The Neuroscience Behind Dance

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Abstract:

This paper explores the intricate relationship between musical performance and the brain, focusing on the perception of music, the learning process in dance, and the role of memory. Musical performance engages multiple regions of the brain, involving both the central and peripheral nervous systems. The perception of music begins with sound waves entering the ear, where they are converted into electrical signals and transmitted to the brain for processing. The learning of dance involves neuroplasticity, where the brain reorganizes its structure and function through processes such as neurogenesis, synapse formation, synaptic strengthening, and synaptic weakening. Various regions of the brain, including the motor cortex, prefrontal cortex, somatosensory cortex, basal ganglia, and cerebellum, are involved in dance and contribute to coordination, decision-making, sensory processing, and motor control. Memory plays a crucial role in dance, with explicit and implicit memory systems being utilized. Dance movements initially stored as explicit memories can become implicit memories through practice and repetition, facilitating smoother execution. Understanding the complex interactions between the brain, perception, learning, and memory in musical performance can shed light on the cognitive processes involved and inform approaches to optimize dance training and performance.

Background:

Musical performance is one of the most complex activities a person can do. Dancing activates every major part of the central nervous system. It often requires the use of both hands to do separate tasks to achieve a brilliant art, thus utilizing both the left and right sides of the brain. Creating more minor intricacies within the technique requires the use of the peripheral nervous system to control gross and fine motor skills. However, it is not enough to be able to dance one section; the dancer must also be actively aware of the upcoming parts. The central nervous assists to ensure focus on the upcoming part. Taking all these parts into consideration, along with the sensory input from all senses, musical performance is an exceptionally complex exertion on the brain.

Dance is a learned skill that requires coordination, technical, and musical development. Dancing requires coordination between different parts of the body as well as coordination with the music and the dancer's surroundings. Developing this coordination is no easy task and requires years of careful training. Most dance styles have intricate techniques. Along with coordination, mastery of this technique also takes a long time. One example of a skill that must be mastered is complete control of one's body from the torso to the tips of the extremities. Dancing also requires one to understand and interpret music thoroughly. The dance must recognize rhythm, beats, and timings to coordinate the body properly with the music. Developing coordination, technique, and musicality are skills that take years to master, along with repetitive practice. This paper seeks to address the four primary elements of musical performance: perceiving, learning, and memorizing steps and music as a dancer.

Perception Of Music:

The two main organs of perception of music are the brain and the ears.

Communication in the brain begins with the neurons. Communication between neurons occurs through charged membranes. A shift in the charge causes an action potential to move through the neuron and to the next neuron. There are two types of neurotransmission: Chemical and Electrical. Chemical neurotransmission utilizes neurotransmitters in vesicles to travel across the synapse and bind to receptors. Electrical neurotransmission allows ions to travel through connexons to the post-synaptic neuron. Action potentials are caused by a rapid movement of ions from one neuron to the next. Neurotransmitter receptors accept ions. There are two types of neurotransmitter receptors: Ligand-gated ion channels and G-protein-coupled receptors. Ligand-gated ion channels require the binding of neurotransmitters to open the protein channel to allow the ions to flow through. GPCRs require the neurotransmitter to bind to the receptor to activate the G-protein, whose subunits or intracellular messengers regulate the channels, allowing the channel to open to let ions in. The type of synapse can determine how far the signal travels as well. Excitatory synapses increase the likelihood of an action potential continuing through the post-synaptic neuron, while an inhibitory synapse decreases the likelihood of the action potential continuing past the synapse.

Perception of music begins with the ears. Sound is a vibration that travels as a wave through a medium. The outer ear channels sound waves into the ear canal and the eardrum. As the eardrum vibrates, the energy is transferred to the middle ear, where the ossicles are. The middle ear is the area between the eardrum and the oval window of the inner ear where the Eustachian tube connects to allow air pressure to equalize. The ossicles vibrate and amplify the energy before it reaches the oval window and into the inner ear. The amplified vibrations cause ripples in the fluid inside the cochlea, causing movement of the hair cells. The movement of the hair cells causes the hair bundles to bend, opening up pore-like channels, which creates an electric signal. The auditory nerve sends this signal to the brain.

The path to the auditory cortex from the ears is long and tedious, although, in reality, it takes only a few milliseconds ("How the brain keeps time"). Inner hair cells in the Organ of Corti are connected to Type 1 Spiral Ganglion neurons, which comprise most of the cochlear nerve. The signals travel to the cochlear nuclei in the brainstem on the ipsilateral side. Each cerebral hemisphere collects and processes sensory information from both the ipsilateral and contralateral sides. This ensures that hearing won't be greatly affected even if damage occurs to one part of one hemisphere. In addition, it allows for increased levels of processing abilities for complicated sounds such as those in speech. When the signals reach the cochlear nucleus, they split as most neurons cross over to the contralateral side. However, part of the signal stays on the ipsilateral side. The signal on both sides reaches the superior olivary complex, then onward along the lateral lemniscus to the inferior colliculus. Each step on this path is critical to our sense of hearing. For example, sound processing would be significantly affected if something were to go wrong in the lateral lemniscus. From the inferior colliculus, the signal moves towards the medial geniculate nucleus, stays on the ipsilateral side, and then moves onto the auditory cortex. The primary auditory cortex is organized by frequency.

Learning of Dance:

There are four primary ways the brain changes to reorganize itself in both structure and function: Neurogenesis, new synapses, weakened synapses, and synaptic strength. These are collectively called neuroplasticity. Neurogenesis is the process by which new neurons are generated. New synapses are formed as new skills and experiences create new neural pathways. Synapses strengthen as actions are repeated and practiced, while synapses are weakened as pathways aren't used. Long-term potentiation is used to strengthen signal transmission. Long-term depression helps identify useless processes and weakens the synapses. Neural recruitment is the manner in which the brain creates new connections between neurons that were not previously there.

Neuroplasticity plays a significant role in how one learns an activity. For example, learning to ride a bike and play an instrument are two very different processes. One key difference between learning to ride a bike and playing an instrument is that one only has to learn to ride a bike once. Once the neural connections have been made, they do not undergo any changes. Every time one rides a bike, the action strengthens these existing neural connections. These connections are strengthened due to myelination, which leads to increased cognitive function and motor skills. On the other hand, in learning to play an instrument, one does not learn it once and executes it repeatedly. With learning an instrument, each piece is a different repetition of varied movements. The neural connections aren't continuously strengthened as it is not just a single movement being repeated. Instead, they are continuously making new connections to adapt to new pieces. In addition, they are constantly forming new connections across the brain, from the auditory cortices to other parts of the brain, including the parietal, temporal, and frontal cortices. Playing an instrument engages almost every part of the brain.

With dance, many areas of the brain are involved. Dance stimulates the motor cortex, prefrontal cortex, somatosensory cortex, basal ganglia, and cerebellum. The motor cortex is heavily involved with the planning, control, and execution of voluntary movement. This region allows the dancer to control their body and accurately coordinate the dance steps. The prefrontal cortex is responsible for decision-making abilities. It takes auditory and visual cues, which is crucial when dancing as it allows the dancer to remember choreography and adapt to change if necessary. The somatosensory cortex is involved with motor control and hand-eye coordination. The basal ganglia work with other brain regions to coordinate movement. The cerebellum helps coordinate fine complex motor actions. These regions allow the dancer to control their body precisely to perform the art smoothly. Studies have shown that dance helps patients with Parkinson's disease. With dance, several structural changes occur in the brain due to neurogenesis. It is shown that there is an increased hippocampal volume, gray matter volume in the left precentral and parahippocampal gyrus, and white matter integrity (Teixeira-Machado et al.). Regarding functional changes, there was a noticeable improvement in memory, attention, and body balance (Teixeira-Machado et al.). The functional improvement shows evidence of long-term potentiation, which strengthens signal transmission.

Neuroplasticity occurs in each region of the brain activated when the dancer dances. In the motor cortex, there is evidence of long-term potentiation (LTP) and long-term depression (LTD); however, further research is required to fully understand the mechanisms and significance of long-term potentiation and depression for motor control and plasticity. The prefrontal cortex also has evidence of long-term potentiation and long-term depression. LTP in the prefrontal cortex is involved with the cellular mechanisms regarding the encoding and storing information in the working memory and synaptic changes associated with learning and memory. LTD in the prefrontal cortex is thought to be involved with the regulation of synaptic strength to maintain a good range for information processing ("Prefrontal Cortex Long-Term Potentiation, But Not Long-Term Depression, Is Associated with the Maintenance of Extinction of Learned Fear in Mice"). Further research is required to determine the exact mechanisms and functional implications of LTD in the prefrontal cortex ("Prefrontal Cortex Long-Term Potentiation, But Not Long-Term Depression, Is Associated with the Maintenance of Extinction of Learned Fear in Mice"). Long-term potentiation in the somatosensory cortex is understood to play a role in the mechanisms of sensory processing. The mechanisms and functions of long-term depression in the somatosensory cortex are currently unknown and require further research. While there is evidence of long-term potentiation in the cerebellum, there is no conclusive research that defines the mechanisms and functional significance of LTP in the cerebellum (HIRANO). Long-term depression in the cerebellum, however, is known to be involved with multiple aspects of motor learning and adaptation, including the fine-tuning of motor commands, motor sequence learning, and the correction of motor ends (HIRANO). It is essential to the cerebellar motor learning processes that enable the refinement and optimization of motor coordination and control (HIRANO).

Memory:

There are two different types of memory: Explicit and implicit memory. Explicit memory is information one memorizes, such as facts and general knowledge, as well as personally experienced events. Implicit memory is information one remembers unconsciously, such as motor and cognitive skills, identification of objects or words, and classical conditioning. In addition to these two types of memory, there are different levels of memory based on longevity, from sensory memory to short-term memory to long-term memory. Sensory memory is the perception of touch, sound, sight, smell, and taste. It is not consciously memorized. When there is attention to these details, it enters short-term memory. For the memory to enter the long-term memory stage, the memory must be continuously retrieved. This process occurs in the hippocampus. It controls how one creates new memories. The cerebellum and basal ganglia help form implicit memories. The prefrontal cortex allows one to mentally represent a memory by integrating many different sensory memories.

Dance utilizes both explicit and implicit memory. When first learning a piece, new movements, experiences, and connections made are stored as explicit memories. They are primarily stored as visual cues and verbal cues. Visual cues are memories that are made from watching choreography, while verbal memories are related to words, counts, and scats. With practice and repetition, these movements can become implicit memories. These are movements that are memorized unconsciously. They are stored as kinesthetic cues related to movement and motor awareness. As a dancer repeats the steps, the synaptic connections between the neurons strengthen and make it easier to execute the steps. How well a dancer remembers their steps depends highly on their dance form. More structured dance forms have more repetition, while more freestyle forms have less repetition. More structured dance forms are, by nature, more tailored toward the process of making implicit memories.

Conclusion:

In conclusion, musical performance, particularly dance, is a highly intricate activity that engages various regions of the brain and requires coordination, technical skill, and musicality. The perception of music begins with the ears, where sound waves are converted into electrical signals that travel through the auditory pathway to the brain. Neurotransmission and neural pathways play a crucial role in this process, allowing us to perceive and interpret music. The learning of dance involves neuroplasticity, which enables the brain to reorganize itself through neurogenesis, the formation of new synapses, and the strengthening or weakening of existing synapses. Different types of memory, including explicit and implicit memory, are utilized in dance, with explicit memories initially formed and later transformed into implicit memories through practice and repetition. The brain regions involved in dance include the motor cortex, prefrontal cortex, somatosensory cortex, basal ganglia, and cerebellum, each contributing to the precise control and execution of dance movements. Neuroplastic changes occur in these regions, including long-term potentiation and long-term depression, which are associated with motor control and plasticity. Additionally, memory processes involve the hippocampus, cerebellum, basal ganglia, and prefrontal cortex, enabling the formation and retrieval of both explicit and implicit memories. Understanding the complex interplay between perception, learning, and memory in the context of musical performance provides valuable insights into the remarkable capabilities of the human brain and its adaptability in mastering the art of dance. Further research in these areas will continue to enhance our understanding of the brain's involvement in musical performance and open avenues for therapeutic interventions and improved learning strategies.

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