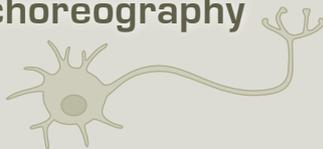


THE NEUROSCIENCE OF Dance

Recent brain-imaging studies reveal some of the complex neural choreography behind our ability to dance



By Steven Brown and Lawrence M. Parsons



KEY CONCEPTS

- Dance is a fundamental form of human expression that likely evolved together with music as a way of generating rhythm.
- It requires specialized mental skills. One brain area houses a representation of the body's orientation, helping to direct our movements through space; another serves as a synchronizer of sorts, enabling us to pace our actions to music.
- Unconscious entrainment—the process that causes us to absent-mindedly tap our feet to a beat—reflects our instinct for dance. It occurs when certain subcortical brain regions converse, bypassing higher auditory areas.

—The Editors

So natural is our capacity for rhythm that most of us take it for granted: when we hear music, we tap our feet to the beat or rock and sway, often unaware that we are even moving. But this instinct is, for all intents and purposes, an evolutionary novelty among humans. Nothing comparable occurs in other mammals nor probably elsewhere in the animal kingdom. Our talent for unconscious entrainment lies at the core of dance, a confluence of movement, rhythm and gestural representation. By far the most synchronized group practice, dance demands a type of interpersonal coordination in space and time that is almost nonexistent in other social contexts.

Even though dance is a fundamental form of human expression, neuroscientists have given it relatively little consideration. Recently, however, researchers have conducted the first brain-imaging studies of both amateur and professional dancers. These investigations address such questions as, How do dancers navigate

though space? How do they pace their steps? How do people learn complex series of patterned movements? The results offer an intriguing glimpse into the complicated mental coordination required to execute even the most basic dance steps.

I Got Rhythm

Neuroscientists have long studied isolated movements such as ankle rotations or finger tapping. From this work we know the basics of how the brain orchestrates simple actions. To hop on one foot—never mind patting your head at the same time—requires calculations relating to spatial awareness, balance, intention and timing, among other things, in the brain's sensorimotor system. In a simplified version of the story, a region called the posterior parietal cortex (toward the back of the brain) translates visual information into motor commands, sending signals forward to motion-planning areas in the premotor cortex and supplementary motor area. These



instructions then project to the primary motor cortex, which generates neural impulses that travel to the spinal cord and on to the muscles to make them contract [see box on next page].

At the same time, sensory organs in the muscles provide feedback to the brain, giving the body's exact orientation in space via nerves that pass through the spinal cord to the cerebral cortex. Subcortical circuits in the cerebellum at the back of the brain and in the basal ganglia at the brain's core also help to update motor commands based on sensory feedback and to refine our actual motions. What has remained unclear is whether these same neural mechanisms scale up to enable maneuvers as graceful as, say, a pirouette.

To explore that question, we conducted the first neuroimaging study of dance movement, in conjunction with our colleague Michael J. Martinez of the University of Texas Health Science Center at San Antonio, using amateur tango dancers as subjects. We scanned the brains of

five men and five women using positron-emission tomography, which records changes in cerebral blood flow following changes in brain activity; researchers interpret increased blood flow in a specific region as a sign of greater activity among neurons there. Our subjects lay flat inside the scanner, with their heads immobilized, but they were able to move their legs and glide their feet along an inclined surface [see box on page 81]. First, we asked them to execute a box step, derived from the basic *salida* step of the Argentine tango, pacing their movements to the beat of instrumental tango songs, which they heard through headphones. We then scanned our dancers while they flexed their leg muscles in time to the music without actually moving their legs. By subtracting the brain activity elicited by this plain flexing from that recorded while they "danced," we were able to home in on brain areas vital to directing the legs through space and generating specific movement patterns.

DANCE is the most synchronized activity people perform. Neuroscientists are trying to discover not only how but why we do it.

[THE BASICS]

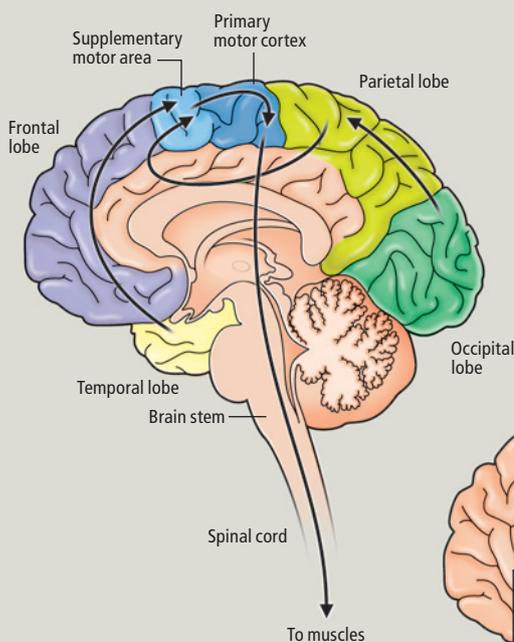
THE BRAIN'S MOVING PARTS

To identify the brain areas that control dance, researchers first need a sense of how the brain allows us to carry out voluntary movements in general. A highly simplified version is presented here.

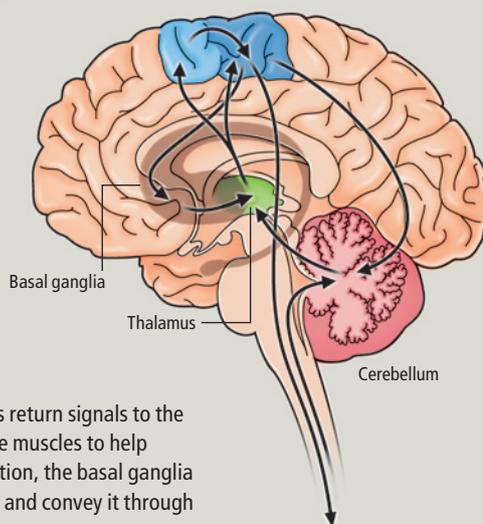
TANTALIZING TANGO FINDING

In a study published in December 2007, Gammon M. Earhart and Madeleine E. Hackney of the Washington University School of Medicine in St. Louis found that tango dancing improved mobility in patients with Parkinson's disease. The condition stems from a loss of neurons in the basal ganglia, a problem that interrupts messages meant for the motor cortex. As a result, patients experience tremors, rigidity and difficulty initiating movements they have planned.

The researchers found that after 20 tango classes, study subjects "froze" less often. Compared with subjects who attended an exercise class instead, the tango dancers also had better balance and higher scores on the Get Up and Go test, which identifies those at risk for falling.



Motion planning (*left*) occurs in the frontal lobe, where the premotor cortex on the outer surface (*not visible*) and the supplementary motor area evaluate signals (*arrows*) from elsewhere in the brain, indicating such information as position in space and memories of past actions. These two areas then communicate with the primary motor cortex, which determines which muscles need to contract and by how much and sends instructions down through the spinal cord to the muscles.



Fine-tuning (*right*) occurs, in part, as the muscles return signals to the brain. The cerebellum uses the feedback from the muscles to help maintain balance and refine movements. In addition, the basal ganglia collect sensory information from cortical regions and convey it through the thalamus to motor areas of the cortex.

As anticipated, this comparison eliminated many of the basic motor areas of the brain. What remained, though, was a part of the parietal lobe, which contributes to spatial perception and orientation in both humans and other mammals. In dance, spatial cognition is primarily kinesthetic: you sense the positioning of your torso and limbs at all times, even with your eyes shut, thanks to the muscles' sensory organs. These organs index the rotation of each joint and the tension in each muscle and relay that information to the brain, which generates an articulated body representation in response. Specifically, we saw activation in the precuneus, a parietal lobe region very close to where the kinesthetic representation of the legs resides. We believe that the precuneus contains a kinesthetic map that permits an awareness of body positioning in space while people navigate through their

surroundings. Whether you are waltzing or simply walking a straight line, the precuneus helps to plot your path and does so from a body-centered or "egocentric" perspective.

Next we compared our dance scans to those taken while our subjects performed tango steps in the absence of music. By eliminating brain regions that the two tasks activated in common, we hoped to reveal areas critical for the synchronization of movement to music. Again this subtraction removed virtually all the brain's motor areas. The principal difference occurred in a part of the cerebellum that receives input from the spinal cord. Although both conditions engaged this area—the anterior vermis—dance steps synchronized to music generated significantly more blood flow there than self-paced dancing did.

Albeit preliminary, our result lends credence

to the hypothesis that this part of the cerebellum serves as a kind of conductor monitoring information across various brain regions to assist in orchestrating actions [see “Rethinking the Lesser Brain,” by James M. Bower and Lawrence M. Parsons; *SCIENTIFIC AMERICAN*, August 2003]. The cerebellum as a whole meets criteria for a good neural metronome: it receives a broad array of sensory inputs from the auditory, visual and somatosensory cortical systems (a capability that is necessary to entrain movements to diverse stimuli, from sounds to sights to touches), and it contains sensorimotor representations for the entire body.

Unexpectedly, our second analysis also shed light on the natural tendency that humans have to tap their feet unconsciously to a musical beat. In comparing the synchronized scans with the self-paced ones, we found that a lower part of the auditory pathway, a subcortical structure called the medial geniculate nucleus (MGN), lit up only during the former set. At first we assumed that this result merely reflected the

[THE AUTHORS]



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presence of an auditory stimulus—namely, music—in the synchronized condition, but another set of control scans ruled out this interpretation: when our subjects listened to music but did not move their legs, we detected no blood flow change in the MGN.

Thus, we concluded that MGN activity related specifically to synchronization and not simply listening. This finding led us to postulate a “low road” hypothesis that unconscious entrainment occurs when a neural auditory message projects directly to the auditory and timing circuits in the cerebellum, bypassing high-level auditory areas in the cerebral cortex.

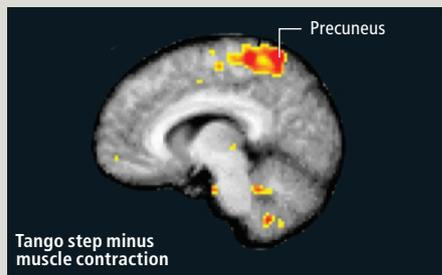
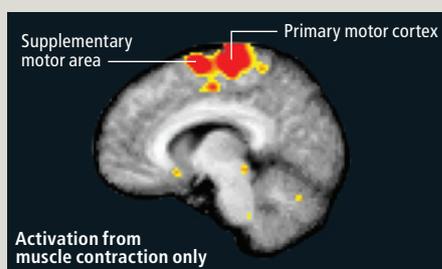
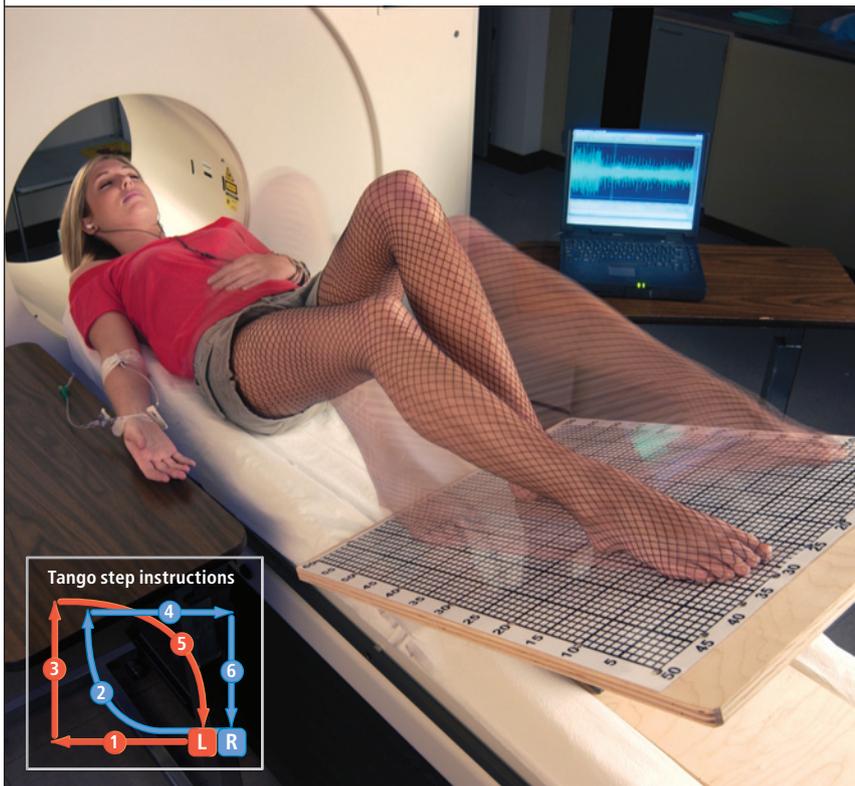
So You Think You Can Dance?

Other parts of the brain engage when we watch and learn dance movements. Beatriz Calvo-Merino and Patrick Haggard of University College London and their colleagues investigated whether specific brain areas become active preferentially when people view dances they have mastered. That is, are there brain areas that

[EXPERIMENTAL SETUP]

FANCY FOOTWORK

To identify brain areas important to dance, the authors had amateur tango dancers lie flat inside a PET scanner. The device held their heads stationary, but they were able to listen to tango music through headphones and move their legs along an inclined surface (*photograph*).



In one such experiment, the machine scanned the brain under two different conditions: when the dancers flexed their leg muscles in time to the music but did not move their limbs and when the subjects performed a basic tango box step (*inset*) with their legs, again in time to the music. When the authors subtracted brain activity caused by muscle contraction (*top scan*) from the tango scans, what remained “lit” was a part of the parietal lobe known as the precuneus (*bottom scan*).

COURTESY OF STEVEN BROWN (Brown); COURTESY OF LAWRENCE M. PARSONS (Parsons and subject in scanner); LUCY READING-IKKANDA (Illustration); FROM “THE NEURAL BASIS OF DANCE,” BY STEVEN BROWN ET AL., IN *CEREBRAL CORTEX*, VOL. 16, NO. 8, 2006 (brain scans)

BALLET FOR BETTER BALANCE?

Roger W. Simmons of San Diego State University has found that, when thrown off balance, classically trained ballet dancers right themselves far more quickly than untrained subjects, thanks to a significantly faster response to the disturbance by nerves and muscles. As the brain learns to dance, it also apparently learns to update feedback from the body to the brain more quickly.



switch on when ballet dancers watch ballet but not, say, capoeira (an Afro-Brazilian martial art stylized as a dance and performed to music)?

To find out, the team took functional magnetic resonance imaging scans of ballet dancers, capoeira dancers and nondancers as they viewed three-second, silent video clips of either ballet or capoeira movements. The researchers found that expertise had a major influence on the premotor cortex: activity there increased only when subjects viewed dances that they themselves could execute. Other work offers a likely explanation. Investigators have found that when people watch simple actions, areas in the premotor cortex involved in performing those actions switch on, suggesting that we mentally rehearse what we see—a practice that might help us learn and understand new movements. Researchers are examining how widely humans rely on such imitation circuits.

In follow-up work, Calvo-Merino and her colleagues compared the brains of male and female ballet dancers as they watched video

clips of either male or female dancers performing gender-specific steps. Again, the highest activity levels in the premotor cortex corresponded to men viewing the male-only moves and to women viewing the female-only moves.

The ability to rehearse a movement in your mind is indeed vital to learning motor skills. In 2006 Emily S. Cross, Scott T. Grafton and their colleagues at Dartmouth College considered whether imitation circuits in the brain increase their activity as learning takes place. Over the course of several weeks, the team took weekly functional MRI scans of dancers as they learned a complex modern dance sequence. During the scans, subjects viewed five-second clips that exhibited either the movements they were mastering or other, unrelated steps. After each clip, the subjects rated how well they thought they could execute the movements they saw. The results affirmed those of Calvo-Merino and her colleagues. Activity in the premotor cortex increased during training and was indeed correlated to the subjects' assessments of their ability to perform a viewed dance segment.

Both investigations highlight the fact that learning a complex motor sequence activates, in addition to a direct motor system for the control of muscle contractions, a motor-planning system that contains information about the body's ability to accomplish a specific movement. The more expert people become at some motor pattern, the better they can imagine how that pattern feels and the more effortless it probably becomes to carry out.

As our research shows, however, the ability to simulate a dance sequence—or tennis serve or golf swing—in the mind is not simply visual, as these studies might suggest; it is kinesthetic as well. Indeed, true mastery requires a muscle sense, a motor image, as it were, in the brain's motion-planning areas of the movement in question.

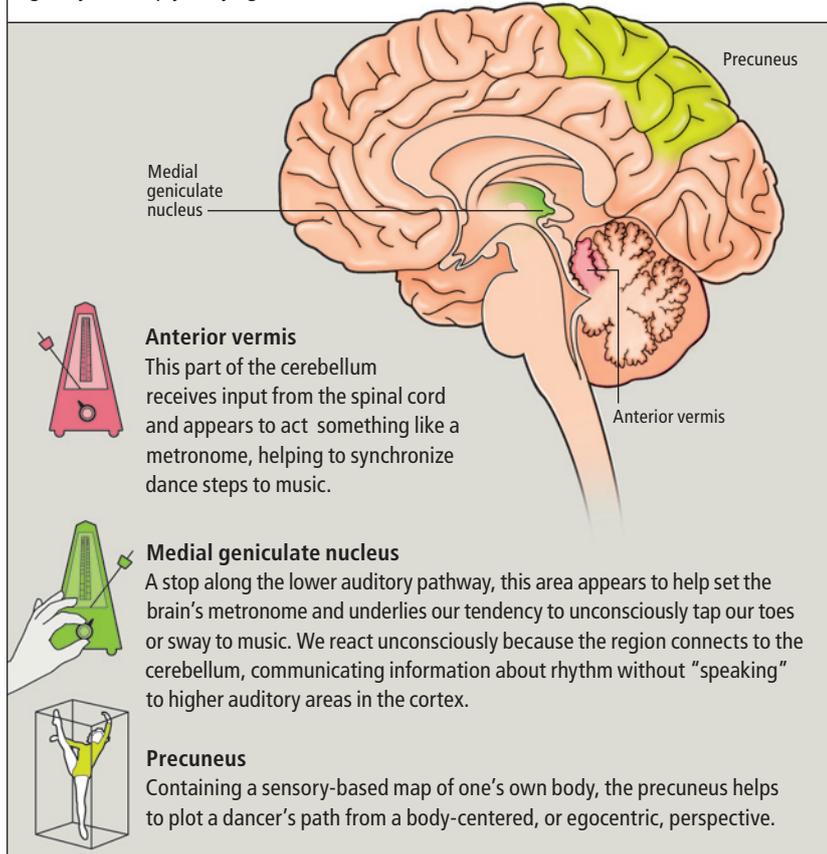
Shake, Rattle and (Social) Role

Perhaps the most fascinating question for neuroscientists to explore is why people dance in the first place. Certainly music and dance are closely related; in many instances, dance generates sound. Aztec *danzantes* in Mexico City wear leggings containing seeds from the ayoyotl tree, called *chachayotes*, which make a sound with every step. In many other cultures, people put noise-making objects—from taps to castanets to beads—on their bodies or clothes while they dance. In addition, dancers frequently clap, snap

[THE RESULTS]

MENTAL CHOREOGRAPHY

The authors found that the following brain regions contribute to dance in ways that go beyond simply carrying out motion.





AZTEC DANZANTES in Mexico City wear leggings containing seeds called *chachayotes* (detail), which rattle with each step. In many cultures, dancers attach noise-making objects to their bodies or clothes. Dance and music most likely evolved together as ways of generating rhythm. Unlike music, though, dance can convey ideas clearly and probably functioned as an early form of language.

and stomp. As a result, we have postulated a “body percussion” hypothesis that dance evolved initially as a sounding phenomenon and that dance and music, especially percussion, evolved together as complementary ways of generating rhythm. The first percussion instruments may well have been components of dancing regalia, not unlike Aztec *chachayotes*.

Unlike music, however, dance has a strong capacity for representation and imitation, which suggests that dance may have further served as an early form of language. Indeed, dance is the quintessential gesture language. It is interesting to note that during all the movement tasks in our study, we saw activation in a region of the right hemisphere corresponding to what is known as Broca’s area in the left hemisphere. Broca’s area is a part of the frontal lobe classically associated with speech production. In the past decade research has revealed that Broca’s area also contains a representation of the hands.

This finding bolsters the so-called gestural theory of language evolution, whose proponents argue that language evolved initially as a gesture system before becoming vocal. Our study is among the first to show that leg movement activates the right-hemisphere homologue to Broca’s area, which offers more support for the idea that dance began as a form of representational communication.

What role might the homologue to Broca’s

area have in enabling a person to dance? The answer does not appear to involve speech directly. In a 2003 study Marco Iacoboni of the University of California, Los Angeles, and his colleagues applied magnetic brain stimulation to disrupt function in either Broca’s area or its homologue. In both cases, their subjects were then less able to imitate finger movements using their right hand. Iacoboni’s group concluded that these areas are essential for imitation, a key ingredient in learning from others and in spreading culture. We have another hypothesis as well. Although our study did not involve imitative movements per se, dancing the tango and copying finger actions both demand that the brain correctly order series of interdependent movements. Just as Broca’s area helps us to correctly string together words and phrases, its homologue may serve to place units of movement into seamless sequences.

We hope that future neuroimaging studies will provide fresh insight into the brain mechanisms behind dance and its evolution, which is highly intertwined with the emergences of both language and music. We view dance as a marriage of the representational capacity of language and the rhythmicity of music. This interaction allows people not only to tell stories using their bodies but to do so while synchronizing their movements with others’ in a way that fosters social cohesion. ■

➔ MORE TO EXPLORE

Action Observation and Acquired Motor Skills: An fMRI Study with Expert Dancers. Beatriz Calvo-Merino, Daniel E. Glaser, Julie Grèzes, Richard E. Passingham and Patrick Haggard in *Cerebral Cortex*, Vol. 15, No. 8, pages 1243–1249; August 2005.

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Seeing or Doing? Influence of Visual and Motor Familiarity in Action Observation. Beatriz Calvo-Merino, Daniel E. Glaser, Julie Grèzes, Richard E. Passingham and Patrick Haggard in *Current Biology*, Vol. 16, No. 19, pages 1905–1910; October 10, 2006.