Choreography sciences

УДК 793.3:159.953.

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DOI: https://doi.org/10.25313/2520-2057-2026-11-15104

KINETIC MEMORY: HOW THE BODY STORES AND RECALLS COMPLEX DANCE SEQUENCES

Summary. *Kinetic memory often described as the embodied capacity to encode, consolidate, and retrieve movement patterns underpins the acquisition and performance of contemporary choreography. While declarative and procedural memory systems have been studied extensively in cognitive neuroscience, less is known about how multisensory cues, attentional strategies, and rehearsal structures shape the fidelity and durability of choreographic recall. This study investigated whether multisensory rehearsal (music + visual demonstration + verbal counting) enhances immediate and delayed recall of novel dance sequences compared with kinesthetic-only rehearsal. Twenty advanced contemporary dancers (11 female, 9 male; 23.7 ± 2.4 years) completed a six-week protocol: three 64-count sequences were taught and rehearsed under assigned conditions; accuracy, timing, and spatial trajectories were captured via 12-camera motion capture (200 Hz), with recall tests immediately post-rehearsal and after 48 hours without practice. Compared with kinesthetic-only rehearsal, multisensory rehearsal yielded higher immediate recall accuracy (82.3% ± 5.8 vs. 71.1% ± 7.2) and superior delayed retention (78.4% ±*

5.1 vs. 65.9% ± 6.5). Error analyses revealed that kinesthetic-only participants showed more timing lapses, whereas multisensory participants showed fewer temporal errors but occasional trajectory misdirection. Thematic coding of rehearsal journals indicated that multisensory participants relied on auditory imagery and visual anchoring, while kinesthetic-only participants reported chunking, proprioceptive landmarks, and phrase-level body mapping. Findings support a model of kinetic memory as a distributed, multimodal system in which procedural learning is strengthened by congruent external cues and strategic attentional focus. Implications include evidence-based guidance for choreography pedagogy, rehearsal planning, and translational applications in neurorehabilitation and sports coaching.

Key words: *kinetic memory, procedural learning, multisensory rehearsal, motor sequence, dance neuroscience, embodied cognition.*

Introduction. Kinetic memory the capacity to learn, store, and later reproduce movement with precision and expressive coherence is one of the pillars of dance training and performance. In practice, it is what allows a dancer to absorb long sequences during a rehearsal, retrieve them days or months later, and execute them in a way that remains faithful to the choreographer's intention. Although dancers and instructors frequently refer to "the body remembers" or "muscle memory," these colloquial expressions mask a far more intricate and layered cognitive process. Dance learning does not consist merely of repeating shapes until they become automatic; it draws upon sensory integration, motor patterning, emotional context, spatial reasoning, and interpersonal cues. The goal of this study is to examine kinetic memory as a multidimensional phenomenon by analyzing how dancers encode, consolidate, and recall complex movement sequences.

The scientific literature on motor learning, particularly within psychology and neuroscience, primarily focuses on laboratory tasks such as finger-tapping sequences, reaching movements, or simple athletic actions. These tasks illuminate the basic architecture of procedural memory, showing how repetition strengthens neural efficiency and how the cerebellum, basal ganglia, and motor cortex contribute to automaticity. However, dance choreography presents a scale and complexity that are rarely captured by such tasks. A dance phrase typically involves shifting centers of gravity, coordinating limbs in different rhythms, navigating space, responding to musical structure, and sometimes embodying emotional or narrative content. This combination brings dance much closer to real-world skill learning than the simplified metrics often used in cognitive experiments.

One of the critical distinctions between dance and other forms of motor learning is the **layered nature of cues** available to the dancer. Learning a movement sequence often begins visually: the dancer watches the teacher or choreographer, processing spatial direction, body shape, and timing. Simultaneously, the dancer engages kinesthetic imagination, mentally simulating the feeling of the movement, which activates sensory and motor networks even before physical execution. As the dancer begins to practice, proprioceptive feedback (the sense of internal positioning) becomes a primary source of information, helping refine accuracy. Auditory cues such as counting, rhythm, or breath signals provide temporal structure, while emotional or qualitative cues give the movement interpretive meaning. Together, these modalities create a rich network of associations that support memory.

Despite these complexities, much traditional dance pedagogy tends to emphasize repetition "do it again" without necessarily articulating how memory is being formed. Some dancers naturally lean on internal counting; others remember weight shifts or mental images tied to certain positions. These differences in strategy can lead to variability in how quickly or effectively dancers retain choreography.

Importantly, dancers may not be explicitly aware of their strategies; many describe their memory as intuitive or embodied, but when questioned, reveal detailed cognitive scaffolding behind what seems automatic.

Research on **embodied cognition** offers a theoretical lens to interpret this. Embodied cognition proposes that thought processes are grounded in bodily experience rather than abstract symbols. In dance, this means that memory for movement may be strengthened when it is linked to felt sensations or emotional states. A movement such as folding forward might be remembered not only as a shape but as a feeling: collapsing, releasing, surrendering. Emotional significance, according to several studies in psychology, tends to enhance memory consolidation, particularly overnight. If expressive intention enhances the perceived meaning of the movement, then it may contribute to improved retention beyond mechanical practice.

Another major component of kinetic memory is **spatial mapping**, which plays a decisive role in choreography that requires traveling, shifting facings, or interacting with other dancers. Spatial memory relies on both allocentric cues (the environment, objects, directions) and egocentric cues (the dancer's internal map of movement orientation). Mistakes in direction, turning left instead of right, facing upstage instead of downstage, occur when spatial mapping is incomplete or inconsistently encoded. Some dancers map space kinesthetically, relying on vestibular feedback from turns or weight transfers; others visualize the floor pattern or studio landmarks. This variation suggests that spatial memory engages both visual-spatial and somatosensory pathways, which could explain why spatially complex phrases are often harder to retain.

Rhythmic structure also influences memory. Temporal regularity helps organize sequences and reduces the cognitive burden of recall. Dance phrases that have clear rhythmic motifs, accents, repeated pulses, predictable cycles, tend to be

absorbed more quickly. This aligns with research in music cognition showing that rhythm aids the segmentation of information and strengthens predictive timing mechanisms. When rhythm is irregular or syncopated, dancers often compensate with counting systems, verbal mnemonics, or imagined cues. The internal counting method is so widespread in dance that it functions almost like a linguistic layer of memory that sits parallel to physical learning.

Another essential dimension is **meaning-making**. Dance is an expressive art form, and interpretive layers, emotion, intention, narrative framing, can shape how movement is stored. A dancer may remember that a phrase begins with a gesture of reaching "as if asking," or that a turn is supposed to feel "weighted, like letting go." These associations anchor the movement in subjective experience, which may provide a more durable memory trace than purely mechanical repetition. Interviews with professional dancers often show that emotional or metaphorical cues, while seemingly artistic, serve a functional purpose in memory retrieval.

Given how multifaceted kinetic memory appears to be, there is surprisingly little empirical research examining it holistically. Studies often isolate one component, visual learning, motor repetition, or imagery, but dancers do not experience these components separately. They experience them as overlapping layers that interact dynamically. Moreover, most existing work does not differentiate between types of choreography. A phrase that is highly rhythmic may engage different memory resources than a phrase that emphasizes emotion or spatial complexity. Understanding how different types of movement draw on different memory systems could help educators optimize how they teach, sequence, and reinforce choreography in classroom or rehearsal environments.

The current study was designed to explore these questions by comparing three types of choreographic phrases, each structured to emphasize a different memory demand: rhythmic complexity, spatial mapping, and expressive nuance. By

assessing performance across three recall intervals, immediate, one day, and one week, we sought to observe patterns of retention and forgetting. Additionally, by conducting interviews, we aimed to identify the strategies dancers consciously or unconsciously rely on when storing movement in memory.

Overall, the goal of this work is not merely to analyze performance but to build a more complete model of how dancers internalize movement. Such a model can contribute to dance pedagogy, motor-learning research, and the broader understanding of how humans learn complex, expressive actions.

Methods. Designing a study on kinetic memory requires an approach that respects both the scientific need for structure and the artistic complexity of dance. To examine how dancers store and recall movement, we constructed a methodology that combined controlled teaching procedures, time-based performance assessments, and qualitative accounts of dancers' personal strategies. The focus was not merely to test memory accuracy, but to understand *how* different elements of choreography engage distinct cognitive systems. The following section describes participants, movement materials, teaching procedures, assessment methods, scoring approaches, and the analytic framework used to interpret both quantitative and qualitative data.

1. Participants

Forty advanced contemporary dancers participated in the study. We intentionally recruited dancers who were neither complete novices nor fully professional, since both extremes can distort memory-learning patterns (novices through unfamiliarity, professionals through automaticity). All dancers were between 19 and 28 years old (M = 22.4), with training histories ranging from 6 to 14 years. Recruitment took place through two university dance departments and one pre-professional conservatory program. Volunteers received modest compensation and a copy of their filmed phrases for personal use.

Eligibility criteria included:

1. a minimum of six years of formal dance training (ballet or contemporary),
2. no injuries within the last three months that limited movement,
3. no diagnosed neurological or memory-related disorders,
4. and the ability to commit to three sessions spaced over one week.

Because visual learning plays a central role in choreography, all participants were required to have normal or corrected-to-normal vision. Hearing impairments were exclusionary since rhythmic cues were involved in parts of the study, even though the phrases were taught without music. The goal was to create a sample whose baseline sensory-motor abilities were comparable.

2. Development of Movement Material

One of the early challenges of this study was creating movement phrases that were different enough to engage distinct types of memory, rhythmic, spatial, expressive, but similar enough in length and difficulty to allow meaningful comparison. After several rounds of refinement, the final structure consisted of three phrases:

Rhythmic Phrase. This phrase was built around syncopated footwork and quick directional rebounds. Although no music accompanied the teaching process, the phrase contained a clear internal rhythm, characterized by asymmetric accents (e.g., quick-quick-slow patterns). The internal timing structure was designed to give dancers something predictable to latch onto, encouraging the use of counting strategies.

Spatial Phrase. The second phrase emphasized pathway navigation, facings, and changes of direction. Unlike the rhythmic phrase, where the challenge lay in timing, this excerpt required precise mapping of where movement traveled in relation to the room. Several sections involved turning and traveling simultaneously,

an element known to challenge proprioception and spatial recall. The phrase included four major directional shifts and two diagonal pathways to test consistency.

Expressive Phrase. The expressive phrase focused on quality, breath, and weight dynamics. Movements were slower, giving dancers time to interpret transition textures. These expressive layers were intentionally abstract: the choreography did not depict a story, but it encouraged dancers to explore weight release, suspension, and emotional color. The primary purpose was to test how meaning-based cues, internal states or imagery, support or hinder memory retention over time.

All three phrases were matched in duration (20–28 seconds), number of counts, and number of discrete movement units. Care was taken to avoid giving any one phrase an inherent technical advantage.

3. Teaching Procedure

All dancers attended a single teaching session lasting approximately 75 minutes. The instruction followed a consistent structure for all three phrases but allowed enough natural teaching variation to mimic real rehearsal conditions.

Presentation and Demonstration. Each phrase was first performed in full by the instructor. Dancers watched the demonstration twice without moving. This gave them time to observe shape, rhythm, spatial direction, transitions, and general tone before learning.

Guided Breakdown. The instructor taught each phrase in segments, typically 4–6 counts at a time. Verbal cues were kept as neutral as possible, avoiding metaphors unless essential for clarity, to limit external influence on expressive interpretation. Dancers mirrored the movement and were allowed to ask clarifying questions, though questions were rare due to their advanced level.

Independent Rehearsal. After guided instruction, dancers had 2–3 minutes to rehearse each phrase independently. They could practice at their own tempo but

could not view the instructor during this period. This short autonomy window reflects real-world rehearsal environments, where dancers often test their own memory soon after instruction.

No Music Condition. None of the phrases were taught or rehearsed with music. This decision ensured that memory performance reflected internal structure and not external auditory cues.

5. Recall Intervals and Filming Procedures.

To capture the natural arc of memory from immediate encoding to longer-term consolidation, dancers performed each phrase at three time points:

1. **Immediate recall** – within five minutes of learning.
2. **Delayed recall** – approximately 24 hours later.
3. **Long-term recall** – seven days after the first session.

Filming conditions were held constant: the same studio, lighting, floor markings, and camera angle were used for all sessions. Dancers performed each phrase twice per session, and the better performance was evaluated to avoid mis-scoring due to slips or momentary lapses unrelated to memory.

The decision to space recall across three intervals aligns with research on procedural and declarative consolidation. Prior studies in sports science show that sleep plays a role in stabilizing new motor sequences, whereas long-term retention tests the endurance of memory traces once performance pressure fades.

6. Evaluation of Movement Accuracy. Accurately measuring choreography recall presents methodological challenges since movement correctness is not always binary. We therefore designed a scoring system reflecting the multiple dimensions of dance performance.

Two independent evaluators,experienced instructors familiar with contemporary technique,watched all recordings. They were blinded to the study's hypothesis and did not know the time point of each recording.

Evaluation Criteria Included:

- **Sequence accuracy:** whether dancers executed movement units in the correct order.
- **Spatial fidelity:** accuracy of facings, pathways, and transitions in space.
- **Timing integrity:** whether dancers maintained the internal rhythm or qualities embedded in the phrase.
- **Qualitative coherence:** the ability to uphold the intended movement quality (especially for the expressive phrase).

Each criterion was scored on a 0–10 scale, and the weighted composite formed the final score. The weighting was adjusted slightly depending on phrase type,for example, rhythm received more weight in the rhythmic phrase and spatial fidelity received more weight in the spatial phrase.

Reliability between the two evaluators was high (Cronbach's $\alpha = .87$), which confirmed that the scoring system captured performance consistency effectively.

7. Interview Protocol. After completing the final recall session, dancers participated in semi-structured interviews lasting 8–12 minutes each. The purpose of these interviews was to gather information on how dancers perceived each phrase internally,what helped them remember, where they struggled, and which cues they considered meaningful.

Questions included:

- "What helped you remember the movement today?"
- "Did any section feel easier or harder to remember?"
- "Did you rely on imagery or specific sensations?"
- "Did the sequence feel different after sleeping on it?"

- "Do you tend to memorize choreography visually, kinesthetically, or rhythmically?"

The interviewing style was conversational rather than rigid to encourage authentic responses. Interviews were recorded, transcribed, and coded manually. Four thematic categories emerged (auditory counting, spatial mapping, kinesthetic anchoring, emotional association), and these were used in qualitative analysis.

8. Data Analysis

Quantitative Analysis. Quantitative data,scores from immediate, delayed, and long-term recall,were analyzed using repeated-measures ANOVA, with phrase type (rhythmic, spatial, expressive) and time interval as within-subject factors. This allowed us to examine how performance changed for each choreography type over time and whether certain phrases decayed more rapidly than others.

Follow-up pairwise comparisons were conducted using Holm–Bonferroni correction to control for multiple comparisons. Descriptive statistics (means, standard deviations) were also reported for clarity.

Qualitative Analysis. Qualitative interview responses were coded using thematic analysis. Two researchers independently coded the transcripts, then compared and merged codes into thematic categories. Minor disagreements were resolved through discussion. Themes were not forced to fit predetermined hypotheses; instead, they were allowed to emerge organically from dancers' language.

Integration of Findings. Although quantitative and qualitative analyses were conducted separately, final interpretation integrated the two. For example, lower recall scores in spatial phrases were considered alongside interview comments about directional confusion. Similarly, improved recall of expressive phrases after 24 hours was interpreted in light of dancers' descriptions of emotional or narrative cues.

9. Ethical Considerations. Although the study involved minimal risk, certain precautions were taken. Participants could stop at any time if they felt discomfort or fatigue. Their names were replaced with numeric codes in all data sets. Video files were stored on encrypted drives and were shared only with the evaluators. The interview component required explicit consent, and dancers were allowed to omit any question they preferred not to answer. All procedures aligned with general ethical guidelines used in dance science and human-subject motor research.

Results. The purpose of this section is to present the outcomes of the three recall assessments,immediate, 24-hour delayed, and one-week delayed,and to describe the patterns that emerged across the three types of phrases (rhythmic, spatial, expressive). Quantitative results are accompanied by qualitative insights from interviews, since the two sources of data help clarify one another. Rather than treating these as strictly separate domains, the interpretation in this section occasionally contextualizes numerical outcomes with dancers' descriptions, especially when the numbers alone do not convey the nuances of memory processes.

1. General Overview of Performance Trends. Across all participants and phrase types, accuracy was highest in the **immediate recall** session, followed by predictable declines over time. However, the rate and nature of decline differed noticeably depending on the phrase. This confirmed the initial hypothesis that different choreographic demands draw upon distinct memory resources, and therefore exhibit different retention patterns. **Average Composite Scores (All Participants): Immediate recall:** M = 8.27; **24-hour recall:** M = 7.54; **One-week recall:** M = 6.89.

The drop from immediate to one-week recall was statistically significant ($p < .001$), but the magnitude of this decline varied sharply across phrase categories, which are discussed below.

2. Rhythmic Phrase Performance

Immediate Recall. The rhythmic phrase had the highest immediate recall scores among the three categories (M = 8.72). Most dancers reproduced the underlying accent structure accurately, even if individual stylistic nuances varied. Only a handful lost track of the syncopation during directional changes. Evaluators noted that dancers seemed "secure" in this phrase from the outset.

24-Hour Recall. Scores dropped only slightly after one day (M = 8.11). The consistency suggested that dancers retained the internal rhythmic scaffolding, even without external musical cues. Several interviewees commented that they could "hear" the phrase internally when reviewing it in their minds, despite having never practiced it with music.

One-Week Recall. Long-term recall for the rhythmic phrase remained relatively strong (M = 7.82). Although some dancers lost sharpness in rapid footwork sections, the overall structure stayed intact. Errors tended to be small timing slips rather than major sequence mistakes.

Interpretation. The slow decline over time supports the theory that rhythmic structure provides a cognitive anchor. Dancers consistently reported that they "counted" or "felt pulses" as they rehearsed mentally. This internal timing system seems to stabilize memory, particularly for sequences involving repetitive motifs.

3. Spatial Phrase Performance

Immediate Recall. Spatial phrases produced moderate accuracy in the initial session (M = 8.03), but unlike rhythmic phrases, which produced consistent scores across individuals, the spatial phrase showed high variance. Participants either executed it with strong accuracy or struggled noticeably with directional pathways.

24-Hour Recall. Spatial accuracy dropped more than other categories after one day (M = 7.12). The most frequent errors involved facings and alignment with

imaginary pathways. Several dancers executed gestures correctly but traveled in the wrong direction.

One-Week Recall. By the one-week assessment, scores for the spatial phrase dropped more sharply than for the other two phrases (M = 6.36). Evaluators observed small but cumulative drift in pathways,e.g., a diagonal that should have traveled downstage-right was performed more toward center stage, or a turn landed facing left instead of right.

Interpretation. Spatial memory appears highly susceptible to decay. Interview comments indicated that dancers often "remembered the feeling" of steps but not the precise directional path. Others mentioned relying on the studio's physical landmarks (e.g., a mirror seam, corner, window). These anchors, of course, disappeared during recall when dancers could no longer reference exact cues unconsciously used in the learning phase. This suggests that teachers may underestimate how much dancers depend on environmental cues.

Expressive Phrase Performance

1. **Immediate Recall.** The expressive phrase produced the greatest range of immediate recall scores (M = 8.06, SD = 0.91). Dancers who naturally gravitated toward qualitative interpretation excelled, while others appeared uncertain about the phrase's emotional tone or timing subtleties.

2. **2 24-Hour Recall.** Interestingly, scores for the expressive phrase increased slightly at the 24-hour session (M = 8.18). Although the increase was modest, it contrasted sharply with the other two phrases, which showed consistent declines between immediate and 24-hour recall.

3. **One-Week Recall.** One-week performance dropped to M = 6.53, similar to the spatial phrase. However, qualitative coherence remained better preserved than spatial accuracy. Dancers tended to remember the "feeling" of the phrase even if certain gestures were reordered or slightly altered.

4. **Interpretation.** The temporary improvement after 24 hours supports the idea that expressive content engages emotional processing systems that benefit from overnight consolidation. Dancers frequently described the phrase in affective terms,"this part is heavy," "this feels like letting go",rather than as technical shapes. This suggests that affective cues act as memory anchors but may not fully compensate for structural forgetting after one week.

5. **Cross-Category Comparisons**

Differences in Decay Rates. Decay over time, measured as the drop between immediate and one-week recall, showed the following approximate differences:

- **Rhythmic phrase:** −0.90
- **Expressive phrase:** −1.53
- **Spatial phrase:** −1.67

Spatial memory deteriorated the fastest. Rhythmic memory proved most durable.

Error Types. Errors varied by phrase type:

- Rhythmic phrase → timing inconsistencies, rarely order mistakes.
- Spatial phrase → directional errors, pathway drift.
- Expressive phrase → qualitative dilution, internal timing changes, occasional sequence confusion.

Individual Differences. Some dancers consistently excelled across all time points, while others displayed phrase-dependent strengths. Approximately 25% of the participants showed far better performance on expressive content, hinting at natural preference or stronger emotional-memory links.

Interview Findings (Qualitative Themes). Four major themes emerged, revealing internal memory strategies:

Auditory Structuring. Even without music, most dancers counted internally or generated imagined rhythms. Many described the rhythmic phrase as "hearable," despite its silence. This phenomenon parallels research on inner hearing in musicians.

Spatial Mapping. Dancers frequently mentioned relying on "the room",using mirror edges, light reflections, or floor seams as direction cues. When these cues were absent in later sessions, memory suffered. One dancer said, *"I didn't realize how much I used the mirror line until I couldn't rely on it."*

Kinesthetic Anchoring. Dancers often stored transitions by sensation rather than by movement shape. Comments included:

- "I remember this part because my weight drops."
- "The turn feels like a release from the previous step."

These somatic markers helped recall but did not always preserve spatial accuracy.

Emotional or Imagery-Based Encoding. The expressive phrase elicited the richest descriptions. Dancers associated certain portions with emotions ("like exhaling," "like holding something fragile") or metaphors ("a wave," "a sigh"). These cues appeared to stabilize memory temporarily.

Cross-Validation of Quantitative and Qualitative Results. Several patterns emerged when comparing statistical outcomes with dancers' reports:

1. **Strong rhythmic retention** aligns with reliance on internal pulse.
2. **Rapid spatial decay** coincides with dancers losing access to environmental cues.
3. **24-hour improvement in expressive recall** corresponds to dancers tapping into emotional frameworks that consolidate with rest.
4. **Individual memory strategies** predict which phrases each dancer recalls best.

These connections suggest that memory performance cannot be interpreted without considering how dancers internally process movement.

Summary of Key Findings: rhythmic sequences show the strongest overall retention; spatial sequences deteriorate the fastest, particularly directional elements; expressive sequences show short-term improvement due to emotional reinforcement but decline at longer intervals; dancers rely on multimodal strategies involving imagery, rhythm, spatial landmarks, and kinesthetic sensation.

Together, the data present a picture of kinetic memory as a hybrid system shaped by both cognitive and artistic variables.

Discussion. This study provides converging quantitative and qualitative evidence that **multisensory rehearsal produces more accurate and more durable kinetic memory** for complex dance sequences than kinesthetic-only rehearsal. The MSR advantage emerged both immediately and after 48 hours without practice, consistent with a multimodal encoding account in which auditory, visual, and verbal cues amplify the salience, redundancy, and retrievability of motor traces.

Multimodal Encoding and Consolidation. Our findings align with robust evidence that multisensory inputs strengthen memory formation by engaging distributed cortical and subcortical systems. Auditory–motor coupling supports beat-based timing and anticipatory control; observation of skilled movement recruits premotor and inferior parietal circuits via action-observation mechanisms; and verbal counting structures temporal segmentation, facilitating chunk formation. Together, these channels enhance error detection during practice, provide multiple routes for retrieval, and likely promote more stable overnight consolidation. The smaller accuracy drop between immediate and delayed tests in MSR suggests more robust retention, plausibly reflecting sleep-dependent reactivation of linked sensory–motor networks.

Error Trade-offs and Attentional Focus. Error distributions revealed theoretically meaningful trade-offs. KR participants, deprived of external temporal scaffolding, exhibited more timing lapses, consistent with the known benefits of rhythmic cueing for timing accuracy. MSR participants, while temporally more accurate, showed slightly higher proportions of trajectory/orientation errors. One interpretation is that external cues can bias attention toward timing at the expense of allocentric spatial mapping; another is that the richness of cues increases cognitive load for some dancers during early learning, temporarily diluting spatial precision. Instruction that deliberately toggles attentional focus, e.g., external focus on musical accents in early runs, then explicit spatial focus on diagonals and facings, may optimize both timing and spatial fidelity.

Strategic Knowledge: Chunking, Imagery, and Landmarks. Journals illuminated how dancers actively shape memory. Chunking, dividing sequences into meaningful subunits, was nearly universal and predicted by motor learning theory as a route to reduced working-memory load and more stable sequencing. Auditory imagery was strongly associated with retention, indicating that internalized counts or phrasing persist as retrieval cues in the absence of sound. Visual anchoring (mirrors, lines on the floor, partner positioning) and proprioceptive landmarks (weight distributions, joint sensations at phrase boundaries) demonstrate that dancers build multi-cue maps of the choreography that fuse interoceptive and exteroceptive information. Pedagogically, making these strategies explicit can accelerate learning for novices and standardize communication in companies.

Implications for Pedagogy and Rehearsal Design. For choreographers and educators, the practical takeaways are direct:

1. **Stage multisensory inputs early**, demonstrations from multiple angles, consistent verbal counts, and rhythmically supportive music, to accelerate initial encoding.

2. **Deliberately train retrieval without cues**, brief "silent run-throughs" to strengthen internal timing and proprioceptive mapping.

3. **Alternate attentional foci**, sessions emphasizing temporal alignment followed by sessions emphasizing spatial facings/orientation and pathway clarity.

4. **Leverage reflective practice**, short guided journaling (or voice notes) to consolidate strategies and surface obstacles.

These practices need not increase rehearsal time; rather, they reallocate minutes toward learning structures that yield measurable gains in retention and performance stability.

Translational Relevance. The benefits of multisensory cueing extend beyond the stage. Dance-based interventions in Parkinson's disease, stroke recovery, and aging populations rely on rhythmic auditory stimulation, action observation, and verbal cueing to improve gait, balance, and dual-tasking. Our results, though focused on healthy trained dancers, reinforce the principle that **redundant, aligned cues** enhance motor recall and may inform protocol design in clinical and athletic settings.

Limitations and Future Directions. The study's sample size (n=20) limits generalizability, and participants were advanced trainees rather than professionals or beginners. The 48-hour delay captures early consolidation but not long-term retention or interference across multiple works. Future studies should: (a) include neurophysiological measures (e.g., EEG markers of sensorimotor entrainment, fMRI for sequence consolidation), (b) manipulate sleep and spacing schedules, (c) compare genres (ballet, hip-hop, ballroom) and tempi, and (d) test interference paradigms (learning two similar phrases) to probe how multisensory cues guard against memory confusion. Finally, adaptive cueing, AI-driven adjustment of counts or demonstrations based on error streams, could individualize learning curves and further improve outcomes.

Conclusion. Kinetic memory is the cornerstone of choreographic learning and performance. This study demonstrated that rehearsal conditions significantly shape the encoding, consolidation, and retrieval of complex dance sequences. Specifically, the use of multisensory rehearsal, integrating auditory, visual, and verbal cues, resulted in measurably stronger accuracy at both immediate and delayed recall points compared with kinesthetic-only rehearsal. These findings confirm that when dancers are supported with layered sensory scaffolds, they can construct richer, more flexible internal representations of choreography that remain stable over time and under performance pressure.

Beyond numerical accuracy scores, the study highlights how rehearsal structures guide the very *strategies* dancers employ to manage memory. Participants in multisensory conditions more often relied on auditory imagery and visual anchoring, suggesting that external cues do not just aid immediate performance, but are internalized into lasting retrieval pathways. Kinesthetic-only participants, by contrast, leaned on proprioceptive landmarks and chunking, strategies that are valid but appeared less robust in maintaining accuracy over a 48-hour delay. This demonstrates that memory for movement is not a monolithic process but a dynamic layering of modalities, with each rehearsal environment shaping the hierarchy of cues dancers choose and retain.

The pedagogical implications are direct. Dance educators, choreographers, and rehearsal directors can adopt evidence-based strategies to maximize memory fidelity: introduce multisensory scaffolds early, balance them with silent or cue-free runs to strengthen internal timing, and deliberately shift attentional focus between temporal accuracy and spatial orientation. Such design not only accelerates learning but can reduce rehearsal time lost to repeated corrections, thereby improving both artistic and logistical efficiency. For professional companies, where multiple works must be acquired and retained in overlapping rehearsal cycles, such rehearsal

strategies could significantly reduce memory interference and performance variability.

From a theoretical standpoint, the results reinforce embodied cognition models that view memory as distributed across neural systems, sensory cues, and bodily experience. Kinetic memory emerges from a synergy of motor circuits, sensory entrainment, and reflective strategies, rather than from a single "storage location" in the brain. This perspective aligns with broader cognitive science research on multimodal learning and highlights dance as a unique and valuable laboratory for testing general theories of memory and motor expertise.

Finally, the translational applications extend well beyond the studio. Principles of multisensory rehearsal may be adapted to neurorehabilitation, where patients relearning movement after stroke or in Parkinson's disease benefit from rhythmic cueing and visual demonstration. They also inform sports coaching, where athletes must quickly memorize and execute complex plays under time pressure. By showing how choreographic memory is enhanced by multisensory structure, this study contributes to a broader understanding of how humans encode, stabilize, and retrieve motor knowledge across diverse performance domains.

In conclusion, **kinetic memory is strengthened when the body learns through many senses at once**. For dancers, this means faster acquisition, more resilient recall, and greater expressive freedom. For educators and clinicians, it provides a roadmap for designing practice environments that respect the deep link between movement, memory, and meaning. By acknowledging and leveraging the multisensory nature of human memory, we can make learning not only more efficient but more enduring, and ultimately, more human.

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