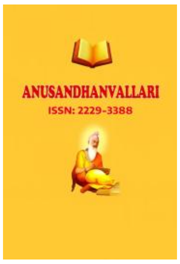

Anusandhanvallari
Vol 2025, No.1
January 2025
ISSN 2229-3388

Sanskrit Shlokas and The Phonological Loop, Working Memory and Sensorimotor–Vocal Learning

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Abstract

The phonological loop is a central component of contemporary models of working memory and is implicated in verbal learning, language acquisition, and short-term retention of auditory–verbal material. This manuscript synthesizes evidence from cognitive psychology, neuroscience, psycholinguistics, and sensorimotor learning to argue that learning phonetically dense chants—exemplified by the *Śiva Tāṇḍava Stotra* (STS)—constitutes a natural, high-load training regimen for the phonological loop and associated executive systems. First, classical and contemporary working memory models (Baddeley & Hitch, 1974; Baddeley, 1992, 2000) are reviewed, with emphasis on the phonological store and articulatory rehearsal processes. Second, cognitive load theory (Sweller, 1988; Paas, Renkl, & Sweller, 2003), Gestalt principles of auditory grouping, and predictive/rhythmic frameworks (Goswami, 2011) are used to explain how rhythmic and prosodic scaffolds reduce extraneous load and facilitate chunking. Third, sensorimotor learning accounts (Shadmehr & Wise, 2005; Dayan & Cohen, 2011) and embodied language theories (Pulvermüller, 2013) are used to model how vocal–motor practice and auditory feedback refine articulatory sequences and consolidate procedural memory. Empirical support from neurophysiological and structural imaging studies—ranging from vagal/autonomic modulation during chanting (Bernardi et al., 2001; Kalyani et al., 2011) to structural brain differences in Vedic chanters (Kumar et al., 2021)—is integrated to demonstrate measurable effects on memory circuits. Applying these frameworks to the STS, the manuscript presents a mechanistic account showing how its phonotactic density, sandhi phenomena, and metrical (chandas) constraints create high intrinsic load that is managed through rhythmic chunking, thereby training the phonological loop, enhancing sensorimotor–vocal integration, and producing transfer to broader working memory functions. The paper closes by proposing empirical tests (behavioral, EEG/fMRI, and longitudinal training studies) and discussing implications for pedagogy and neurorehabilitation.

Keywords: phonological loop; working memory; chanting; Śiva Tāṇḍava Stotra; sensorimotor learning; cognitive load; Sanskrit; verbal memory; neuroplasticity

1. Introduction

Working memory—the set of processes and temporary stores that allow information to be held in mind and manipulated—has been central to cognitive psychology and neuroscience for decades (Baddeley & Hitch, 1974; Baddeley, 1992). Within dominant multicomponent models, the phonological loop plays a crucial role for auditory–verbal information: it temporarily stores phonological representations and refreshes them by articulatory rehearsal (Baddeley, 1992; Baddeley, Thomson, & Buchanan, 1975). The functional capacity and efficiency of the phonological loop predict language acquisition, vocabulary learning, and performance on complex cognitive tasks (Gathercole & Baddeley, 1993).

Repetitive vocal practices such as chanting, recitation, and singing constitute ecologically valid instances of intense phonological rehearsal, combining cognitive, sensorimotor, and affective elements. Practices within Sanskritic traditions—particularly Vedic chant and highly structured stotras—provide especially rich stimuli because of their phonological density, morphological complexity, and strict metrical constraints (chandas). The *Śiva Tāṇḍava Stotra* (STS) is an exemplary case: its lines contain dense consonantal clusters, compound sandhi, and rapid alternations that place exceptional demands on articulatory sequencing and auditory–phonological maintenance.

This paper develops an integrated theoretical account of how learning a phonetically dense śloka such as the STS trains the phonological loop, refines vocal–sensorimotor representations, and leads to measurable improvements in working memory. We bring together (a) models of working memory and the phonological loop; (b) cognitive load and perceptual grouping accounts that explain how rhythm and prosody enable chunking; (c) sensorimotor learning theory and embodied language approaches that explain how repeated vocal practice consolidates motor programs and sensory predictions; and (d) empirical neurophysiological and neuroanatomical data on chanting and expert reciters. Finally, the STS is used as a worked example to show the mechanisms at play and to suggest testable experimental paradigms.

2. Background: models of working memory and the phonological loop

2.1 Baddeley's multicomponent model and the phonological loop

Baddeley and Hitch (1974) proposed a multicomponent working memory model comprising a central executive and two subsidiary stores: the phonological loop and the visuospatial sketchpad. The phonological loop itself is typically decomposed into a short-lived phonological store and an articulatory rehearsal process (Baddeley, 1992). The phonological store is thought to hold acoustic–verbal traces that decay over ~2 s unless refreshed via subvocal rehearsal, which is implemented by the articulatory control system (Baddeley, 1992; Baddeley, 2000). This system accounts for classical phenomena such as the phonological similarity effect, word-length effect, and articulatory suppression effects (Baddeley, 1992; Miller, 1956).

2.2 The episodic buffer and multimodal binding

In 2000 Baddeley introduced the episodic buffer, a limited-capacity store that binds information from different modalities and interfaces with long-term memory (Baddeley, 2000). The episodic buffer is relevant when verbal rehearsal becomes integrated with semantic, episodic, and motor codes—precisely the kind of multimodal binding that occurs during chanting, where auditory, articulatory, prosodic, and semantic dimensions are present simultaneously.

2.3 Working memory, attention, and executive control

Working memory is intimately linked to attention and executive functions (Miyake et al., 2000). The ability to maintain, update, and manipulate phonological representations during chanting requires selective attention, inhibition of competing responses, and temporal sequencing—functions ascribed to the central executive and prefrontal networks (Baddeley, 1992; Engle, 2002).

3. Cognitive load, chunking, and perceptual grouping

3.1 Cognitive load theory: intrinsic, extraneous, germane

Cognitive load theory (Sweller, 1988; Paas, Renkl, & Sweller, 2003) distinguishes between intrinsic load (inherent complexity of material), extraneous load (task presentation and irrelevant demands), and germane load (resources devoted to schema construction). The STS, by design, has high intrinsic load due to dense phonology and morphological complexity. However, chant traditions often supply rhythmic, prosodic, and pedagogical scaffolds that reduce extraneous load and increase germane load (i.e., promote the formation of phonological and motor schemas).

3.2 Chunking and Gestalt grouping in auditory perception

Chunking—the grouping of elements into larger units—extends working memory capacity by creating higher-level units (Miller, 1956). Gestalt principles (proximity, similarity, continuity, closure) apply to auditory sequences (Wagemans et al., 2012) and operate via rhythmic and alliterative structures in chanting. Chandas (metrical structure) imposes regularity and temporal landmarks that facilitate chunking and reduce working-memory demands despite high phonological complexity.

3.3 Rhythm as predictive scaffolding

Human auditory systems exploit rhythm for prediction (Jones, 2010; Goswami, 2011). Rhythmic regularity entrains neural oscillations (theta/alpha bands), enabling temporal expectations and enhancing accuracy of phonological rehearsal. Thus, rhythm acts as a scaffold that allows the phonological loop to retain longer sequences by aligning internal rehearsal cycles with external temporal frames.

4. Sensorimotor learning, vocal–motor integration, and neural plasticity

4.1 Sensorimotor control and motor learning frameworks

Sensorimotor learning involves the formation and refinement of internal models that predict sensory consequences of motor commands (Shadmehr & Wise, 2005; Wolpert, Diedrichsen, & Flanagan, 2011). In vocal learning, feedforward (motor plan) and feedback (auditory/ somatosensory) loops interact to optimize articulation and timing. Repeated practice reduces prediction error and consolidates motor sequences into procedural memory (Dayan & Cohen, 2011).

4.2 Auditory–vocal coupling in speech and singing

Vocal production uniquely couples auditory perception with fine articulatory control. Training studies in singing and speech demonstrate that repetitive vocal practice increases connectivity between auditory and motor regions (arcuate fasciculus, superior temporal and inferior frontal regions) and enhances cortical thickness in relevant areas (Wan & Schlaug, 2010). Similar mechanisms are likely engaged in sustained chanting practice.

4.3 Neuroplasticity in expert memorists and chant traditions

Structural imaging studies on individuals with long-term verbal memory training report regional cortical thickness and white matter differences. Notably, Kumar et al. (2021) reported increases in cortical thickness and gyrification in regions including temporal poles, insula, and supplementary motor area in experienced Vedic pandits, suggesting that intense verbal–vocal training drives structural plasticity in language, memory, and motor networks. These findings parallel evidence from musical training showing experience-dependent changes (Wan & Schlaug, 2010).

5. Empirical evidence linking chanting to physiology, attention, and memory

5.1 Autonomic and neurophysiological effects of chanting

Controlled physiological studies show that rhythmic recitation can modulate cardiorespiratory coupling and increase parasympathetic activity (Bernardi et al., 2001). Kalyani et al. (2011) used fMRI to show neurohemodynamic correlates of audible "OM" chanting, implicating regions involved in emotion and autonomic regulation. EEG studies indicate changes in theta and alpha power during mantra-based practices (Harne & Hiwale, 2018; Inbaraj et al., 2022), consistent with enhanced attentional states and reduced cortical arousal.

5.2 Chanting and working memory outcomes

Intervention studies, though still limited, suggest chanting can improve aspects of working memory and attention. For example, longitudinal and controlled trials with OM chanting and Vedic recitation report improvements in digit span and other verbal memory measures (e.g., small-scale trials reported in Telles et al., 1995; and subsequent school-based interventions). Note that the field requires larger randomized controlled trials to establish robust generalizable effects.

5.3 Song and lyrics research as an analogy

Studies on learning lyrics and music show that melody and rhythm provide dual encoding paths that aid verbal memory (Racette & Peretz, 2007; Ferreri & Verga, 2013). Though chanting is distinct from singing, these studies demonstrate that rhythmic and melodic scaffolds can facilitate memory encoding and retrieval processes—mechanisms that likely generalize to metric chanting.

6. The *Śiva Tāṇḍava Stotra* as a case study: phonological density, meter, and cognitive demands

6.1 Linguistic features of STS relevant to working memory

The STS includes long compounds, heavy sandhi, consonant clusters (e.g., sequences with aspirates and retroflexes), and front-to-back articulatory shifts. These features increase the demands on articulatory sequencing, phonological encoding, and the rate of rehearsal required to keep segments in the phonological store. In working memory terms, intrinsic cognitive load is high.

6.2 Meter and prosody as mnemonic scaffolds

Despite high intrinsic load, chandas provides a metrical frame with regularity (for example, repeated laghu/guru alternations or triplet groupings). This meter enables Gestalt chunking and rhythmic entrainment, reducing extraneous load and allowing rehearsal processes to exploit temporal predictability. The episodic buffer binds phonological strings with prosodic and semantic information, yielding robust multimodal memory traces.

6.3 Sensorimotor–vocal training demands

Executing STS accurately requires breath control (to maintain long phrases), precise tongue and velar movements (for consonant clusters), and rapid transitions across articulatory gestures. The motor system (cerebellum, basal ganglia, motor cortex), together with auditory monitoring systems, is repeatedly engaged during practice—conditions known to produce procedural consolidation and neural adaptation.

7. Mechanistic account: How learning STS trains the phonological loop and working memory

Combining the models and evidence above, we propose a multi-step mechanistic account:

1. **Initial encoding and high intrinsic load.** The learner encounters long, phonetically dense sequences that exceed naïve phonological loop capacity. Articulatory rehearsal is necessary to prevent decay.
2. **Prosodic chunking via chandas.** Metrical frames impose temporal landmarks, helping to group syllables into chunks that the phonological loop can maintain more efficiently (Miller, 1956).
3. **Rehearsal-driven sensorimotor learning.** Subvocal and overt rehearsal engage articulatory mechanisms, leading to feedforward model formation and error-based refinement (Shadmehr & Wise, 2005); auditory feedback enables corrective updates. The repeated co-activation of auditory and motor circuits strengthens auditory–motor connections.
4. **Episodic buffer integration and semantic deepening.** As articulatory patterns stabilize, attention can shift to semantic content; the episodic buffer integrates sound, meaning, rhythm, and context into unitary representations that support retrieval.
5. **Proceduralization and transfer.** Over time, sequences become proceduralized (automatic articulatory programs), reducing reliance on the phonological loop for basic execution and freeing resources for higher-order manipulation—this constitutes transfer to broader working memory capacity and attentional control.
6. **Neuroplastic consolidation.** Repeated practice induces structural and functional changes in language, memory, and motor networks (Kumar et al., 2021; Wan & Schlaug, 2010), reflecting long-term training effects.

8. Discussion

8.1 Theoretical implications

The account underscores that the phonological loop is not an isolated short-term buffer but operates within a broader, embodied cognitive system integrating motor control, rhythm, attention, and semantic processing. Learning a dense chant like the STS intensifies demands on the phonological loop in ways that create opportunities for schema formation and neuroplastic change. Importantly, rhythm and prosody play a central role in making high intrinsic load tractable—consistent with cognitive load theory and predictive coding frameworks.

8.2 Practical and translational implications

If validated, chant-based interventions may have applications in language learning, rehabilitation for aphasia or dysarthria, and cognitive training programs targeting working memory. The low-cost, culturally embedded nature of chanting makes it an attractive complement to standard cognitive interventions, though rigorous controlled trials are required.

8.3 Limitations and caveats

The current synthesis relies on converging literature but direct causal evidence linking STS training to generalized working-memory gains is limited. Individual differences (musical training, baseline working memory, age), stylistic variability in chanting, and cultural factors (motivation, ritual context) must be accounted for in empirical work.

9. Conclusion

Learning phonetically dense ślokas such as the *Śiva Tāṇḍava Stotra* places robust demands on the phonological loop and associated executive and sensorimotor systems. Through rhythmic chunking, repeated articulatory rehearsal, and auditory feedback, learners develop stable phonological–motor schemas that reduce cognitive load for execution and free resources for higher-level processing. Empirical evidence from neurophysiological and structural imaging studies supports the plausibility of neuroplastic change following long-term verbal–vocal training. A focused research program employing behavioral, electrophysiological, and neuroimaging methods can test the proposed mechanisms and explore translational opportunities for education and rehabilitation.

Acknowledgements:

Research supported by a grant from the Indian Knowledge Systems Initiative, Ministry of Education, PI: Dr. Deepti Navaratna Indian Knowledge System Research Project Scheme (3921) 2-50/IKS/RFP-5/2023-24/293

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