A Posterior Visual Network-Targeted N-Back Paradigm:

A Theoretical Proposal Informed by Research on Autism Spectrum Disorder

Author: Koichi Yano

Abstract

The extent to which working memory (WM) training can produce far transfer to fluid intelligence (Gf) remains a matter of considerable debate. The present paper draws on neuroimaging evidence indicating that individuals with autism spectrum disorder (ASD) show enhanced activation in posterior visual network regions—including the cuneus and lateral occipitotemporal cortex—during performance of Raven's Progressive Matrices (RPM; Soulieres et al., 2009), and proposes a new N-back paradigm, Nexus N-back, designed to preferentially engage these posterior pathways. Whereas conventional Dual N-back relies on audiovisual cross-modal stimulation and primarily recruits frontoparietal networks, the proposed paradigm requires simultaneous tracking of three visual channels—spatial position (dorsal pathway), shape (ventral pathway), and color (area V4)—each selected for its hypothesized overlap with the neural substrates engaged during RPM performance. Three anti-strategy mechanisms are incorporated: N−1 back lure trials, inter-stimulus interval jitter, and accuracy-triggered channel rotation. The present work differs from the exploratory quad N-back approach of Lindeløv et al. (2019) in its neuroscientifically grounded channel selection, deliberate exclusion of auditory stimulation, and structured anti-strategy design. This paper constitutes a theoretical proposal without experimental verification; its aim is to provide a principled design framework for future randomized controlled trials.

Keywords: working memory, fluid intelligence, posterior visual network, N-back, autism spectrum disorder, transfer

1. Introduction

1.1 The Transfer Problem in Working Memory Training

Working memory (WM) is known to correlate strongly with fluid intelligence (Gf; Kane & Engle, 2002), and the possibility of improving Gf through WM training attracted considerable attention following Jaeggi et al. (2008), who reported gains of up to 40% on a Gf measure after 19 days of Dual N-back training. However, subsequent large-scale randomized controlled trials (RCTs) and meta-analyses have painted a more sobering picture: when active control groups are used, effect sizes for far transfer are small ($d \approx 0.19$; Melby-Lervåg et al., 2016), and some studies have found no significant transfer at all (Redick et al., 2013). One possible explanation for these modest results is that conventional Dual N-back, which primarily recruits the dorsolateral prefrontal cortex (DLPFC) and frontoparietal network, may not sufficiently overlap with the neural substrates most directly implicated in Gf.

1.2 Insights from ASD Research

A potentially informative observation is that individuals with ASD tend to achieve higher scores on RPM relative to other cognitive measures (Dawson et al., 2007). Using functional MRI, Soulieres et al. (2009) demonstrated that ASD individuals can achieve performance levels on RPM comparable to neurotypical controls while showing a markedly different pattern of neural recruitment. Specifically, ASD individuals showed relatively enhanced task-related activation in the left cuneus and middle occipital gyrus (approximately BA18), alongside reduced activation in the left middle frontal gyrus (BA9) and medial posterior parietal cortex (BA7). These findings are consistent with the hypothesis that reliance on frontal-lobe-mediated reasoning may be reduced in ASD, while engagement of the posterior visual network may be increased—though the direction of causality and generalizability of these observations remain open questions.

The Enhanced Perceptual Functioning (EPF) model proposed by Mottron et al. (2006) provides a broader theoretical context, attributing the cognitive profile of ASD to a tendency toward local processing and augmented low-level perceptual functioning, with posterior visual processing playing a central role.

1.3 Aim and Central Hypothesis

Building on the above observations, the present paper proposes the following hypothesis:

By selecting training channels that are hypothesized to partially overlap with the posterior visual network regions showing enhanced activation during RPM performance in ASD, it may be possible to facilitate improvement in RPM performance through a more direct form of neural engagement, rather than relying on far transfer.

This hypothesis represents a departure from the conventional framing of WM training research, which asks whether transfer occurs from a training task to a separate outcome measure. Instead, the proposed design principle holds that the neural substrates of the training task should be selected for their hypothesized overlap with those of the target cognitive function.

2. Theoretical Background

2.1 The Posterior Visual Network and Gf

The posterior visual network can be broadly organized into three processing streams. First, the dorsal pathway extends from primary visual cortex through V3 and MT/V5 to the intraparietal sulcus (IPS) and superior parietal lobule (SPL), supporting spatial localization, parallel tracking of multiple objects, and the spatial component of visuospatial WM (Ungerleider & Mishkin, 1982). Second, the ventral pathway passes through V2 and V4 to the inferior temporal cortex and lateral occipitotemporal cortex (LOTC), supporting object shape recognition, categorical perception, and pattern abstraction. Third, area V4 constitutes a relatively specialized processing stage for color information (Zeki et al., 1991), and has also been implicated in the integration of color and shape (Zeki & Marini, 1998).

These three processing streams are hypothesized to contribute jointly to RPM performance. Dorsal-pathway processing may support the detection of spatial relational patterns across rows and columns; ventral-pathway processing may support the recognition of shape-based regularities; and V4 may contribute to the integration of color and form as co-varying attributes in the matrix. The enhanced cuneus and middle occipital activation observed by Soulieres et al. (2009) is consistent with the possibility that these posterior streams may play an important role in RPM reasoning, though the precise functional contribution of each region remains to be established.

2.2 Limitations of Conventional Dual N-Back

The Dual N-back task introduced by Jaeggi et al. (2008) requires simultaneous tracking of a visually presented spatial position and an auditorily presented letter. This design has several potential limitations from the perspective of the present proposal.

First, the inclusion of an auditory channel recruits the superior temporal gyrus and auditory cortex—regions outside the posterior visual network—potentially diverting cognitive resources away from the pathways hypothesized to be most relevant to RPM performance. Second, the task predominantly activates the frontoparietal network (DLPFC and IPS), which may show limited overlap with the cuneus and LOTC regions showing enhanced activation in ASD during RPM. Third, fixed stimulus formats are susceptible to strategy learning, which may reduce the effectiveness of training over time.

Salminen et al. (2016) demonstrated that transfer following Dual N-back training depends on changes in striatal activation, suggesting that cross-modal binding may be a key mechanism. However, it is unclear whether this cross-modal binding mechanism overlaps sufficiently with the within-visual-system binding hypothesized to be important in RPM.

2.3 The Quad N-Back of Lindeløv et al. (2019) and its Implications

Lindeløv et al. (2019) explored a quad N-back task incorporating spatial position, audio, color, and shape channels. Critically, however, color and shape were used as transfer measurement tasks rather than as training channels; the training task remained conventional Dual N-back (position plus audio). The authors themselves note that channel selection was done in a relatively exploratory manner without a strong theoretical rationale. No anti-strategy mechanisms were included, and training lasted only ten minutes. No significant transfer was observed ($BF_{01} = 23.3$).

The present proposal interprets this null result as potentially consistent with the hypothesis that the mismatch between the neural substrates of the training task (position and audio) and the transfer measurement tasks (color and shape) may have been one contributing factor to the absence of transfer. The inclusion of auditory stimulation may also have reduced preferential engagement of the posterior visual network. These observations suggest that deliberate, theory-driven channel selection—rather than the addition of channels per se—may be important for achieving meaningful near transfer.

3. Proposed Paradigm: Nexus N-Back

3.1 Design Principles

The design of Nexus N-back is guided by three principles:

(1) Only channels corresponding to posterior visual processing streams that showed enhanced activation during RPM performance in ASD are selected—specifically the dorsal pathway (position), ventral pathway (shape), and area V4 (color).

(2) Auditory stimulation is excluded entirely, with the aim of preferentially engaging posterior visual network resources.

(3) Multiple anti-strategy mechanisms are combined to sustain training demands over extended practice.

3.2 Channel Design

Three visual channels are tracked simultaneously.

Position channel: Stimuli appear at random locations within a 3×3 grid. Spatial position processing recruits the dorsal pathway (IPS and SPL), and is hypothesized to engage neural substrates involved in the detection of spatial relational patterns in RPM.

Shape channel: Six geometric shapes (triangle, square, circle, diamond, hexagon, cross) are used. Object shape processing recruits the ventral pathway (LOTC and inferior temporal cortex) and is hypothesized to engage neural substrates involved in the recognition of shape-based regularities in RPM.

Color channel: Six colors are used as stimuli. Area V4 is specialized for color processing (Zeki et al., 1991) and has been implicated in color–shape integration (Zeki & Marini, 1998). According to feature integration theory (Treisman & Gelade, 1980), color is processed as an independent visual attribute that must be bound with other features such as shape and location. In RPM, multiple visual attributes may co-vary as part of the rule structure, and V4 may contribute to the detection of color-related regularities. In the evolved mode, the color channel functions either as an active tracking target or as an interference stimulus, simultaneously training V4 engagement and inhibitory control.

3.3 Trial Structure

Stimulus presentation duration is set at 400–800 ms (baseline 600 ms) with ±200 ms inter-stimulus interval (ISI) jitter; response window duration is 2000–2400 ms (baseline 2200 ms) with ±200 ms jitter. ISI jitter is introduced to prevent rhythm-based strategy formation. On each trial, participants judge whether each active channel matches the stimulus presented N trials earlier. A match requires a button press; a non-match requires withholding a response. Correct omissions are scored as correct rejections.

3.4 Anti-Strategy Mechanisms

Three anti-strategy mechanisms are incorporated.

Lure trials: Approximately 15% of trials contain N−1 back stimuli (i.e., stimuli matching one trial prior rather than N trials prior). These lure trials provide direct training of resistance to proactive interference (PI), consistent with the transfer effects associated with inhibitory N-back variants (de Simoni & von Bastian, 2018). They also counteract the strategy of relying on a sense of recency.

Accuracy-triggered channel rotation: In the evolved mode, two of the three channels are active at any given time. When accuracy on the active channel pair—measured as a Hautus-corrected signal detection sensitivity index (d'; Hautus, 1995)—exceeds a threshold equivalent to 82% correct for four consecutive trial evaluations, the active channel pair is randomly reassigned. This prevents the formation of fixed strategies tied to a particular channel configuration.

Consecutive position repetition prevention: Identical spatial positions are prevented from appearing three or more times in succession, reducing the possibility of location-based chunking strategies.

3.5 Adaptive Difficulty Adjustment

Every ten trials, d' accuracy for the current channel pair is evaluated. If accuracy exceeds the 82% threshold, N is incremented (maximum N = 7); if accuracy falls below 60%, N is decremented (minimum N = 2). Hautus correction is applied to prevent infinite d' values at ceiling or floor performance levels.

4. Differentiation from the Quad N-Back

Dimension	**Quad N-Back (Lindeløv et al., 2019)**	**Nexus N-Back (Present Proposal)**
Rationale for channel selection	Exploratory; no stated neurological basis	Grounded in ASD neuroimaging research (Soulieres et al., 2009)
Auditory channel	Included (recruits superior temporal gyrus)	Excluded; aims to preferentially engage posterior visual network
Role of color and shape	Transfer measurement tasks only (not trained)	Core training channels
Anti-strategy mechanisms	None	Lure trials, ISI jitter, accuracy-triggered channel rotation
Difficulty adjustment	Fixed (N = 1 or 2)	Accuracy-triggered adaptive adjustment via SDT d'
Training duration	10 minutes (single session)	Designed for extended longitudinal practice
Design approach	Exploratory transfer spectrum mapping	Theory-driven partial overlap with RPM-engaged networks
Transfer outcome	No significant transfer ($BF_{01} = 23.3$)	Untested; future RCT required

Table 1. Comparison of Quad N-Back and Nexus N-Back.

The most fundamental distinction between the two paradigms lies in their underlying design philosophy. Lindeløv et al. (2019) asked whether adding more channels would produce transfer—an empirical question pursued without strong theoretical guidance. The present proposal asks which channels are most likely to engage neural substrates that partially overlap with those recruited during RPM performance—a theory-driven question grounded in ASD neuroimaging findings.

Furthermore, the null transfer result reported by Lindeløv et al. (2019) may be interpretable as consistent with this framework: the training task (position and audio) may have engaged neural substrates with insufficient overlap relative to the transfer measurement tasks (color and shape). This observation is offered as one possible explanation rather than a definitive account.

5. Predicted Effects

5.1 Neural-Level Predictions

Sustained Nexus N-back practice is hypothesized to produce the following neural changes.

First, strengthening of visual WM updating circuits in the cuneus, LOTC, and V4 is anticipated. Synaptic potentiation (long-term potentiation; LTP) through repeated activation of these regions is consistent with the white-matter structural connectivity changes associated with WM training documented by Takeuchi et al. (2010).

Second, strengthening of within-visual-system cross-channel binding in the striatum may occur, reflecting the parallel maintenance of multiple visual attributes. This is broadly consistent with the striatal activation changes associated with WM transfer reported by Salminen et al. (2016), though the specific binding mechanisms may differ.

Third, lure trials are hypothesized to strengthen inhibitory control circuits involved in resistance to proactive interference, consistent with the transfer effects observed for inhibitory N-back variants (de Simoni & von Bastian, 2018).

5.2 Behavioral-Level Predictions

At the behavioral level, the following outcomes are predicted. First, improvement on RPM scores may occur as a result of increased engagement of neural substrates hypothesized to partially overlap with those recruited during RPM performance. Second, near transfer to other visuospatial WM tasks may emerge through strengthening of the dorsal and ventral pathways. Third, improvement in inhibitory control may occur as a result of lure trial training.

6. Limitations

Several important limitations must be acknowledged.

First, this paper is a theoretical proposal without experimental verification. Whether near or far transfer actually occurs cannot be established without controlled experimental evidence.

Second, the central hypothesis—that preferential engagement of posterior visual network regions will contribute to RPM score improvement—is theoretically motivated but causally unverified. The neural substrates of RPM performance are likely to involve a distributed network, and the specific contribution of the channels selected here remains speculative.

Third, even a fully visual multi-channel design may not entirely replicate the cross-modal (audiovisual) binding effects of Dual N-back, which rely on striatal integration mechanisms that may partially differ from within-visual-system binding.

Fourth, the ASD neuroimaging findings referenced here (Soulieres et al., 2009) document enhanced posterior network engagement in an ASD population. Whether analogous posterior pathway engagement can be elicited in neurotypical individuals through the proposed training remains an empirical question.

Fifth, the interpretation of Lindeløv et al.'s (2019) null result as being consistent with the present framework is one possible explanation among others, and should not be taken as confirming the framework.

7. Future Directions

To evaluate the theoretical framework proposed here, the following research directions are indicated.

First, an RCT comparing Nexus N-back against an active control condition (e.g., conventional Dual N-back) over four to eight weeks of daily training would allow assessment of near and far transfer effects. RPM and related visuospatial measures should be included as primary outcomes.

Second, pre- and post-training fMRI measurement during RPM performance would allow direct examination of whether posterior visual network activation changes as a function of training, providing a neural-level test of the proposed mechanism.

Third, once sufficient user data have been accumulated, the current within-person Cognitive Index (CI; scored 70–145 based on Hautus-corrected d' weighted by channel) could be supplemented by normative population-level comparisons.

8. Conclusion

The present paper proposed Nexus N-back, a new N-back paradigm designed to preferentially engage the posterior visual network regions—cuneus, LOTC, and area V4—that show enhanced activation during RPM performance in ASD (Soulieres et al., 2009). The core contribution of this proposal lies in three aspects: a shift in design philosophy from "seeking transfer" to "directly training hypothesized overlapping circuits"; the exclusion of auditory stimulation and adoption of three visual channels corresponding to the dorsal pathway, ventral pathway, and area V4; and the incorporation of lure trials, ISI jitter, and accuracy-triggered channel rotation as combined anti-strategy mechanisms.

While Nexus N-back shares a superficial resemblance to the quad N-back of Lindeløv et al. (2019), the two differ fundamentally in the theoretical basis for channel selection, the role assigned to color and shape (training versus measurement), and the presence of structured anti-strategy mechanisms. The null transfer result of Lindeløv et al. may be interpretable as one piece of evidence consistent with the importance of theory-driven channel selection, though this interpretation should be treated as tentative.

This paper remains a theoretical proposal, and experimental verification is required before any claims about transfer can be made. Nonetheless, it is hoped that the design framework offered here may serve as a useful starting point for future empirical investigation.

References

Dawson, M., Soulières, I., Gernsbacher, M. A., & Mottron, L. (2007). The level and nature of autistic intelligence. Psychological Science, 18(8), 657–662.

de Simoni, C., & von Bastian, C. C. (2018). Working memory updating and binding training: Bayesian evidence supporting the absence of transfer. Journal of Experimental Psychology: General, 147(6), 829–858.

Hautus, M. J. (1995). Corrections for extreme proportions and their effect on estimated values of d'. Behavior Research Methods, Instruments, & Computers, 27(1), 46–51.

Jaeggi, S. M., Buschkuehl, M., Jonides, J., & Perrig, W. J. (2008). Improving fluid intelligence with training on working memory. Proceedings of the National Academy of Sciences, 105(19), 6829–6833.

Kane, M. J., & Engle, R. W. (2002). The role of prefrontal cortex in working-memory capacity, executive attention, and general fluid intelligence. Psychonomic Bulletin & Review, 9(4), 637–671.

Lindeløv, J. K., Jensen, S. B. T., Holst, M. K., Randrup-Thomsen, T., & Brøchner, C. E. (2019). Can you instruct for far transfer? An RCT on N-back variants. Retrieved from https://lindeloev.net

Melby-Lervåg, M., Redick, T. S., & Hulme, C. (2016). Working memory training does not improve performance on measures of intelligence or other measures of 'far transfer'. Perspectives on Psychological Science, 11(4), 512–534.

Mottron, L., Dawson, M., Soulières, I., Hubert, B., & Burack, J. (2006). Enhanced perceptual functioning in autism: An update, and eight principles of autistic perception. Journal of Autism and Developmental Disorders, 36(1), 27–43.

Pahor, A., Stavber, G., Jamsek, J., & Jaeggi, S. M. (2023). Near transfer to an unrelated N-back task mediates the effect of N-back working memory training on matrix reasoning. Nature Human Behaviour, 7, 462–472.

Redick, T. S., Shipstead, Z., Harrison, T. L., Hicks, K. L., Fried, D. E., Hambrick, D. Z., Kane, M. J., & Engle, R. W. (2013). No evidence of intelligence improvement after working memory training. Journal of Experimental Psychology: General, 142(2), 359–379.

Salminen, T., Strobach, T., & Schubert, T. (2016). Transfer after dual n-back training depends on striatal activation change. Journal of Neuroscience, 36(39), 10198–10213.

Soulières, I., Dawson, M., Samson, F., Barbeau, E. B., Sahyoun, C. P., Strangman, G. E., Mottron, L., & Gernsbacher, M. A. (2009). Enhanced visual processing contributes to matrix reasoning in autism. Human Brain Mapping, 30(12), 4082–4107.

Takeuchi, H., Taki, Y., Sassa, Y., Hashizume, H., Sekiguchi, A., Fukushima, A., & Kawashima, R. (2010). Working memory training using mental calculation impacts structural connectivity. Human Brain Mapping, 31(2), 174–188.

Treisman, A. M., & Gelade, G. (1980). A feature-integration theory of attention. Cognitive Psychology, 12(1), 97–136.

Ungerleider, L. G., & Mishkin, M. (1982). Two cortical visual systems. In D. J. Ingle, M. A. Goodale, & R. J. W. Mansfield (Eds.), Analysis of visual behavior (pp. 549–586). MIT Press.

Zeki, S., Watson, J. D. G., Lueck, C. J., Friston, K. J., Kennard, C., & Frackowiak, R. S. J. (1991). A direct demonstration of functional specialization in human visual cortex. Journal of Neuroscience, 11(3), 641–649.

Zeki, S., & Marini, L. (1998). Three cortical stages of colour processing in the human brain. Brain, 121(9), 1669–1685.