

Dancing towards speech improvement: Repurposing dance for motor speech deficits in neurodegenerative diseases

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Abstract

Dance or rhythmic movement-based training has demonstrated significant efficacy in addressing a range of motor and cognitive deficits associated with neurodegenerative diseases like Parkinson's and Alzheimer's diseases. Leveraging both human and non-human animal behavioral and neurobiological evidence, I hypothesize a possible untapped role of dance training in mitigating impairments in the motor control of speech, a complex sensorimotor behavior affected in these conditions. Here, this hypothesis is supported by an in-depth examination of motor speech deficits in Parkinson's and Alzheimer's diseases, at a behavioral, physiological, and neural level. Additionally, literature on the impact of dance training on behaviors and brain pathways possibly relevant to speech motor control in populations with neurodegenerative diseases is thoroughly reviewed. Synthesizing these findings, I propose repurposing dance as a novel treatment for motor speech deficits and outline specific experiments to test this hypothesis. By comprehensively investigating the full spectrum of the effects of a motor-based training, i.e., dance, on often overlooked motor-based behaviors, such as speech, we may uncover novel therapeutic avenues of a practice that has already shown promising implications.

Keywords

Alzheimer's disease, communication, dance, language, motor, neurodegenerative, Parkinson's disease, primary motor cortex, speech

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Introduction

Dance or rhythmic movement-based training, henceforth referred to as dance training, has proven effective in addressing diverse motor deficits associated with neurodegenerative diseases such as Parkinson's disease (PD), Alzheimer's disease (AD), or mild cognitive impairment (MCI). Significant improvements in motor performance, balance, sit-to-stand and timed-up-and-go performance, endurance, walking velocity, and a reduction in freezing of gait have been documented.^{1–7} However, while speech, another motor behavior, is significantly affected in various neurodegenerative disorders (e.g.,^{8,9}), the potential impact of dance training on the deficits relevant to speech motor control has not been explicitly hypothesized. Only a few dance training studies have integrated verbal tests (e.g.,^{10,11}), though primarily focusing on assessing other language modules, such as semantics, rather than the specific language module this proposal focuses on: the motor control of muscles relevant to speech production. Henceforth, for clarity, the term “speech” will be used to refer to the specific motor control

of muscles (e.g., laryngeal, tongue, mouth) involved in producing and articulating sound, whereas “language” will be used as an umbrella term that includes the various modules involved in this complex behavior, such as speech, semantics, and syntax, among others.

In this paper, I aim to present the evidence that led me to propose dance as a potential treatment for the motor control aspects of speech deficits observed in neurodegenerative diseases. My hypothesis is rooted in the evolutionary concept known as the “vocal learning and rhythm synchronization hypothesis”,^{12–14} which posits a strong evolutionary link between fundamental features of speech (i.e., vocal

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production learning, namely the ability to learn new complex vocal sequences) and dance (i.e., body movement rhythm synchronization). This hypothesis is based on findings that indicate that the only two species that have been identified so far to display evidence of rhythm synchronization, humans and parrots, also exhibit the most advanced vocal learning abilities.^{13,14} The central idea is that advanced vocal learning in these species may have served as a preadaptation for their beat synchronization abilities.^{12–14} At a molecular level, this hypothesis is supported by findings¹⁵ showing that in vocal learning birds, all cerebral nuclei that control singing (i.e., syrinx movements, analogous to larynx movements) lie immediately adjacent to those activated during hopping (i.e., limb movements).¹⁵ Further, Gordon et al.¹⁶ demonstrated that genes showing specialized upregulation or downregulation in one of the singing control nuclei in vocal learning birds significantly overlap with genes in humans carrying signatures predictive of beat synchronization abilities. These findings altogether suggest that the neural pathways and genes that enable us to speak and to dance share important connections.

Building on the “vocal learning and rhythm synchronization hypothesis”,^{12–14} I proposed a potential underlying neural mechanism grounded in compelling evidence showing the *very same* neurons that project to speech-control muscles (e.g., laryngeal) also project to dance-relevant movement muscles (e.g., arm).¹⁷ In two relevant studies, intracortical electrodes, implanted in the conventionally identified “hand” area of the dorsal primary motor cortex (M1), showed significant firing rate changes not only during hand movements but also during speech production.^{18,19} These studies not only showcased that the “hand” area encodes specific spoken phonemes but also achieved high-accuracy decoding of these phonemes using both intracortical multiunit spikes and local field potential power. In another relevant study, Willett et al.²⁰ recorded multi-unit activity from the hand knob area of the precentral gyrus (M1) while participants performed various movements, such as face (including speech), head, arm, and leg movements. They found strong neural tuning to all movement types, with single neurons showing responsiveness to multiple movement categories. Pertinently, recent functional magnetic resonance imaging (fMRI) studies by Gordon et al.²¹ unveiled that human M1 comprises motor-specific regions intermingled with so-called “inter-effector” integrating areas lacking movement specificity. Overall, these and other^{22,23} studies suggest that contrary to the “one muscle, one motor neuron” principle advocated by Penfield’s motor homunculus,²⁴ motor representations in human M1 are organized based on different principles, enabling the same neurons to control multiple types of movement. For the “vocal learning and rhythm synchronization hypothesis”, I hypothesize this implies that the very same neurons involved in the control of speech-related muscle movements (e.g.,

laryngeal movements) could have been co-opted to control dance-related rhythmic muscle movements (e.g., rhythmic arm movements). Moving forward, it would be intriguing to investigate whether overlapping or adjacent regions in other brain areas of these movement pathways are co-activated during both speech and dance-related movements.

Moreover, both speech and dance movements rely on a tight auditory-to-motor integration. The importance of this integration becomes more apparent when auditory feedback lacks temporal or acoustic precision. In speech experiments with delayed auditory feedback, participants were more prone to producing incorrect sounds, making incongruous repetitions, and exhibiting distorted speech patterns compared to conditions with no delay.^{25,26} Similarly, in rhythm entrainment experiments where participants received distorted auditory feedback of their own finger-tapping sounds on a table, they displayed increasing inaccuracies and deviations from tempo, highlighting the reliance of entrained movements on auditory-to-motor integration.²⁷ These parallels may partly explain developmental findings in human children, where the ability for sustained beat synchronization was found to predict the development of phonological (speech) production until late childhood.²⁸

Drawing on this cumulative evidence, in combination with evidence I will present in detail here, I posit that training the brain pathways responsible for dance-activated body movements could potentially impact the pathways responsible for speech-activated movements (Figure 1). Here, I review the evidence that led me to formulate this hypothesis. I begin by examining the motor speech deficits observed in PD and AD across behavior, physiology, and underlying brain pathways. Subsequently, I delve into the dance literature, exploring its potential relevance to motor speech behaviors and associated brain pathways in populations with neurodegenerative diseases. Combining these strands, I articulate my hypothesis regarding the potential of dance as a treatment for motor speech deficits in neurodegenerative diseases and propose experimental approaches to empirically test it.

Motor speech deficits and underlying brain pathways in Parkinson’s disease

PD is a progressive neurodegenerative disorder known for its array of motor symptoms, extensively studied over the years, including tremor, bradykinesia, rigidity, gait dysfunction, and postural instability.²⁹ Despite this, deficits in speech, another motor domain affected by PD, have not received comparable attention in terms of assessment and intervention. Yet, research indicates that motor speech impairments affect a significant proportion of PD patients, with estimates ranging from 70% to 89%.^{8,30}

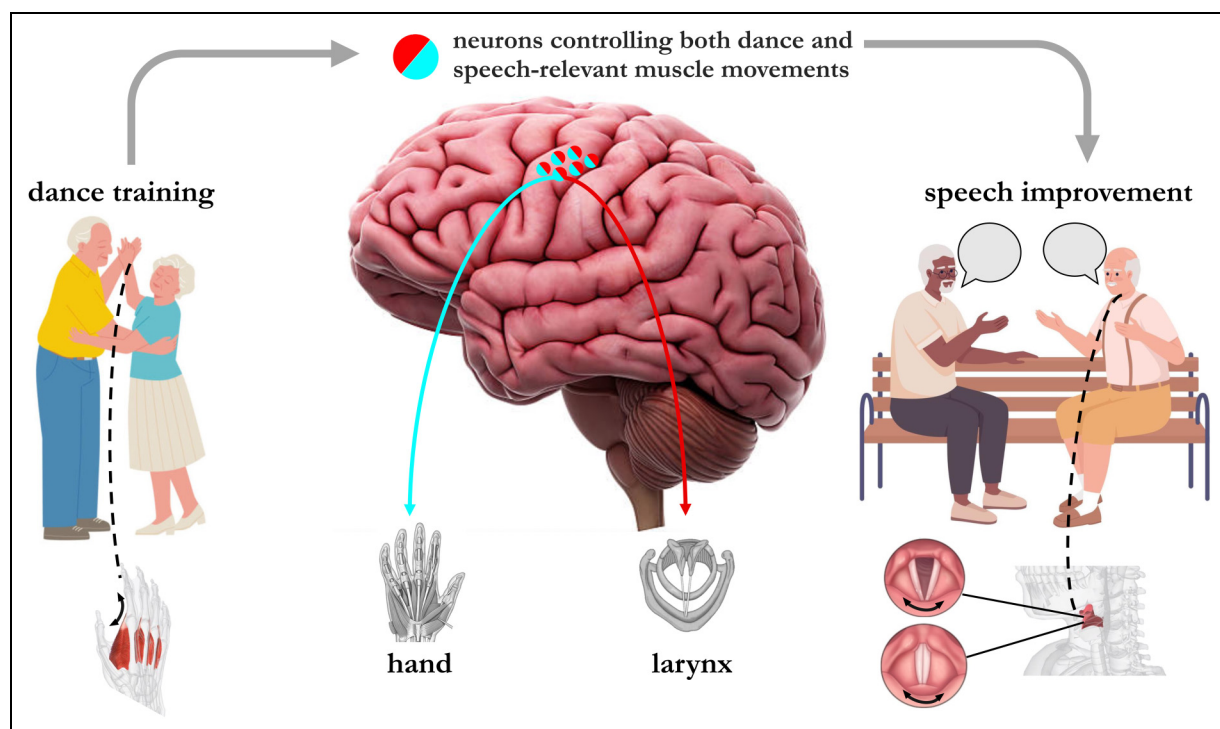


Figure 1. Diagram of the proposed effect of dance training on speech-motor performance in individuals with neurodegenerative diseases. During dance training, participants activate motor pathways that control dance-related muscle movements (e.g., hand, arm, hip, and knee muscles). For example, during partnered dance training, participants typically hold each other during paired dances, which can activate motor pathways that control hand/arm muscle movements. According to evidence reviewed in the article (e.g.,^{18–20}), neurons in the M1 region control muscles involved in dance-related (e.g., hand) and speech-related (e.g., larynx) movements. Consequently, while dancing, participants engage these overlapping neural pathways, potentially enhancing not only the control of muscles involved in dancing but also those involved in speech-motor coordination. Thus, dance training may contribute to speech improvement through enhanced control of relevant laryngeal muscles that control the abduction and adduction of the vocal folds.

Importantly, for 29% of these patients, motor speech deficits are identified as a primary concern, alongside the hallmark whole-body motor symptoms.

Motor speech impairments in people with PD (henceforth, PwPD) encompass a range of challenges, including but not limited to difficulties in articulation, loudness, speech rate, fundamental frequency, and pitch. Specifically, key characteristics of these deficits include imprecise articulation,^{30,31} often marked by imprecise consonants;^{32,33} monotony and reduced loudness;^{31,33,34} variable and abnormal speech rate,^{30,31,33,34} sometimes with rushes reminiscent of stuttering;^{30,34} abnormal fundamental frequency,³⁵ leading to prosodic insufficiency, such as reduced stress on typically emphasized syllables or words;^{30,33,34} and monotonous^{33,34} or higher³⁵ vocal pitch, hindering the ability to convey intended emotional tones. Consequently, these impairments contribute to decreased speech intelligibility,³⁶ with researchers commonly classifying them under the umbrella term “dysarthria”.^{33,34}

Our understanding of these speech deficits as motor is supported by evidence indicating aberrations in the function

of laryngeal muscles and vocal folds in PwPD, as revealed by various diagnostic tests such as electromyography, telescopic cinelaryngoscopy, (videolaryngo)stroboscopy, endoscopy, and fiberoptic endoscopic evaluation.^{37–40} These assessments have unveiled several irregularities in laryngeal muscle movements, including laryngeal tremor, limited thyroarytenoid muscle movement, and altered firing patterns of thyroarytenoid muscle motor units,^{37–39} as well as spontaneous intrinsic cricothyroid muscle activity during rest (“hypertonicity”).⁴⁰ During speech production, these laryngeal muscle contractions control vocal fold movement, where PwPD exhibit atypical features, such as vocal fold bowing, preventing complete closure for efficient sound production.^{37,41–43} Additionally, asymmetrical vibratory patterns in the vocal folds have been observed, indicative of uncoordinated vocal fold movement during phonation.³⁷ Corroborating these findings, PwPD demonstrate significantly higher subglottal pressure during phonation compared to neurotypical individuals, aligning with reports of difficulty in vocal projection.⁴⁴

Numerous studies have delved into the neural correlates and connectivity alterations linked to motor speech

impairments in PD, with particular emphasis on the M1, housing the laryngeal and orofacial motor cortices essential for motor control of speech.^{45,46} Liotti et al.⁴⁷ using PET scans, revealed stronger speech-related activations in the mouth area of the M1, premotor cortex (PMC), and supplementary motor area (SMA) in PwPD compared to controls. Conversely, Pinto et al.⁴⁸ observed reduced activation in the right orofacial M1 and cerebellum but increased activity in the right superior PMC and SMA during speech production in PwPD. Using fMRI, Rektorová et al.⁴⁹ found increased involvement of the left orofacial M1 and right M1, which they termed “primary orofacial sensorimotor cortex”, correlating with reading initiation. Connectivity studies by Manes et al.⁵⁰ showed increased resting-state connectivity between the left dorsal laryngeal motor cortex (LMC) in the M1 and left internal globus pallidus (GPi) in PwPD with motor speech deficits. Similarly, Chen et al.⁵¹ reported correlations between dysarthria severity and morphological changes in the right precentral cortex, where the M1 is located, and the right fusiform gyrus. Mollaei et al.⁵² utilizing diffusion tensor imaging (DTI) in PwPD detected increased mean diffusivity in their left hemisphere, spanning from the LMC in the M1 to the putamen. These findings underscore robust associations between motor speech deficits in PwPD and altered speech production-related neural activity or connectivity patterns, primarily centered on the M1, which notably demonstrates overlapping activity at the neuronal level for both laryngeal and other body movements relevant to dance.^{18–20}

Other experiments have demonstrated aberrant connectivity patterns in brain regions crucial for speech production or perception, as evidenced in studies comparing PwPD with neurotypical individuals. Rektorová et al.⁵³ focused their study on the periaqueductal grey matter, revealing greater functional connectivity between this region and the right basal ganglia, posterior superior temporal gyrus (STG), supramarginal gyrus, fusiform gyrus, and inferior parietal lobe in PwPD versus controls. Within the PD cohort, connectivity strength in the right putamen and supramarginal gyrus correlated with pitch variability, while connectivity in the right posterior STG and inferior parietal lobule correlated with speech loudness. New et al.⁵⁴ investigated resting-state functional connectivity in the voice network of PwPD, detecting reduced connectivity from the left thalamus and bilateral putamen to cortical areas such as STG and the Rolandic operculum. More recently, Elfmarkova et al.⁵⁵ observed diminished connectivity between the right caudate and right dorsolateral prefrontal cortex in PwPD compared to controls. These findings collectively highlight the intricate neural substrates associated with motor speech deficits in PD, implicating multiple brain regions and connectivity patterns crucial for speech production (e.g., M1, SMA, PMC, basal ganglia)⁵⁶ and auditory feedback control (e.g., STG).⁵⁷

Motor speech deficits and underlying brain pathways in Alzheimer's disease

AD is typically characterized by progressive memory impairment and overall cognitive decline.⁵⁸ Initially, motor impairments were not considered core deficits of AD,⁵⁹ but recent studies have illuminated various motor difficulties in AD, including challenges in gait and balance performance.^{60–62} Similarly, dysfunctions in the language realm were initially explored primarily through tasks assessing memory functions, such as picture naming or word recall tasks.⁶³ Consequently, the motor aspects of speech production, including phonation, articulation, and prosody, were somewhat overlooked. However, more comprehensive assessments have since revealed impaired motor speech abilities even in individuals with mild AD.^{64,65}

Research on the speech of people with Alzheimer's disease (PwAD) has identified distinctive features in temporal, acoustic, and prosodic parameters compared to cognitively typical elderly individuals. Most frequently reported motor speech issues include voice changes with larger variations in frequencies (jitter) and amplitude (shimmer), more and longer voice pauses, higher noise-to-harmonic ratio, and lower articulation rate.^{64,65} Specific examples of articulatory impairments include false starts and phonological errors.⁶⁶ These deficits impact the overall articulation rate and speech tempo,⁶⁷ which are also found to be lower. In terms of prosody, PwAD were found to be less able to modulate their pitch when emotional prosody needs to be recruited, for example, when expressing happiness or anger.⁶⁸ According to Cera et al.,⁶⁹ these deficits closely resemble the ones identified in “speech and orofacial apraxia”, which interferes with the capacity to plan and execute muscle movements properly for producing phonemes.³⁴ In their study, they found that some degree of speech and orofacial apraxia is nearly always present in AD, regardless of disease stage.⁶⁹ Overall, these findings suggest that, although overlooked for a long time, motor speech deficits are important characteristics of AD, which have since been utilized to aid in early AD diagnosis.

Finding relevant neuroimaging studies that could help uncover the neurobiological basis of motor speech deficits in PwAD was challenging: on one hand, there was a predominant emphasis on the “semantic” network in the existing literature, and, on the other, studies primarily focused on Broca's and Wernicke's areas as seed regions of interest, neglecting exploration of motor regions crucial for speech, such as the M1. For instance, one study using magnetoencephalography (MEG)-based functional imaging⁷⁰ found a significant reduction in speaking-induced suppression of the primary auditory cortex in PwAD, suggesting inaccurate auditory feedback predictions contributing to speech abnormalities in AD. Another study by Pistono et al.⁷¹ revealed a global increase in functional connectivity

in individuals with MCI due to AD in brain regions often activated in language tasks. In contrast, Weiler et al.⁷² identified significant decreases in functional connectivity in the default mode network (DMN) and Wernicke's area in patients with mild AD compared to controls. These studies collectively emphasize the need for more focused investigations into the neural underpinnings of motor speech deficits in AD, particularly within motor-related brain regions.

The impact of dance training on behaviors and brain pathways potentially relevant to speech motor control

To the best of my knowledge, this is the first explicit proposal suggesting that dance could potentially improve motor speech deficits in neurodegenerative disorders. However, certain published reports have included tests relevant to overall language abilities within their dance studies. Most of these assessments are part of broader questionnaires, such as the Unified Parkinson's Disease Rating Scale.^{73,74} For instance, in submodule 3.1 of this scale, "free-flowing speech" is evaluated in terms of "volume, modulation (prosody), and clarity, including slurring, palilalia (repetition of syllables), and tachyphemia (rapid speech, running syllables together)", all being categories relevant to motor speech production. A comprehensive meta-analysis of 14 randomized controlled trials with a total of 372 patients undergoing dance training for PD⁷⁵ reported a significant improvement in overall UPDRS module 3 scores after 3, 6, or 12 months of dance therapy. Unfortunately, none of these studies provided detailed results for submodules, limiting the ability to understand the specific impact of dance on speech motor control (submodule 3.1).

Still, there are dance studies conducted on relevant neurodegenerative diseases that have demonstrated significant improvements in tests assessing different aspects of language, with some of their findings being possibly relevant to speech motor control (Table 1). For instance, Lazarou et al.¹⁰ found that 10 months of International Ballroom Dancing led to enhanced performance in verbal fluency and learning among elders with amnesic MCI compared to controls. This improvement was assessed using the Verbal Fluency F-A-S test and the Rey Auditory Verbal Learning Test. The former evaluates word recall and phonemic fluency by requiring participants to produce as many words as possible starting with F-A-S, while the latter focuses mostly on word recall from given word lists. In a separate study,⁷⁶ elders with metabolic syndrome who engaged in Latin dancing for over 6 months showed improvement in speech-relevant domains, including verbal fluency, word list delayed recall, and word list recognition. Although the specific tests used were not detailed,

these typically assess word recall based on specific cues or word lists. Meanwhile, Hokkanen et al.¹¹ observed improved language abilities, assessed by the "Cookie Theft picture" from the Boston Diagnostic Aphasia Test, in participants with various types of dementia, including AD, after 13 weeks of dancing. This test requires participants to describe a depicted domestic scene in which a woman is drying dishes next to a sink in the kitchen, with water overflowing from the tap, while two children attempt to take cookies from a jar without their mother's notice. Although this test covers a range of speech categories, from phonology to semantics, the authors did not specify the categories they measured. Considering that in these studies, improvement in overall language performance,¹¹ or phonemic¹⁰ and verbal fluency⁷⁶ might reflect enhanced speech-related muscle control, these studies' findings could be considered relevant to the hypothesis that dance training could enhance motor speech production (Table 1).

Evidence from other studies primarily point to improvement in other aspects of language production, such as semantic recall (Table 1). For example, Dominguez et al.⁷⁷ noted an enhancement in the Boston Naming Test following 48 weeks of structured modular ballroom dance intervention in individuals with MCI, with this test mostly evaluating word retrieval through the spontaneous naming of line-drawn pictures. Relevantly, Wharton et al.⁷⁸ assessed progress in the d-KEFS Color Word Interference test in African American women with family history of Alzheimer's disease after 12 weeks of Adapted Argentine Tango. In this test, participants are presented with a list of words naming colors that are printed in different colored ink (e.g., the word "green" printed in red color), where they are asked to shift between color naming and word reading. Tango participants were found to show improved or maintained number of errors performed during the inhibition condition, where they were asked to utter the color the word was printed and inhibit their dominant verbal response to read the word out. These findings suggest improvement in various aspects of language-based communication, but more so in non-motoric aspects. Further studies focusing on the motor aspects of speech, such as articulation and prosody, are necessary to elucidate the impact of dance on these aspects (see next section for suggested practices).

When examining the brain pathways affected by dance training, there is a paucity of neuroimaging studies specifically targeting individuals with neurodegenerative conditions such as PD, AD, or MCI. To gain relevant insights, one can turn to investigations into neural changes following dance training in healthy elderly individuals or studies comparing professional dancers with non-dancers, although it remains unclear if these effects are translatable to individuals with neurodegenerative disorders (also see relevant review⁷⁹). When it comes to studies in neurodegenerative diseases, Batson et al.⁸⁰ demonstrated increased network

Table 1. Summary of findings from previous studies using language assessments and their possible relevance to speech motor control. 1st column: "Study" referenced; 2nd column: specific "Dance-type" tested in the cited intervention; 3rd column: "Demographics" of the populations tested, including age (e.g., elders), type of disease (e.g., MCI), and nationality or ethnicity (if reported) (e.g., Greek); 4th column: "Duration" and "Frequency" of the dance intervention; 5th column: "Number of participants" as reported for the "Intervention/Control groups"; 6th column: name of "Language-relevant test(s)" used in each study; 7th column: "Language-relevant performance" of the intervention groups compared to the control groups; 8th column: assessment of the studies' findings' possible "Relevance to speech-motor control" and rationale.

Study	Dance-type	Demogra-phics	Duration/ Frequency	Number of Participants (Intervention/ Control groups)	Language-relevant test(s)	Language-relevant performance	Relevance to speech-motor control
Lazarou et al. ¹⁰	International Ballroom Dancing	elders with amnesitic MCI (Greek)	10 months/ twice a week	66/63	•Verbal Fluency F-A-S •Rey Auditory Verbal Learning Test	improved •word recall •phonemic fluency	Possibly: "Phonemic fluency" in phoneme/sound production requires speech-related muscle control.
Kim et al. ⁷⁶	Latin dance (Cha-Cha)	elders with metabolic syndrome (Korean)	6 months/twice a week	26/12	Consortium to Establish a Registry for Alzheimer's disease (Korean version)	improved •verbal fluency •word list delayed recall •word list recognition	Possibly: If "verbal fluency" in these findings reflects performance in speech (sound) production, the improvement might result from enhanced control of speech-related muscles.
Holkanen et al. ¹¹	Dance (type not specified)	elders with various types of dementia	13 weeks/once a week	19/10	Boston Diagnostic Aphasia Test	overall language improvement	Error-based scoring would be needed to determine relevance. Possibly: The authors did not specify performance by category; if the "overall language improvement" reflects improvement in categories relevant to speech motor control, it could be relevant. Error-based scoring would be needed to determine relevance.
Dominguez et al. ⁷⁷	structured modular ballroom dance	elders with MCI (Filipinos)	48 weeks/twice a week	101/106	Boston Naming Test	enhancement in word retrieval	No: This test evaluates semantic/ memory recall. It is not relevant to speech motor control.
Wharton et al. ⁷⁸	Adapted Argentine Tango	middle-aged women with family history of AD (African American)	12 weeks/twice a week (at least 20 lessons per participant)	24/10	d-KEFS (Delis-Kaplan Executive Function System) Color Word Interference test	improved or maintained (decreased or no change) number of errors performed during the inhibition condition	No: The "inhibition condition" tests the ability to suppress the automatic task of reading words in favor of naming the color of the ink in which the words are printed. It is not relevant to speech motor control.

connectivity between the basal ganglia and PMC in a person with PD after undergoing 7 weeks of improvisation dance training. In another study,⁸¹ the brains of 17 PwPD were scanned over an extensive 8-month dance training period, revealing differences in the activity of their seed region of interest, the subgenual cingulate gyrus. A more recent study⁸² with 58 PwPD explored potential fMRI effects of leader versus follower roles in a 12-week adapted tango training; the follower group showed increased brain activation in the M1 lower limb region and right cerebellar lobule VIIa. Qi et al.⁸³ compared resting-state fMRI (rsfMRI) data from older adults with MCI who participated in moderate-intensity aerobic dance to a control group and observed a significant increase in the amplitude of low-frequency fluctuation in several brain regions, including the bilateral fronto-temporal, entorhinal, anterior cingulate, and parahippocampal cortex. MRI studies in healthy elderly individuals undergoing 6-month dance protocols^{84–86} demonstrated significantly larger gray matter volumes in multiple areas, including key frontal areas highlighted in this article, such as the left precentral gyrus (M1). Studies focusing on the structural brain changes in professional dancers compared to non-dancers,^{87,88} have highlighted, among other findings, higher diffusivity values and larger tract volumes in M1 pathways descending from head, hand, arm, and leg motor regions to the cerebral peduncles. These findings emphasize the potential brain changes induced by dance training across different populations, including in brain areas (e.g., M1) that are directly relevant to this hypothesis.

In the context of the potential role of dance training in speech motor performance, it is important to note that while these studies' findings refer to broad brain regions implicated in various behaviors, many of the areas affected by dance training are also associated with speech production. This includes regions like the M1 (precentral gyrus),⁴⁵ SMA,⁸⁹ PMC,⁹⁰ frontal cortex areas,^{91,92} and several structures within the basal ganglia, such as the putamen.⁹⁰ For these results to be more comparable across dance and speech studies, it would be beneficial for researchers to report subregions more specifically, such as "posterior putamen", instead of just "basal ganglia", or "dorsal LMC", instead of "M1". Drawing from studies indicating overlap between hand and laryngeal areas in the M1,^{18,19} one might speculate that the higher diffusivity values and larger tract volumes descending from the hand M1 area to the cerebral peduncles observed in professional dancers⁸⁷ could involve the M1 area where neurons controlling both hand and laryngeal movements overlap. Overall, while there is suggestive evidence that dance training may impact pathways related to speech motor control, further studies directly investigating this relationship are warranted.

Hypothesis on the role of dance in motor speech deficits and testable approaches

Synthesizing all the evidence, I propose a hypothesis suggesting that dance training may influence not only brain pathways associated with body movement but also those linked to speech movement, particularly those responsible for laryngeal and/or orofacial movements (Figure 1). This hypothesis finds substantial support from research in humans^{18–20,93,94} and non-human animals,⁹⁵ indicating that overlapping brain areas or single neurons in the M1 control hand, leg, and laryngeal movements, of which the latter are involved in speech control. Similar functional overlaps between hand and speech-relevant muscle activity have been shown in neurons within other brain regions of the M1 network, such as the supramarginal gyrus⁹⁴ and middle frontal gyrus.⁹³ Behavioral studies, particularly those demonstrating improvements in verbal fluency following dance interventions in individuals with neurodegenerative diseases, further bolster this hypothesis. Moreover, I postulate that investigating the impact of dance training on individuals with conditions like PD and AD, characterized by measurable motor speech deficits, could provide valuable insights. Given the documented efficacy of dance training in enhancing various motor, cognitive, and emotional functions in PD and AD, repurposing it to address motor speech deficits could offer a promising therapeutic avenue without imposing additional burdens on affected individuals.

To experimentally assess the behavioral aspect of this hypothesis—whether dance training can ameliorate motor speech deficits in PwPD or PwAD—a study could be designed to evaluate speech motor performance before versus after dance intervention. Established programs like Dance for PD^{®96} or AdapTango^{®97} could provide structured protocols for the dance training sessions. Considering the duration of training, existing literature suggests that at least 13 weeks of training may yield observable improvements in language abilities,¹¹ hence a training period exceeding this minimum duration would be advisable. In terms of control groups, an ideal experimental setup might include: a) a control group maintaining their usual daily activities without any therapeutic intervention, as advised by their healthcare provider; b) a control group engaged in repetitive physical exercises; and c) a control group participating in social conversational activities. These control groups would help discern the specific effects of dance training on speech compared to other interventions or natural activities, though each comes with its own pros and cons. For example, since the dance intervention is social in nature, maintaining daily activities (a) would not control for the social aspect. Control group (b) could address this by engaging in physical exercises in a group (social) setting. Control group (c) would also control for the social element

but includes the speech element (conversation), which would not be controlled for. Therefore, a combination of control groups would ideally enable the experimenters to control for various confounding factors.

For assessing speech motor performance, a comprehensive battery of tests drawn from standard evaluation materials commonly used in speech-language therapy could be employed. For example, the Assessment of Intelligibility of Dysarthric Speech (AIDS) test, developed by Yorkston et al.,⁹⁸ is a widely used tool to quantify speech intelligibility and speaking rate. Additionally, semi-automated acoustic analyses using tools like Praat software,⁹⁹ along with fully automated analyses,^{100,101} could offer objective insights into various speech parameters. These tests collectively cover aspects like intelligibility, loudness, duration, pitch, frequency variability, vocal quality, prosody, and speech rate, providing a comprehensive evaluation of speech characteristics relevant to the study hypothesis.

A pertinent question arises regarding the actual necessity of additional or novel therapeutic practices for addressing motor speech deficits, given the existing practices of speech and language therapy (SLT). Although various forms of SLT, such as Lee Silverman Voice Treatment (LSVT),¹⁰² have been widely employed to tackle speech impairments associated with neurodegenerative diseases, the robustness of the evidence supporting their effectiveness remains questionable.^{103,104} Moreover, PwPD and PwAD have expressed dissatisfaction with SLT focusing on repetitive drills and motor exercises, feeling that functional communication should be the primary focus.¹⁰⁵ Another consideration is the demanding nature of many SLT approaches, such as LSVT-based practices, which typically require intensive therapy sessions 4 times per week,¹⁰⁶ contrasting with the weekly dance classes often employed in the aforementioned dance training studies. Furthermore, dance training offers a more socially rewarding environment, facilitating interaction among individuals with neurodegenerative diseases, unlike traditional speech training, which involves one-on-one sessions with a speech therapist and may not be as motivating or socially engaging as dance training. Given these factors, repurposing dance training to address motor speech deficits could alleviate the burden of attending multiple therapy sessions per week. Should a significant positive effect of dance on speech performance be observed, subsequent studies would need to incorporate control groups undergoing SLT alone, as well as groups undergoing both dance training and SLT, to shed light on the individual and combined effects of these interventions on speech outcomes. This approach would provide valuable insights into the progression of speech performance under different therapeutic modalities.

Testing the hypothesis that dancing affects speech-relevant circuits at a neural level would require integrating behavioral studies with neuroimaging techniques,

such as fMRI and DTI. One plausible experimental design entails scanning participants' brains before, during, and after dance training to evaluate potential changes in brain activation patterns throughout different phases of the training process. In each scan session, participants' effector regions, such as finger and larynx effector areas, would be assessed during simple and rhythmic movements (e.g., control finger movements and finger tapping; swallowing and speech). Since conducting full-fledged dance routines within an MRI scanner is unfeasible, participants could engage in simplified choreographies that are compatible with the scanning environment, possibly aided by an inclined board (e.g.,¹⁰⁷), as well as engage in tasks where they visualize themselves dancing (e.g.,⁸¹). Additionally, they would undergo a series of speech tasks, ranging from reading aloud and repeating words to generating spontaneous speech samples. Brain activity within the motor speech-related regions of each participant would then be compared before, during, and after dance training. Moreover, using the identified effector areas as seed regions, potential changes in connectivity between brain regions pertinent to speech production, such as the LMC and the nucleus ambiguus, could be uncovered using rsfMRI or DTI. Identifying changes in these brain pathways will not only help narrow down the specific dance-activated brain pathways that might mediate speech improvements but also enable us to tailor future experiments more optimally, such as determining the optimal study duration and intensity or deciphering brain correlates for those who respond more or less to the training.

Conclusion

Emerging evidence highlights the efficacy of dance training in ameliorating motor and psychological symptoms among individuals grappling with neurodegenerative disorders like PD and AD. In this paper, I posit that an often-overlooked motor impairment in both PD and AD lies within their motor speech deficits. Contrary to previous notions framing these deficits solely within the domain of memory-related impairments, recent findings suggest a distinct motor deficit, particularly evident in categories such as amplitude and fundamental frequency. Drawing from insights gleaned from human and non-human animal neuroscience, I propose repurposing dance training to target the motor aspects of these speech impairments, focusing on areas within the M1 that project to both laryngeal and other body muscles—where the former is involved in speech and the latter in dance. This hypothesis finds support in existing evidence demonstrating the significant improvement of language facets, possibly including speech, and broader brain pathways associated with speech regions following dance training. However, as this hypothesis is novel, no published study, to my knowledge, directly substantiates it at either the behavioral or neural

level. Thus, I outline a testable approach that can serve as a framework for future investigations. Beyond the potential social and mental health benefits for participants, exploring this hypothesis offers an opportunity to probe the “vocal learning and rhythm synchronization hypothesis”.^{12–14}

In conclusion, testing this hypothesis promises insights into: a) human neurobiology, as it may unveil overlaps in motor pathways, potentially challenging conventional notions of distinct motor functions being supported each by different neurons and brain regions; b) therapeutic avenues for individuals with PD and AD experiencing motor speech deficits; and c) human evolution, shedding light on the origins of two pivotal modes of human sensorimotor communication—speech and dance.

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Statements and declarations

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