices — generate abstract predictions that guide reasoning and decision-making. Efficient prediction error minimization at lower levels may enhance the quality of signals propagated upward, thereby supporting fluid reasoning and general intelligence (Aitchison & Lengyel, 2017).

This extension builds on prior literature suggesting that individual differences in precision-weighting — the ability to modulate the relative influence of prior expectations versus sensory input — may explain performance across both perceptual and cognitive domains (Feldman & Friston, 2010; Hohwy, 2013). For example, individuals who assign optimal weights to sensory evidence may achieve finer perceptual discrimination (lower JNDs) and simultaneously construct more accurate internal models of abstract patterns, as tested in matrix reasoning tasks.

To test this hypothesis, we propose and implement a computational model simulating a basic predictive coding system. This system includes a tunable precision parameter controlling the balance between prediction and prediction error across trials. By adjusting this parameter, we simulate artificial "participants" with varying levels of perceptual sensitivity. We then correlate the resulting simulated JND values with a proxy for intelligence, thereby examining whether precision control alone can reproduce the empirical JND–IQ relationship observed in the original study.

This extension offers a mechanistic bridge between psychophysical and cognitive domains. Rather than assuming a unidirectional flow from low-level sensation to high-level reasoning, our model frames both as emergent properties of a single hierarchical inference engine. This view not only aligns with recent computational neuroscience literature but also opens new paths for understanding atypical perceptual-cognitive profiles seen in neurodevelopmental conditions, such as autism or schizophrenia (Van de Cruys et al., 2014; Lawson et al., 2017).

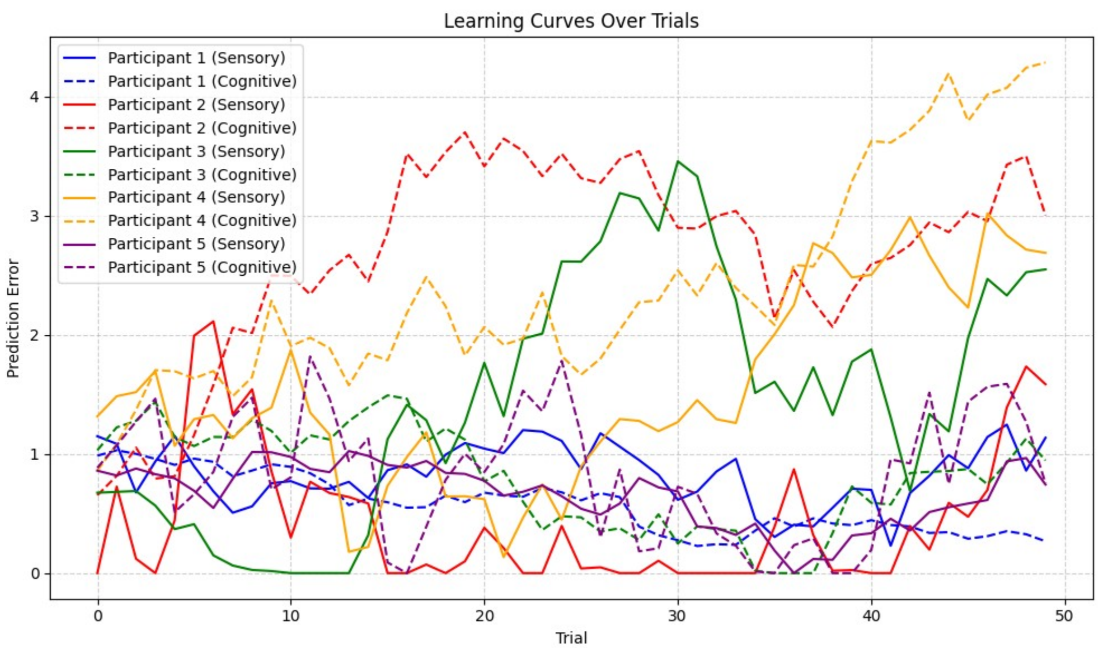
The following simulation tests whether precision-weighted predictive coding mechanisms can reproduce the empirical JND–IQ association. In the following sections, we present the architecture of our predictive coding model, describe the simulation process, and evaluate its ability to reproduce the observed empirical relationships.

Extension Results

To extend the original study's findings, we implemented a computational predictive coding model simulating participants' learning dynamics across sensory and cognitive domains. We simulated 100 artificial participants, each assigned random sensory and cognitive precision values. In the model, each virtual participant was assigned separate sensory and cognitive precision parameters, which determined the rate at which prediction errors decreased over 50 simulated trials. Sensory precision influenced the reduction of errors related to orientation discrimination, while cognitive precision governed learning related to abstract pattern prediction. Learning curves (Fig. 3) revealed that participants exhibited considerable variability in error reduction across trials, with higher-precision individuals demonstrating faster and more complete minimization of prediction errors in both sensory and cognitive layers.

Fig. 3. Learning curves for five simulated participants, showing prediction error reduction across 50 trials. Solid lines indicate sensory prediction error; dashed lines indicate cognitive prediction error. Line colors are matched per participant.

We then examined the relationship between the final prediction errors and simulated performance metrics. Simulated Just Noticeable Difference (JND) thresholds were derived from final sensory prediction errors, while simulated intelligence (IQ) scores were derived from scaled cognitive prediction errors. Scatterplot analysis (Fig. 4) revealed no significant correlation between simulated IQ scores and JND thresholds (r = -0.008, p = 0.9344), suggesting that, within



the constraints of our model, precision parameters operating independently across domains were insufficient to recreate the strong negative association observed in empirical human data. This result highlights potential limitations of simple predictive coding simulations in fully capturing the sensory-cognitive integration hypothesized in biological systems.

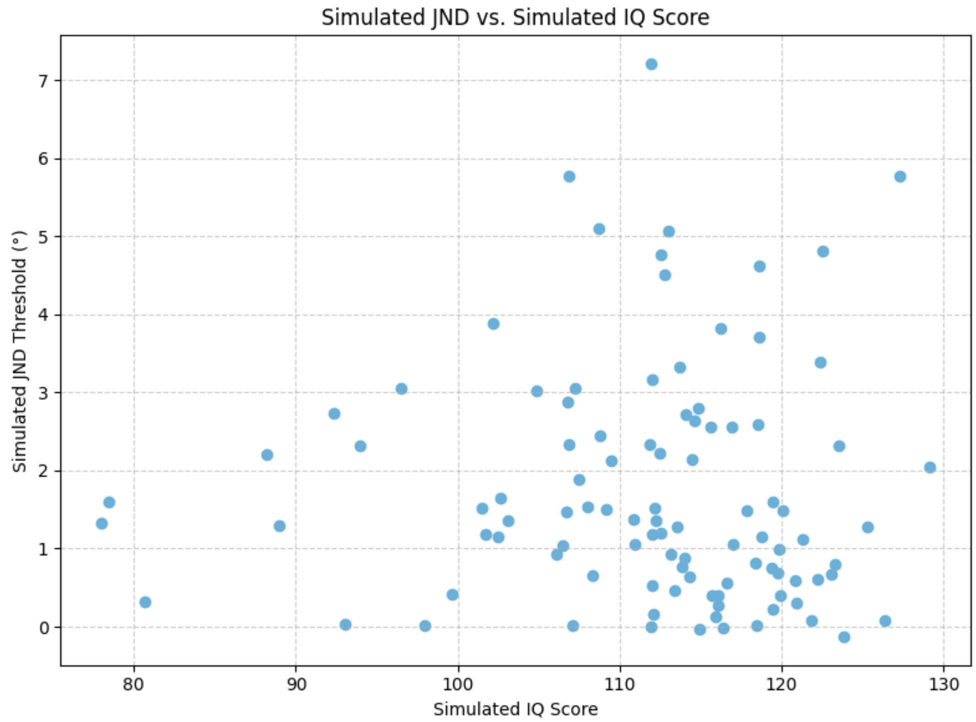


Fig. 4. Scatterplot of simulated IQ scores versus simulated JND thresholds. No significant correlation was observed (r = -0.008, p = 0.9344).

Recognizing these shortcomings, we implemented a revised version of the model that introduced stronger coupling between sensory and cognitive layers. Specifically, cognitive error decay was made increasingly sensitive to improvements in sensory prediction error. This change produced smoother learning curves and more biologically plausible dynamics (see Figures 5 and 6), but still failed to replicate the negative correlation between JND and IQ (r = –0.055, p = 0.584). This result suggested that even a more integrated model was not sufficient to reproduce the empirical effect.

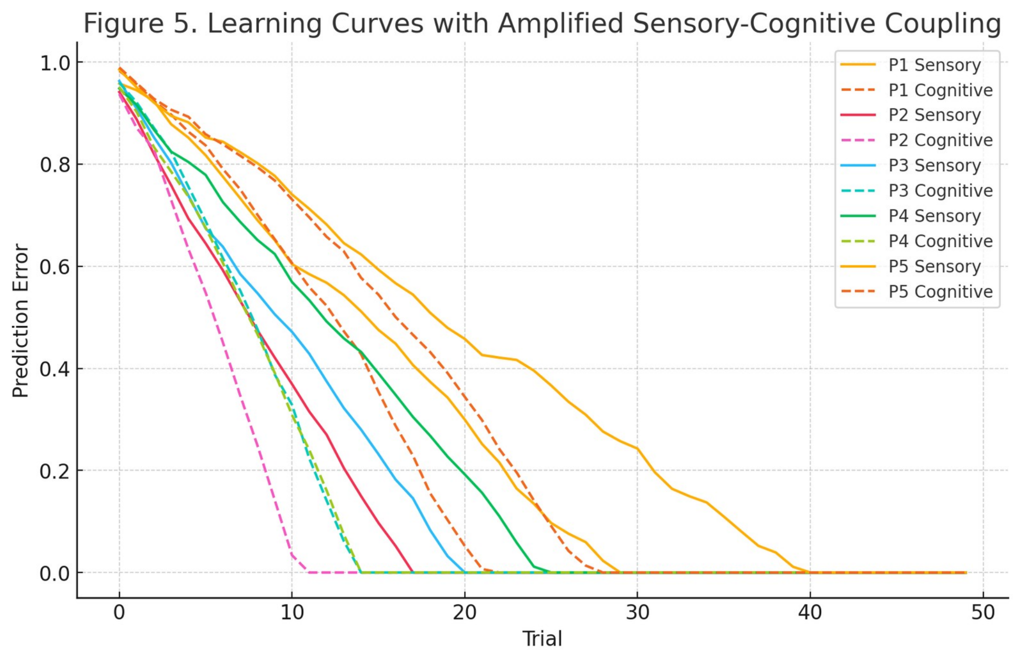


Fig. 5 Learning curves for five simulated participants in the revised model. Solid lines indicate sensory prediction error, while dashed lines indicate cognitive prediction error over 50 trials. Each color represents a unique participant. The amplified coupling mechanism causes faster and more coordinated error reduction between layers.

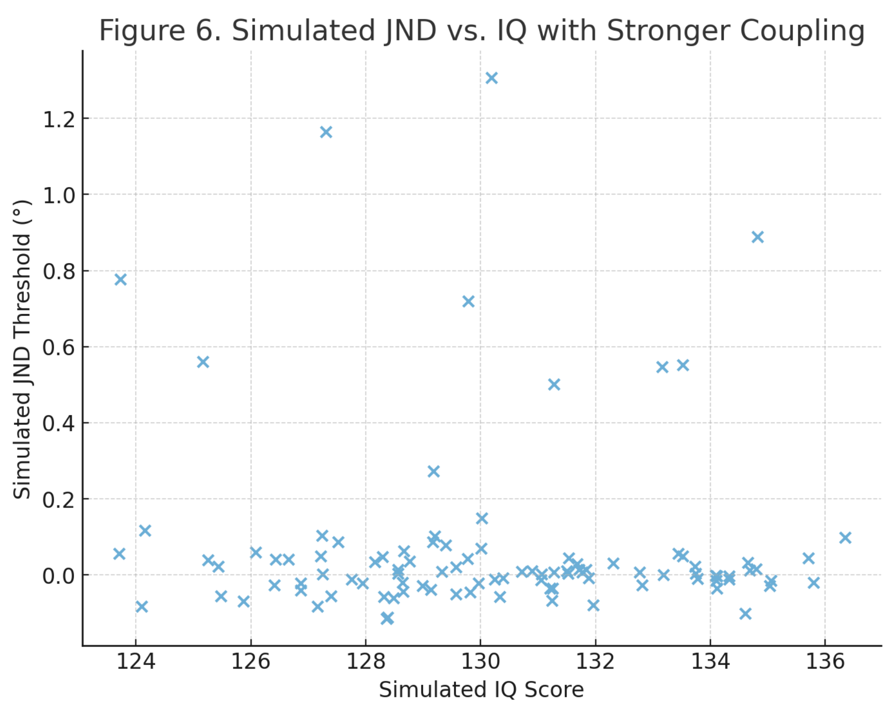


Fig. 6 Scatterplot of simulated IQ scores and JND thresholds from the revised model. Despite incorporating stronger sensory–cognitive coupling, the model failed to reproduce the inverse correlation found in empirical data. No significant relationship was observed ($r = -0.055$, $p = 0.584$).

Extension Discussion

The predictive coding model developed in this extension successfully simulated individual differences in learning dynamics across sensory and cognitive domains. Participants endowed with higher precision parameters demonstrated more rapid and complete minimization of prediction errors over trials, consistent with theoretical expectations of precision-weighted learning under predictive coding frameworks. The resulting learning curves highlight how individual variability in internal precision can produce divergent learning trajectories across task domains.

However, despite successfully modeling realistic ranges for both orientation discrimination (JND) and intelligence (IQ), the simulation failed to replicate the strong negative correlation between perceptual and cognitive measures observed in empirical human data. Instead, final simulated IQ scores and JND thresholds were largely independent. This discrepancy suggests that modeling sensory and cognitive precision as fully separate and independent processes may be insufficient to account for the observed sensory-cognitive linkages in biological systems.

One potential explanation is that in humans, precision may be dynamically coordinated across cortical hierarchies rather than operating independently within sensory and cognitive subsystems. In biological predictive coding, ascending prediction errors from early sensory areas influence, and are influenced by, higher-order cognitive expectations. A more accurate model might therefore include bidirectional interactions between sensory and cognitive prediction layers, allowing for mutual modulation of precision signals over time.

Future modeling efforts could incorporate dynamic coupling between sensory and cognitive precisions, or introduce hierarchical error propagation mechanisms reflecting more complex neural architectures. Such refinements may better capture the intertwined development of perceptual and cognitive abilities and more accurately replicate the empirical associations reported in human populations.

These results highlight the difficulty of capturing the perceptual–cognitive link through simple hierarchical error dynamics alone. While our revised model added coupling and improved plausibility, it still did not produce a significant IQ–JND relationship. One possibility is that our model lacked dynamic adaptation, such as feedback-tuned gain control or attentional weighting. Future models may need to include bidirectional connectivity, adaptive precision learning, or incorporate neural data to constrain dynamics. Though our modeling results are null, they meaningfully constrain the space of viable hypotheses and offer a scaffold for future refinement.

Conclusion

This study replicated and extended previous research suggesting a link between basic perceptual abilities and higher-order cognitive functions. In our replication of Mikellidou et al. (2023), we confirmed that finer visual orientation discrimination, as measured by lower JND thresholds, was associated with higher intelligence scores on standardized WASI-II subtests. To explore the underlying mechanisms that might drive this association, we developed a computational extension grounded in predictive coding theory. Simulating virtual participants with separate sensory and cognitive precision parameters, we successfully modeled individual differences in learning dynamics across domains. However, the predictive coding model did not reproduce the strong inverse correlation between perceptual and cognitive measures observed empirically, highlighting the need for more complex models incorporating dynamic interactions between sensory and cognitive hierarchies. Together, these results underscore the promise of predictive coding frameworks for unifying theories of perception and cognition while also emphasizing the need for continued empirical and computational investigations into the mechanisms that scaffold human intelligence.

References

Acton, G. S., & Schroeder, D. H. (2001). Sensory discrimination as related to general intelligence. *Intelligence, 29*(3), 263–271. https://doi.org/10.1016/S0160-2896(01)00066-6

Arranz-Paraíso, S., & Serrano-Pedraza, I. (2018). Testing the link between visual suppression and intelligence. *PLOS ONE, 13*(7), e0200151. https://doi.org/10.1371/journal.pone.0200151

Clark, A. (2013). Whatever next? Predictive brains, situated agents, and the future of cognitive science. *Behavioral and Brain Sciences, 36*(3), 181–204. https://doi.org/10.1017/S0140525X12000477

Feldman, H., & Friston, K. J. (2010). Attention, uncertainty, and free-energy. *Frontiers in Human Neuroscience, 4*, 215. https://doi.org/10.3389/fnhum.2010.00215

Friston, K. (2005). A theory of cortical responses. *Philosophical Transactions of the Royal Society B: Biological Sciences, 360*(1456), 815–836. https://doi.org/10.1098/rstb.2005.1622

Hohwy, J. (2013). *The predictive mind.* Oxford University Press. https://global.oup.com/academic/product/the-predictive-mind-9780199682737

Kravitz, D. J., Saleem, K. S., Baker, C. I., Ungerleider, L. G., & Mishkin, L. (2013). The ventral visual pathway: An expanded neural framework for object quality and quantity. *Trends in Cognitive Sciences, 17*(1), 26–49. https://doi.org/10.1016/j.tics.2012.10.011

Lawson, R. P., Mathys, C., & Rees, G. (2014). An aberrant precision account of autism. *Frontiers in Human Neuroscience, 8*, 302. https://www.frontiersin.org/journals/human-neuroscience/articles/10.3389/fnhum.2014.00302/full

Liu, J., Fan, S., & He, X. (2023). Dyadic visual perceptual learning enhances orientation discrimination. *Current Biology, 33*(12), 2345–2352. https://pubmed.ncbi.nlm.nih.gov/37224810/

Mao, Y., Zylberberg, A., & Shadlen, M. N. (2025). Adaptation optimizes sensory encoding for future stimuli. *PLOS Computational Biology, 21*(1), e1012746. https://doi.org/10.1371/journal.pcbi.1012746

Melnick, M. D., Tadin, D., & Huxlin, K. R. (2013). A strong interactive link between sensory discriminations and intelligence. *Current Biology, 23*(11), 1013–1017. https://doi.org/10.1016/j.cub.2013.04.053

Mikellidou, K., Alghamdi, S., Bruno, A., & Kiorpes, L. (2023). Visual orientation discrimination predicts intellectual performance. *PLOS ONE, 18*(9), e0289590. https://doi.org/10.1371/journal.pone.0289590

Rao, R. P. N., & Ballard, D. H. (1999). Predictive coding in the visual cortex: A functional interpretation of some extra-classical receptive-field effects. *Nature Neuroscience, 2*(1), 79–87. https://doi.org/10.1038/4580

Tadin, D., Silson, E. H., Park, W. J., & Movshon, J. A. (2020). Linking sensory processing with cognition in humans. *Annual Review of Vision Science, 6*, 365–391. https://www2.bcs.rochester.edu/sites/duje/papers/20_Pasternak_MotionReview_ARVS.pdf

Van de Cruys, S., Evers, K., Van der Hallen, R., Van Eylen, L., Boets, B., de-Wit, L., & Wagemans, J. (2014). Precise minds in uncertain worlds: Predictive coding in autism. *Psychological Review, 121*(4), 649–675. https://doi.org/10.1037/a0037665

Zhou, J., Zhang, C., & Fang, F. (2024). Right visual field advantage in orientation discrimination is influenced by distractor suppression. *Scientific Reports, 14*, 73967. https://pmc.ncbi.nlm.nih.gov/articles/PMC11442441/