

Precision Weighting in Predictive Coding Frameworks: A Neurocognitive Account of Musical Expertise in Autism

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Abstract

Exceptional musical ability has repeatedly been reported among autistic individuals. Absolute pitch occurs in under 1% of the general population but in approximately 5–11% of autistic individuals, and enhancements have been documented in pitch discrimination, melodic memory, and the recognition of emotion conveyed by music. In some autistic individuals, these abilities exceed those of non-autistic listeners, yet their neural mechanism remains unresolved. This study develops that mechanism within the predictive coding framework. Precision accounts of autism converge on a setting in which the inverse-variance weight, or

precision, assigned to sensory prediction errors is elevated and insufficiently modulated by context. This setting is proposed to produce musical expertise along a chain running from the gain on prediction-error units in auditory cortex, through the population-level precision of pitch representation and locally hyperconnected network organization, to perceptual-categorical learning through veridical mapping. Because precision is a continuous parameter and different musical abilities depend on different levels of the chain, from enhanced recognition of emotion in music at the first level to absolute pitch at the fourth, outstanding musical ability would be expected in only a subset of individuals. The chain is likely to operate only where the statistical structure of the input is stable. Music, being hierarchical, repetitive, and governed by a closed rule system, satisfies that condition more fully than speech, whose grammatical regularities coexist with variation across talkers and contexts, and social interaction, so musical strength and social difficulty can both be understood as consequences of the same precision setting operating in two statistical environments. The same setting would impose a cost on rhythmic entrainment, which requires sensory attenuation. Four testable predictions are derived from the account.

Keywords: predictive coding, precision weighting, autism spectrum disorder, absolute pitch, auditory cortex, musical expertise

1. Introduction

Autism is associated with an unusual concentration of musical ability. Absolute pitch, the capacity to identify or produce a musical tone without an external reference, occurs in well under 1% of the general population but has been reported in approximately 5–11% of autistic individuals (DePape et al., 2012; Rimland & Fein, 1988; Wenhart et al., 2019). Musical savants, whose musical skill far exceeds what their general cognitive profile would predict, also occur more frequently among autistic people than in the general population, music being one of the domains in which savant skills most often appear (Daniel & Menashe, 2020; Meilleur et al., 2015). Beyond these categorical abilities, autistic listeners discriminate pitch more finely, retain melodies over longer intervals, and identify emotion in music more accurately than comparison listeners (Sivathanas et al., 2023; Stanutz et al., 2014; Weiss et al., 2021). The advantage is not distributed evenly across autistic individuals: ability far exceeding that of non-autistic listeners is concentrated in a subgroup (Dumont et al., 2024; Wang et al., 2023).

The mechanism underlying these abilities remains unclear. Autistic perception has been characterized by two influential accounts. Enhanced perceptual functioning holds that low-level processing operates with greater autonomy and plays a larger role in cognition (Mottron et al., 2006). Weak central coherence holds that processing is biased toward local over global information (Happé & Frith, 2006). Although both describe the pattern accurately, neither specifies what differs computationally between autistic and non-autistic perceivers, how that difference is implemented in the brain, how it becomes a musical skill, or why it does so in only some individuals.

Musical listening rests on capacities that are shared by all listeners. The auditory system encodes frequency along a tonotopic map in which neurons are tuned to narrow frequency

bands, and the precision of that encoding sets the finest pitch difference a listener can resolve. Above this, listeners acquire the regularities of their musical culture through passive exposure, so that a familiar style generates expectations about which pitch, chord or beat will follow. Musical perception is on current accounts a predictive process: the brain continuously anticipates upcoming events, and the resulting expectations govern not only what is heard but the emotional response to it and the capacity to move in time with it (Koelsch et al., 2019; Vuust et al., 2022). On this view, musical expertise can be understood as a change in how precisely these predictions and their violations are represented.

The relevant quantity is precision, the inverse-variance weight assigned to sensory prediction errors within a hierarchical inference system (Friston, 2010; Lawson et al., 2014). Where this weight is elevated and insufficiently modulated by context, sensory evidence is encoded with unusual fidelity. This fidelity can be converted into musical expertise across four levels. First, the gain on the superficial pyramidal cells that report prediction error in the auditory cortex is set high by inhibitory circuitry and cholinergic neuromodulation. Second, that gain is expressed in the precision of the pitch estimate supported by a neuronal population. Third, dense local connectivity integrates the outputs of that population into a single code. Fourth, veridical mapping binds precise perceptual values to categories and consolidates them as priors. Different musical abilities may depend on different levels of the proposed chain; together with the continuous nature of precision, this could explain why musical ability exceeding that of non-autistic listeners appears in only some autistic listeners. The chain is likely to produce skill only where the statistics of the input are stable, a condition that music meets more fully than speech and social interaction. The same setting would also impose a cost on rhythmic entrainment and vocal imitation, which require lowering the sensory precision of self-generated sound. Each link is stated as a measurable quantity, so the account can be tested at the level of its individual components. The review draws on behavioral, neuroimaging, electrophysiological and computational studies, giving priority to original research on music and auditory perception in autism published since 2018.

2. Enhanced Auditory Perception in Autism

The behavioral evidence for altered auditory perception in autism is now substantial. The enhancement is confined to domains, and it is pronounced in a subset of autistic individuals (Table 1).

2.1 Pitch and Melody

Enhanced pitch processing has been documented across paradigms and age ranges, and the earliest of the modern demonstrations already indicated that it is not uniform across the spectrum. Bonnel et al. (2010) found superior pure-tone pitch discrimination among autistic participants but not among participants with Asperger syndrome, a dissociation that tracks a history of language delay rather than diagnosis as such. Stanutz et al. (2014) tested musically untrained autistic children against age- and IQ-matched comparison children and found finer discrimination of isolated tones together with better retention of melodies across a week-long interval, so that the advantage was present both in immediate resolution and in storage. Weiss et al. (2021) extended the memory result to vocal melodies and reported comparable

enhancement in Williams syndrome, indicating that the effect is not unique to autism among neurodevelopmental conditions. A narrative review of the wider auditory literature concludes that non-linguistic auditory perception in autistic children differs from that of non-autistic children and locates the difference in a processing bias toward local-level acoustic information (Hisaizumi & Tantam, 2024). Absolute pitch represents the categorical expression of the same capacity. Its prevalence in autism, at 5–11%, is an order of magnitude above the general-population rate (DePape et al., 2012; Rimland & Fein, 1988; Wenhart et al., 2019), and among professional musicians absolute-pitch proficiency covaries with autistic traits (Wenhart et al., 2019). Musical savant skills show the same asymmetry at the level of whole abilities: roughly half of savant individuals are autistic, and 10–30% of autistic people show some savant skill, with music among the domains in which such skills most often appear (Daniel & Menashe, 2020; Meilleur et al., 2015).

2.2 Domain Specificity

The advantage is specific to the auditory-musical domain rather than general, and the sharpest evidence comes from studies that measure the same capacity inside and outside music within the same participants. Sivathanan et al. (2023) found that autistic children recognize basic emotions conveyed by music more accurately than comparison children while recognizing the same emotions in faces and voices at typical levels. Melodic and rhythmic perception, assessed with cognitively matched tasks, is intact (Jamey et al., 2019). The dissociation therefore appears to depend on whether the regularities of a domain can be extracted from the signal itself. Vocal imitation separates perception from production within the auditory domain itself. Wang et al. (2021) compared 25 autistic children and 19 autistic adults with comparison participants matched on age, gender, musical training, and cognitive ability, and found the autistic groups less accurate on absolute pitch and duration matching in both speech and song while performing at comparison level on relative pitch and duration. A subsequent study of 33 autistic and 30 non-autistic Mandarin speakers did not reproduce that pattern in the same form: relative pitch imitation was less accurate in the autistic group for speech but not for song, and the groups did not differ on absolute pitch matching for song (Wang et al., 2025). Read together, the two studies indicate that precise perceptual representation is available while its conversion into vocal output is not, and that where the boundary falls depends on the domain and on the listener's language.

2.3 Subgroup-specific Enhancement

The group-level pitch advantage is consistent but modest, and it is concentrated in a subset of individuals within the autistic population. A meta-analysis of 22 studies comprising 464 autistic participants obtained a standardized effect of $g = 0.26$ for non-speech pitch perception, moderated by intellectual ability (Chen et al., 2022), and in a sample of 164 autistic and non-autistic participants, cognitive abilities likewise moderated the relationship between pitch performance and diagnosis (Ong et al., 2024). Using reverse correlation to recover mental representations of pitch contours, Wang et al. (2023) found that 5 of 32 autistic participants exceeded the comparison mean by more than two standard deviations. Among 46 French-speaking autistic children aged 9–16 years, Dumont et al. (2024) identified 12 who

had acquired English solely through exposure to screens; these children performed above chance in every condition of a pure-tone discrimination task with pairs differing by 1–3%, outperforming both their autistic and their non-autistic peers, and overall linguistic ability did not predict pitch performance. In that study, screen-acquired English was used to identify the subgroup, not to measure pitch ability, and the exposure was neither supervised nor quantified. Musical training is another possible moderator. Stanutz et al. (2014) tested musically untrained children and Wang et al. (2021) matched groups on musical training, but the interaction between training and cognitive ability has not been examined in autistic samples. If precision is a continuous parameter, the subgroup showing musical ability beyond that of non-autistic listeners would be the upper tail of its distribution, and the moderating role of cognitive ability likely reflects the resources required to convert a perceptual advantage into a musical skill.

Table 1. Primary behavioral evidence for altered auditory and musical perception in autism

Sample	Task	Principal finding	References
Participants with autism or Asperger syndrome	Pure-tone pitch discrimination	Enhancement in autism, not in Asperger syndrome	Bonnell et al., 2010
Autistic children, age- and IQ-matched	Tone discrimination; melodic memory over one week	Finer discrimination and better retention	Stanutz et al., 2014
Autism and Williams syndrome	Memory for vocal melodies	Enhancement in both groups	Weiss et al., 2021
Autistic children	Emotion recognition in music, faces and voices	Enhanced for music, typical for faces and voices	Sivathanas et al., 2023
Autistic children	Cognitively matched melodic and rhythmic perception	Intact	Jamey et al., 2019
44 autistic children and adults	Speech and song imitation	Absolute matching impaired, relative matching intact	Wang et al., 2021
33 autistic Mandarin speakers	Speech and song imitation	Relative pitch impaired for speech only	Wang et al., 2025
12 autistic children with screen-acquired English	Two-alternative forced-choice pitch discrimination	Above chance at all difficulties; outperformed both peer groups	Dumont et al., 2024
Meta-analysis: 22 studies, 464 participants	Non-speech pitch perception	$g = 0.26$, moderated by intellectual ability	Chen et al., 2022
164 autistic and non-autistic participants	Five pitch tasks	Group difference modulated by cognitive ability	Ong et al., 2024
32 autistic participants	Reverse correlation of pitch contours	Greater within-group variability; five extreme performers	Wang et al., 2023

3. Precision Weighting in Predictive Coding

Predictive coding holds that the brain does not passively register sensory input but predicts incoming input and processes the difference between prediction and input (Friston, 2010; Lawson et al., 2014). Higher levels of the cortex predict the signals arriving at lower levels, and the difference between prediction and actual input, the prediction error, is passed upward to revise the prediction. Prediction errors are not weighted equally. Each is weighted by its precision, the inverse of its expected variance, which expresses how far the signal is to be trusted; the higher the precision, the more strongly a small discrepancy revises the prediction. Physiologically, precision corresponds to neuromodulatory gain on the neuronal populations that report prediction error (Lawson et al., 2014). Within this framework, elevated precision of sensory prediction errors in autism would mean that fine acoustic differences are weighted

more heavily than usual, which sharpens the perception of detailed auditory information such as pitch. Precision is characterized by two properties. First, it is continuous, so differences between individuals are differences of degree rather than of kind. Second, its optimal value depends on the environment: where the generative process behind the input is stable, a high weight on sensory evidence is warranted because that evidence is informative, whereas where the process is changing, the same weight causes the system to treat noise as signal.

Pellicano and Burr (2012) proposed attenuated or inflexibly weak priors, leaving perception dominated by sensory evidence. Lawson, Rees and Friston (2014) located the difference in a failure to attenuate sensory precision, so that sensory evidence receives disproportionate weight. Van de Cruys et al. (2014) proposed high and inflexible precision of prediction errors, the HIPPEA account, under which precision is elevated and insufficiently modulated by context. Brock (2012) proposed inflexibly low precision of both priors and sensory evidence. With the exception of Brock's account, these proposals converge on an inference system in which sensory evidence carries more weight than usual, and the present account builds on this shared element. HIPPEA is particularly relevant because it specifies how such a system behaves across environments. Under HIPPEA, an inflexibly high precision setting behaves differently depending on the volatility of the environment: in a volatile environment it forces continual model revision, whereas in a stable environment a precise prior matched to an invariant signal generates little prediction error. The consequences of the setting are therefore domain-dependent, and the statistical properties of the domain must be considered in the explanation. Table 2 compares the four accounts on this criterion.

Table 2. Precision accounts of autism and their predictions under stable and volatile input

Account	Core claim	Under stable input	Under volatile input	Implication for music
Attenuated priors	Priors weak or inflexibly weak; perception dominated by sensory evidence	Prior formation slow but achievable with exposure	Perception dominated by momentary evidence	Advantage possible, but no account of why it is musical
Aberrant precision	Failure to attenuate sensory precision	Sensory evidence encoded with high fidelity	Noise treated as signal	Predicts fine discrimination and reduced sensory attenuation in action
HIPPEA	Precision of prediction error high and insufficiently context-modulated	Precise prior matched to invariant signal; little prediction error	Continual, unwarranted model revision	Advantage confined to low-volatility domains, such as music
Inflexibly low precision	Both priors and sensory evidence weighted low	Weak learning of regularities	Weak learning of regularities	Does not predict a perceptual advantage

A meta-analysis of the auditory mismatch negativity, treating the response as an index of prediction error, reports group differences that emerge specifically in uncertain contexts and that differ between children and adults (Sapey-Triomphe et al., 2025), and prediction learning combined with magnetic resonance spectroscopy has related this behavior to excitatory and inhibitory metabolite concentrations in autistic adults (Sapey-Triomphe et al., 2021). Comparing 52 autistic and 52 non-autistic adults across three tasks, Ong et al. (2025) found comparable performance where cue-outcome associations were strongly predictive and a disadvantage only where predictive strength was weak, and only late in learning. Statistical

learning, which measures the acquisition of regularities rather than the response to their violation, is repeatedly found intact: dissociated from specific language impairment in an early meta-analysis (Obeid et al., 2016), showing few behavioral group differences across 37 studies apart from slower reaction times (Bell et al., 2026), and reported as intact or enhanced in autistic adults (Nader et al., 2022; Pesthy et al., 2023; Roser et al., 2015). Taken together, these findings count against a global learning deficit and instead indicate a system whose performance depends on how reliably the input predicts itself, and whose learning improves with extended exposure to a stable signal. Here, stability and volatility refer to the entropy of the distribution over upcoming events under a model learned from the input (Pearce, 2018); in a volatile environment, that distribution itself changes over time.

4. Musical Input Statistics and the Autistic Advantage

Music has four properties relevant to a precision account. Its structure is hierarchical: pitches are organized into intervals, intervals into chords and contours, and these into phrases and forms. It is highly repetitive, both within a piece and across a listener's exposure history, so that the same statistical relations recur at intervals of seconds and again over years. Its rule systems are closed and finite: a tonal system contains a fixed number of pitch classes in fixed relations, which bounds the space of possible continuations at every point. Finally, its regularities require no social interpretation: the mapping from acoustic input to musical structure does not depend on inferring another agent's mental state.

4.1 Quantifying Stability

The information dynamics of music framework acquires the structure of a musical style through statistical learning of variable-length sequential dependencies and, by processing a piece event by event, generates a probability distribution over the next event. Two information-theoretic measures follow: information content, the negative log probability of the event that occurs, and entropy, the uncertainty of the distribution before that event is heard (Pearce, 2018). Entropy is the formal counterpart of volatility. Where a style is closed, and a listener is enculturated, the distribution over continuations is narrow, and entropy is correspondingly low. Two further findings connect this formalism to the brain and to development. Melodic surprise and entropy estimated in this way predict cortical responses during music listening, indicating that these quantities are represented in neural activity (Di Liberto et al., 2020). In addition, the internal model that generates them is acquired through passive exposure, so stylistic enculturation constitutes a form of statistical learning (Pearce, 2018). The mechanism by which a listener comes to possess low-entropy expectations about music is therefore the same statistical learning mechanism that is preserved in autism (Bell et al., 2026; Obeid et al., 2016; Pesthy et al., 2023). The predictive coding of music model formalizes musical listening as the continuous generation of predictions over melody, harmony and rhythm, with perception, action, emotion and learning all resting on this predictive capacity (Koelsch et al., 2019; Vuust et al., 2022). Within that model, the four properties above amount to a hypothesis about volatility: musical input is likely among the most statistically stable structured input a human being encounters. Speech has rule-governed grammar and robust statistical regularities at the phonological and syntactic levels, but it is

less stable at the level relevant here, since talkers, accents, and pragmatic contexts vary continuously and the mapping from acoustics to meaning is many-to-many. Social interaction is plausibly the least stable, since the generative process behind another person's behavior is itself changing and only partially observable. Entropy has not yet been estimated for music, speech and social interaction on a common measure, so this ordering remains theoretical.

4.2 Precision and Input Volatility

A precision setting that is high and insufficiently context-modulated would be costly in volatile environments and advantageous in stable ones. Musical strength and social difficulty in autism can therefore be understood as consequences of the same precision setting operating in two different statistical environments (Figure 1). The comparison holds within an individual, where a single precision value operates in both environments. The social cost follows from that value and not from how far the chain proceeds, so autistic individuals in whom the chain does not complete carry the cost without the musical gain. This relation is consistent with two independent lines of evidence. Emotion recognition is enhanced for music but typical for faces and voices within the same children (Sivathanan et al., 2023), and autistic learning matches comparison learning under strong contingencies but falls behind under weak ones (Bell et al., 2026; Ong et al., 2025). If musical contingencies are more stable than those in speech and social interaction, music may place lower demands on the learning mechanism. Because the explanation rests on the interaction between a parameter and an environment, the advantage should also appear in other domains with stable input statistics. Calendar calculation and numerical computation, two of the domains in which savant skills cluster (Daniel & Menashe, 2020; Meilleur et al., 2015), rest on closed and fully deterministic rule systems, and statistical learning of structured visual scenes is enhanced in autistic adults (Roser et al., 2015).

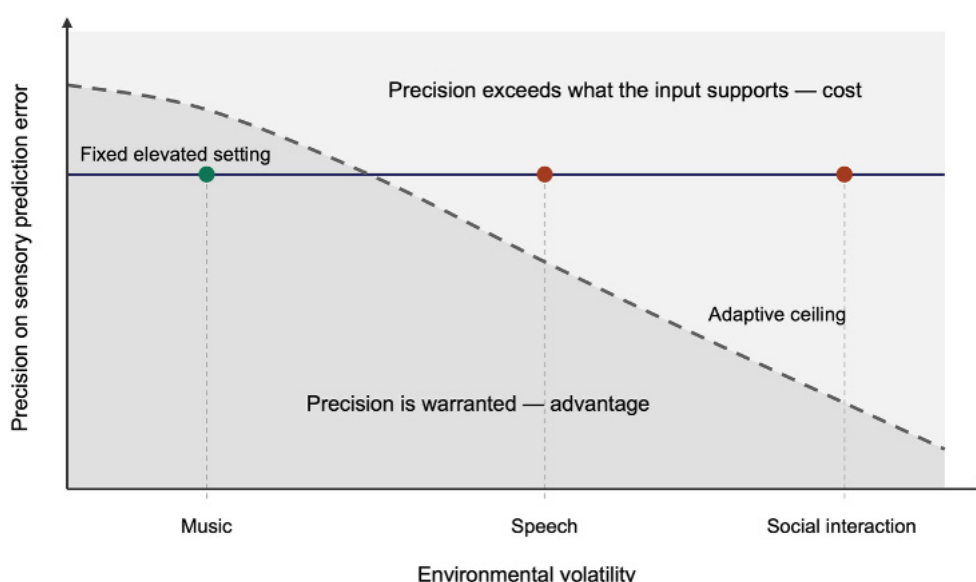


Figure 1. Precision on sensory prediction error against environmental volatility

The dashed line is the highest precision that remains adaptive at a given volatility. A single elevated setting falls below it for music and above it for speech and social interaction.

5. Neural Implementation: From Synaptic Gain to Musical Expertise

5.1 Where Precision Is Implemented in the Cortical Circuit

The canonical microcircuit formulation of predictive coding assigns precision to a specific neuronal population. Within a cortical column, layer 4 receives driving input from the thalamus or a lower cortical area; superficial pyramidal cells in layers 2 and 3 encode prediction error and project forward to layer 4 of the area above; deep pyramidal cells in layers 5 and 6 encode predictions and project back to lower areas, terminating outside layer 4 so that descending messages modulate rather than drive. Precision is the postsynaptic gain of the superficial population (Bastos et al., 2012). Within the proposed framework, an elevated precision setting could correspond physiologically to increased gain on the layer 2/3 cells that report auditory prediction error (Figure 2), and the precision accounts of autism would imply that this gain is set high and insufficiently modulated by context. Pyramidal gain is set by fast-spiking parvalbumin-expressing interneurons acting through GABA-A receptors, so the excitation-inhibition ratio within a column provides a candidate physiological basis of precision (Bastos et al., 2012). Because superficial and deep populations differ in intrinsic dynamics, feedforward prediction error is carried in the gamma band and descending prediction in the alpha and beta bands (Bastos et al., 2012; Heilbron & Chait, 2018). A system running high gain on its prediction-error units should therefore show elevated gamma activity, which can be measured with scalp electrophysiology. Gamma activity also reflects general cortical excitability and oscillatory synchrony, however, so a gamma difference alone would not show that precision is elevated.

Above the local circuit, gain is set by ascending neuromodulatory systems. Cholinergic projections from the basal forebrain terminate throughout the auditory cortex, and microiontophoretic application of acetylcholine there selectively increases the prediction-error component of the neuronal mismatch response while leaving repetition suppression unchanged (Pérez-González et al., 2024), a change in line with the direction the precision accounts attribute to autism. Noradrenergic projections from the locus coeruleus are held to signal unexpected uncertainty, that is, volatility, the environmental parameter that determines the domain dependence proposed here. In autism, post-mortem assays of the frontal and parietal cortex found nicotinic receptor binding 65–73% lower than in comparison brains, with reduced $\alpha 4$ and $\beta 2$ subunit levels and unchanged choline acetyltransferase activity (Perry et al., 2001). Auditory cortex was not examined, and noradrenergic function has not been related to auditory processing in autism, so the neuromodulatory links remain to be measured directly.

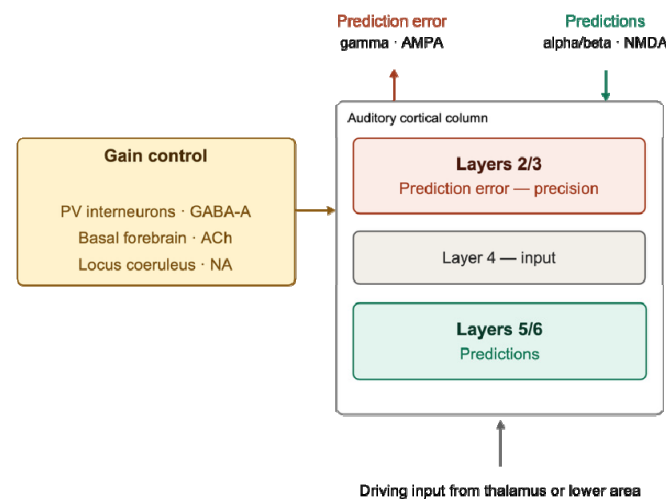


Figure 2. Precision in the cortical microcircuit

5.2 Inhibitory Gain and the Sharpness of Frequency Tuning

In the pitch domain, representational precision is expressed in the width of frequency tuning and in the signal-to-noise ratio of auditory cortical responses, and both are set by inhibition. Interhemispheric callosal projections in primary auditory cortex preferentially target parvalbumin-expressing interneurons; silencing the contralateral cortex raises spontaneous activity and broadens tuning curves, and the feedforward inhibition these interneurons mediate sharpens tuning and enforces response fidelity (Slater & Isaacson, 2020). The interneurons are themselves well tuned for frequency, so their inhibition can sharpen a receptive field rather than merely suppress it (Moore & Wehr, 2013), and manipulating their activity alters the overall gain of auditory cortical responses (Cooke et al., 2020).

Gain and sharpness are nonetheless separable. In *Fmr1* knock-out mice, parvalbumin cell density and perineuronal net formation are reduced in layers 4 and 2/3 of auditory cortex, cortical responses are hyperexcitable, resting gamma power is elevated and sound-evoked gamma synchrony reduced (Lovelace et al., 2020; Wen et al., 2018), the pattern also recorded in humans with fragile X syndrome (Ethridge et al., 2016). However, frequency tuning in the knock-out primary auditory cortex is broader (Rotschafer & Razak, 2013), and fragile X is not associated with enhanced pitch discrimination. Loss of inhibitory tone raises response magnitude while degrading tuning, so an elevated evoked response is not evidence of elevated precision. Because inhibitory circuitry also differs between rodent and human cortex in interneuron composition and laminar organization, these knock-out findings cannot be transferred directly to autistic auditory cortex. The present account would therefore require an inhibitory change that preserves or sharpens tuning while increasing the weight on prediction errors. The circuitry reviewed here contains one such combination: feedforward inhibition from parvalbumin-expressing interneurons, which sharpens tuning (Moore & Wehr, 2013; Slater & Isaacson, 2020), left intact, together with a gain increase confined to prediction-error signals, of the kind acetylcholine produces without altering repetition suppression (Pérez-González et al., 2024). Whether autistic auditory cortex shows this combination has

not been measured, and establishing it is the first experimental requirement of the account.

Magnetic resonance spectroscopy gives region-dependent results. GABA and glutamate concentrations across primary visual, auditory and motor regions were comparable in autistic and non-autistic young adults (Kolodny et al., 2020), whereas Glx is elevated in primary sensorimotor cortex, where it correlates with parent-reported sensory reactivity and reduced feedforward inhibition during tactile perception (He et al., 2021), and in the auditory cortex of autistic adults and of parents of autistic children (Brown et al., 2013). Combining magnetoencephalography with edited spectroscopy in 27 typically developing and 30 autistic individuals, Port et al. (2017) related resting superior temporal GABA concentration to phase-locked gamma in auditory cortex and found that the relationship follows an altered developmental trajectory in autism, linking inhibitory concentration to the spectral signature of prediction-error gain within one sample. The divergent spectroscopy results could reflect differences in region, age and acquisition method, and suggest that excitatory-inhibitory balance in autism differs by region. None of these concentrations is a direct index of precision, and none has yet been related to auditory tuning width.

5.3 Representational Precision in the Auditory System

The enhancement extends beyond discrimination to memory: retention of melodies across a week-long interval (Stanutz et al., 2014) and enhanced memory for vocal melodies (Weiss et al., 2021) require that a precise perceptual value be stored and retrieved, not merely resolved at presentation. In autistic and non-autistic Mandarin and English speakers, individual differences in musical and linguistic ability mediated predictive processing of music and language (Zhao et al., 2024), suggesting that the relevant variation lies in how auditory input is weighted and represented. At this level, precision is a property of neuronal populations. Single neurons in human auditory cortex show frequency tuning considerably finer than population-level imaging estimates for the same regions (Bitterman et al., 2008), and in musicians fine pitch-discrimination thresholds scale with responses in right auditory cortex and, across participants, in the inferior colliculus (Bianchi et al., 2017). Using population receptive field modeling of tonotopic maps in 61 listeners, McKetton et al. (2019) found that musicians with absolute pitch had larger A1, rostral, and rostral-temporal areas than musicians without it or non-musicians, with the additional territory devoted to broader voxel-level frequency tuning. For inference, the relevant quantity is the variance of the estimate supported by a population, and a larger population of moderately tuned units with scattered center frequencies can specify a frequency more exactly than a smaller population of narrowly tuned ones. The difference associated with absolute pitch therefore appears to lie in population size and organization, and studies reporting voxel-level tuning width do not measure the precision this framework refers to.

5.4 Network Organization: Local Hyperconnectivity

Precise low-level representations become musically useful only when organized into a system. Absolute pitch and autism have been proposed to share a profile of local hyperconnectivity with global hypoconnectivity, and within a single sample of professional musicians, Wenhart et al. (2019) related absolute-pitch proficiency and autistic traits to small-worldness, global

clustering coefficient, and average path length. If absolute pitch is associated with a larger cortical territory rather than narrower units (McKetton et al., 2019), dense local connectivity may influence whether the outputs of that territory are read together as one high-dimensional code or function as poorly communicating fragments. Local overconnectivity in posterior sensory cortex has been reported robustly: across 12 analysis pipelines, 29 autistic children and adolescents showed local overconnectivity in occipital and posterior temporal regions with underconnectivity in cingulate and medial prefrontal cortex, holding in low-motion subsamples and under global signal regression (Maximo et al., 2013). The pattern is region-specific, since an analysis of 565 autistic and 602 non-autistic males found reduced local functional connectivity density in the thalamus alongside stronger thalamocortical connectivity with auditory, somatosensory and motor cortices (Tomasi & Volkow, 2019). Sharda et al. (2015) scanned 22 autistic children spanning a wide range of functioning during passive listening to spoken words, sung words and piano tones. Sung words engaged bilateral temporal networks at levels comparable to an age- and gender-matched comparison group, whereas spoken words produced right-lateralized activity and reduced inferior frontal activation that varied with language ability. That the same lexical material recruits the network normally when sung suggests that the difference between conditions lies in the statistical regularity of the signal, although sung and spoken words also differ in pitch contour, duration and rhythmic structure. No study has yet related local connectivity within auditory cortex to an auditory-perceptual measure in the same autistic sample.

5.5 From Precision to Expertise: Veridical Mapping

Perceptual discrimination alone does not constitute musical knowledge. Absolute pitch requires that a precise perceptual value be bound reliably to a category label, and musical competence requires that intervals be bound to harmonic functions and rhythmic patterns to metrical structures. Veridical mapping was proposed to account for the joint overrepresentation in autism of savant abilities, absolute pitch and synesthesia-like associations: perceptual brain regions are functionally re-dedicated to higher-order operations, enhancing the detection and memorization of isomorphisms between perceptual and non-perceptual structures across multiple scales (Bouvet et al., 2014). In predictive coding terms, high sensory precision yields low-level representations of unusually low variance. Where the mapping between two representational systems is statistically stable, as between pitch and pitch class within a fixed tuning system, such representations allow the mapping to be learned reliably and, with repeated exposure, to consolidate as a strong prior at a higher level of the hierarchy (Pearce, 2018). Veridical mapping may thus represent one possible consequence of elevated sensory precision operating on a domain that is hierarchical, repetitive, closed, and free of social interpretation. Precision accounts ordinarily hold that high sensory precision impedes the formation of priors, since priors are formed by discounting sensory variability; that holds for volatile input, but where input statistics are stable the variance preserved by high precision is signal rather than noise, and prior formation may be facilitated. The consolidation is exposure-dependent and developmentally bounded. Among more than 600 conservatory musicians, 40% of those who began training at or before 4 years of age reported absolute pitch, compared with 3% of those who began at 9 years or

later, making early training necessary without being sufficient (Baharloo et al., 1998), and direct testing in an American conservatory reproduced the same dependence on age of onset (Deutsch et al., 2009). The learning mechanism is in place earlier still: 8-month-old infants segment continuous tone streams on transitional probabilities alone, as they do syllable streams (Saffran et al., 1999). The developmental window therefore constrains not the extraction of musical statistics but the period over which the resulting mapping can consolidate as a categorical prior.

5.6 Phenotypes along the Precision Chain

The levels form a single chain, but each documented phenotype is assumed to require the chain only up to a particular level (Figure 3). Enhanced recognition of emotion in music may be explained primarily by the first level, elevated gain on prediction-error units acting on stable input. The same children recognize emotion in music more accurately than comparison children and in faces and voices at typical levels (Sivathanan et al., 2023), with identical levels available in both cases. Musical cues to emotion are conveyed by acoustic regularities such as mode, tempo and articulation that are stable across instances, whereas facial and vocal cues are generated by a process that is itself changing. This phenotype is therefore attributed to the stability of the input. Emotion can be recognized from mode, tempo and articulation without binding a precise value to a category, so no later level is required. Greater attention to or engagement with music could also explain the advantage, and musical and non-musical stimuli matched for acoustic regularity would distinguish the two accounts. Absolute pitch is hypothesized to depend on the full chain: a low-variance percept must exist, be elaborated within a system that holds many such values apart, and be bound to a category label across a mapping stable enough to consolidate as a prior. Because each level adds a further condition, absolute pitch remains absent in approximately 90% of autistic individuals despite an order-of-magnitude enrichment over the general population (DePape et al., 2012; Rimland & Fein, 1988; Wenhart et al., 2019). Its dependence on the age at which training begins (Baharloo et al., 1998; Deutsch et al., 2009) also contributes to its rarity. Musical savant skill, by contrast, is placed at veridical mapping alone: savant abilities appear in calendar calculation, drawing, and numerical computation as well as music (Daniel & Menashe, 2020; Meilleur et al., 2015), suggesting that their common basis is the binding of a precisely represented structure to a second, isomorphic structure (Bouvet et al., 2014). This placement reflects the mechanism savant skills share across domains, not their difficulty: a musical savant relies on veridical mapping even where the auditory levels that absolute pitch requires are incomplete. Two phenotypes represent costs: impaired absolute pitch and duration matching in vocal imitation with intact relative matching (Wang et al., 2021) and reduced rhythmic entrainment with preserved rhythmic perception. Both require sensory attenuation, the down-weighting of the sensory consequences of self-generated action, which is implemented by lowering sensory precision (Lawson et al., 2014), so on this account the parameter that produces the enhancements also produces these costs. Because each phenotype requires the chain up to its own level, the dependencies among them should be asymmetric: an individual with absolute pitch should also show enhanced pitch discrimination, whereas enhanced discrimination need not entail absolute pitch, and the same holds for melodic

memory relative to discrimination. Prevalence should decrease as the number of required levels increases, and the abilities should not be independently distributed within a sample.

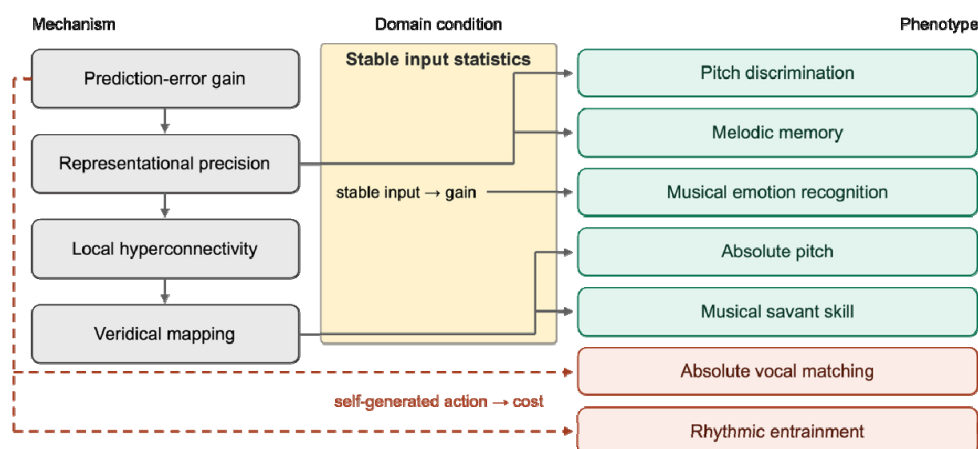


Figure 3. The precision chain and the phenotypes it produces

Solid arrows mark gains obtained under stable input; dashed arrows mark costs arising from the failure to attenuate sensory precision during action.

5.7 Rhythm: Perception and Entrainment

Rhythmic perception is largely preserved. Melodic and rhythmic perception are intact in autistic children on cognitively matched tasks (Jamey et al., 2019), musical beat perception is broadly comparable in autistic and non-autistic children (Dahary et al., 2024) and relates to phonological skill in the expected direction (Rimmer et al., 2024). Among 78 autistic and 83 non-autistic adults matched on nonverbal IQ, the benefit of temporally predictive cues for detecting faint sounds was practically identical in the two groups, although rhythm shifted the autistic group toward reporting detections (Cannon et al., 2023). In contrast, sensorimotor entrainment is impaired. In paced finger tapping, autistic adults keep tempo adequately once the metronome stops but synchronize poorly while it runs, with greater variability of asynchrony (Kasten et al., 2023), and autistic children show reduced phase locking of neural oscillations to temporally predictable stimuli together with altered neural indices of anticipatory prediction (Beker et al., 2021). One report also finds reduced precision in perceptual rhythmic timing (Cannon et al., 2024), which suggests that the dissociation between perception and production is partial. These two capacities place opposing demands on precision. Perceptual discrimination of rhythmic structure, like pitch discrimination, benefits from precise sensory representation, whereas active entrainment requires sensory attenuation, implemented by reducing sensory precision (Lawson et al., 2014). A system that maintains high and inflexibly modulated sensory precision would therefore be suited to the perceptual task but not to the sensorimotor task. The same holds for vocal imitation, where precise perceptual representation is available but its conversion into motor output requires attenuation of the same signals (Wang et al., 2021).

6. Limitations and Future Perspectives

The evidence reviewed here comes largely from autistic individuals with higher intellectual

and language ability (Chen et al., 2022) and from Western tonal music, and the levels of the chain have so far been examined in separate samples. Several lines of research would extend the account toward the development of musical ability in autistic children. Longitudinal studies that follow autistic children from early childhood, measuring pitch discrimination thresholds together with auditory gamma activity, auditory cortical GABA and local connectivity, could establish which neural profile precedes outstanding musical ability and whether that profile can be identified before formal training begins. Because categorical pitch knowledge consolidates within a developmental window, such studies could also define the period in which musical exposure is most effective for children with a high-precision profile. Extending the same measures to minimally verbal children and to non-Western musical systems would show whether the mechanism holds across the autistic population and across musical cultures. Intervention research could test how the mechanism can be used to build musical skill. Music programs that begin with highly regular material and introduce variability gradually would show whether a precision advantage established on stable input can be carried into more variable settings such as improvisation and ensemble playing. Training that targets sensorimotor synchronization alongside perceptual strengths could establish whether the entrainment cost can be reduced, which bears directly on participation in ensemble music. Music-based intervention has already been associated with gains in social communication and auditory-motor connectivity (Sharda et al., 2018); trials that stratify children by auditory-perceptual sensitivity could determine which children benefit most and whether skills acquired in a stable musical environment transfer to less predictable domains.

7. Conclusions

Exceptional musical ability in autism has long been documented without a mechanism linking it to the perceptual differences with which it co-occurs. This study proposes that this link is the precision assigned to sensory prediction errors. An elevated and inflexibly modulated precision setting can produce musical expertise along a chain running from prediction-error gain in the auditory cortex, through the population-level precision of pitch representation and locally hyperconnected networks, to stable perceptual-categorical mappings. Because different abilities depend on different levels of the chain, from enhanced recognition of emotion in music at the first level to absolute pitch at the fourth, and the chain operates on stable input, the advantage would be expected to appear in some autistic individuals, in music rather than in speech or social cognition, and alongside a cost in sensorimotor entrainment. The links of the chain have so far been examined in separate samples, partly with evidence from related conditions and animal models, so the account remains a proposal to be tested. It yields four testable predictions. First, if the advantage depends on the stability of input statistics rather than on the musical domain as such, parametrically manipulating the statistical volatility of a musical sequence should reveal an autistic advantage within a bounded range of volatility, diminishing or reversing outside it. Second, because a pitch advantage and reduced sensorimotor entrainment follow from a single parameter, they should co-occur within the same individual. Third, if precision is implemented as neuromodulatory gain over prediction-error units (Lawson et al., 2014), cholinergic and noradrenergic manipulation should produce differential and predictable

effects on pitch discrimination thresholds, with effect size varying by baseline auditory-perceptual sensitivity. Fourth, the dependencies among the phenotypes should be asymmetric in the direction the chain specifies, so that an ability requiring more levels implies one requiring fewer, but not the reverse. Longitudinal studies tracing the full chain within the same autistic children, together with evidence from a broader range of the autistic population and of musical cultures, would allow the account to be extended into a developmental model of musical ability in autism.

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Data sharing statement

No additional data are available.

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