Motor Control and Dance

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Introduction

While many dancers think that movement is about muscles, joints, and bones, movement is actually initiated by the nervous system, that is, the brain and its pathways to the muscles. *Motor control* examines how the nervous system organizes and directs the body's muscles and joints to create coordinated movement, and how the sensory systems (for example, vision) and information from the environment are used to achieve this task (Schmidt & Lee, 2011). *Information* is communication in which there is a clear context and meaning, and it becomes knowledge through experience or expertise. *Feedback* is the transmission of information, and can be visual, auditory (hearing), or somatosensory (sensations from the body). For example, dance teachers can provide verbal feedback, a form of information that is a response to observing a skill or movement combination. This form of feedback gives information about the result and what caused the result, to be used as a basis for improvement. When dancers receive verbal feedback (sometimes called corrections), they might hear verbal instructions in several ways. Knowing how the nervous system functions provides teachers with the best means of communication, so that they can develop language that stimulates efficient and clear responses from students. The purpose of this paper is to describe various aspects of motor control and how it can inform and enhance dance training. Part one, Organization of Motor Control, outlines the nervous system, defines the various reflexes of the movement systems, and gives suggestions for dance training. Part two, Attention and Performance, provides an overview of attention, describes arousal, defines internal and external focus, and discusses attention under pressure, with suggestions for both teachers and dancers. Part three, Motor Control and the Sensory Systems, defines open-loop and closed-loop systems, how dancers use the following sensory systems to inform movement: visual, auditory, vestibular, and somatosensory, and describes

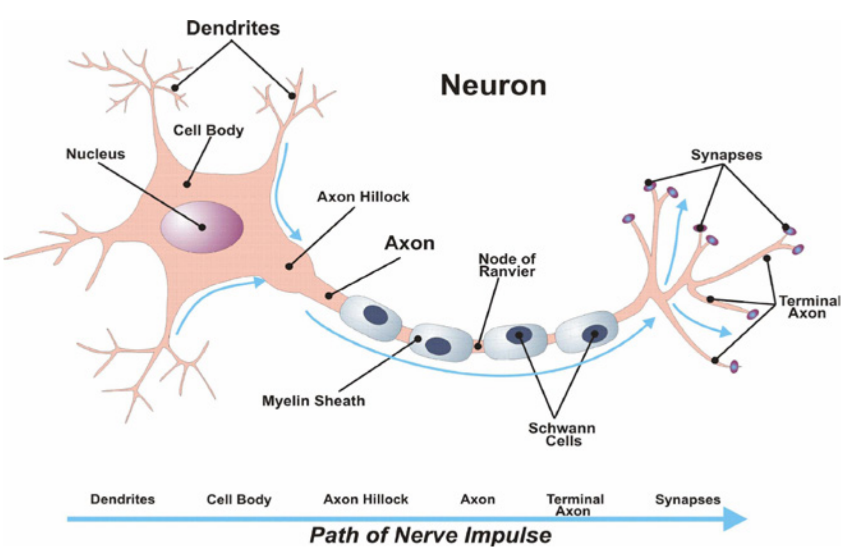
how dance training can be improved by utilizing knowledge of these systems and how they function in motor control. Part four, Motor Control and Central Organization, focuses on open-loop processes, and defines central pattern generators and generalized motor programs to inform and support dance training. Part five, Speed, Accuracy, and Coordination, examines these finer aspects of motor control, defines how dancers learn and practice to develop high level skills, and gives examples for dance training. Learning to dance is a complex and enjoyable process that involves many hours of practice. It can be made far more effective through an understanding of the motor control systems.

Part One: Organization of Motor Control

The nervous system

The nervous system has two parts. The brain and the nerves residing in the spinal column are the *central nervous system* (CNS). The nerves outside the spine that connect to the muscles and organs are called the *peripheral nervous system* (PNS). All of these pathways come down to a single cell level, called the *neuron*. Figure 1 shows a typical neuron and its parts. Sensory or afferent neurons send information from the body to the CNS to give the brain information about the environment, and motor or efferent neurons send information from the CNS to the muscles to create movement.

Figure 1, Nerve Cell



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The brain includes the forebrain, the cerebellum, the brain stem, and the limbic system, seen in Figure 2a. The *forebrain* is responsible for all conscious thought and control of attention; it is critical to plan, coordinate, and execute movement. Two important areas that lie in the forebrain and relate to motor control for dancers are the motor cortex and the somatosensory cortex as seen in Figure 2b. The motor cortex, which lies in the posterior frontal lobe, generates signals to direct movement. The somatosensory cortex, which lies at the front of the parietal lobe, processes sensory information. These two cortices are essential for all movement and lie right next to each other in the brain.

The *brain stem* controls body functions such as chewing, swallowing, and breathing; it is important for regulating muscle activity and tone. (For example, when a dancer feels anxious, muscles contract.) The *cerebellum* gives smoothness of motion and exact positioning; it controls force and range of movement. It is called the comparator because it acts as a movement error detection and correction system. Posture control, balance, muscle tone, and learning of motor skills are all part of its function. The *limbic* system is the most ancient brain area (formed in early human evolution) and is crucial to forming memories and to the desire to act; the fight-or-flight response forms here. It is the primary center of emotions. The brain regulates every level of movement organization. What is called "muscle memory" actually refers to the phase of motor learning when control of actions moves from conscious planning in the brain to automatic patterning. With practice, dancers arrive at the point where they no longer need to focus attention on movement components, but rather can give attention to whole tasks or actions and to qualitative aspects of movement.

Figure 2a, Brain Organization

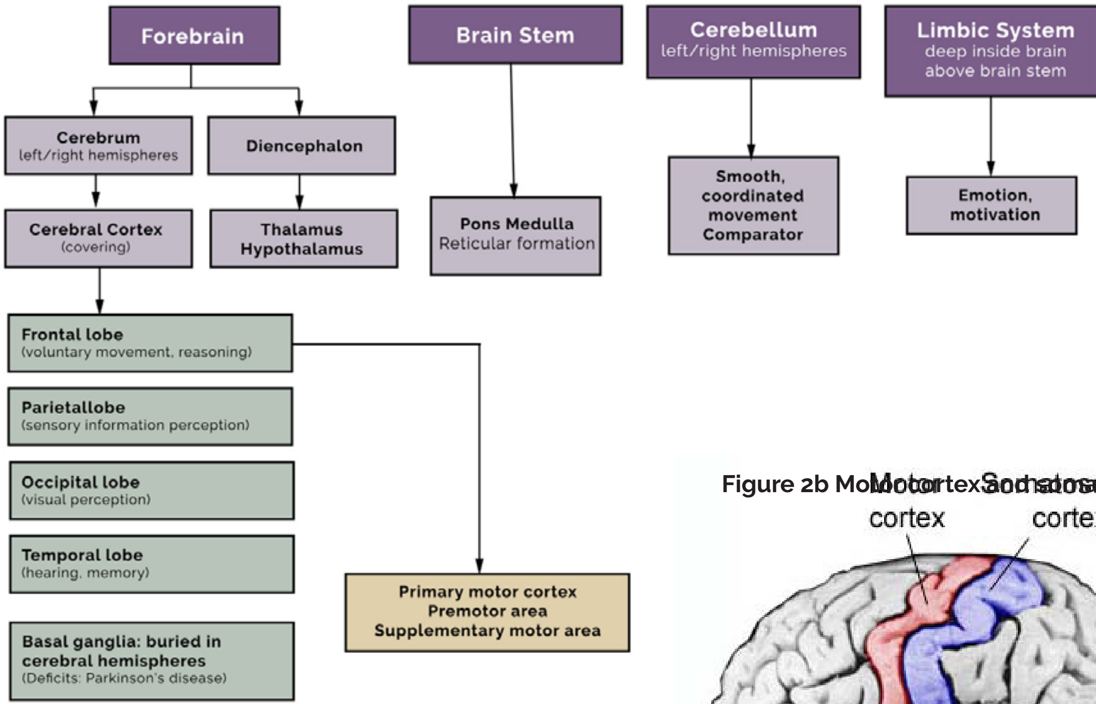
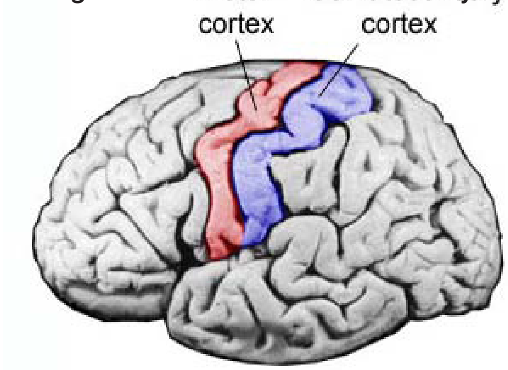


Figure 2b Motor Cortex and Somatosensory Cortex



The reflexes

Movements can be divided into three overlapping types: voluntary movement (such as dance phrases), reflexes (such as the stretch reflex), and rhythmic motor patterns (such as walking). Voluntary movement is under our conscious control, that is, we can plan and direct it. Reflexes are automatic, and not under conscious control at all. The muscles reacting receive the messages from the spinal cord long before the brain receives the information about what is occurring. Rhythmic motor patterns are a mix, that is, they are automatic, but we can alter certain aspects of the pattern as conditions require.

The main reflexes are as follows: myotatic (stretch) reflex, autogenic inhibition reflex, reciprocal inhibition reflex, and the gamma efferent system. The *myotatic reflex* is the simplest and fastest, activated by rapid or extreme stretch, which causes the muscle to contract. One example is turning over an ankle when tripping off a curb; another is the use of bouncing or too much force when stretching. Dancers understand that bouncing or force during flexibility work can cause injury, but what they may not realize is that due to this reflex, the muscle will contract and is therefore not being stretched. The *autogenic inhibition reflex* allows the muscle to adjust its level of contraction, supplying information about muscle tension or force. The receptors (receivers) of information are the golgi tendon organs (GTO's) that reside in the tendons, and signal when the tendon is being stretched. The *reciprocal inhibition reflex* is used to inhibit (relax) the antagonist (opposite) muscle when the agonist muscle is contracting. For example, when you contract your quadriceps, the hamstrings receive messages to relax. This reflex is the underlying theory behind one type of proprioceptive neuromuscular facilitation (PNF) stretching. The *gamma efferent system* is the most complex reflex system, and influences flexibility and alignment. It explains why some people are very flexible in passive stretches but have much less range in dynamic movement. The receptors (receivers) of information are the muscle spindles which reside in the muscles, and signal when the muscle is being stretched. The brain can regulate the tension in the spindles and therefore allow different lengths of the muscle for different circumstances. For example, when lying down, the muscles that determine alignment (such as the abdominals) can stretch to a great extent, but when standing, they will engage when stretched to a small degree to maintain upright stance. It is important to remember that all of the reflexes are automatic, not under conscious control, and are protective mechanisms.

Training applications

Dance teachers can use knowledge about the neural reflexes to create far more effective training procedures for their dancers, related to alignment and flexibility. For example, when addressing anterior pelvic tilt (swayback), muscle imbalances should first be assessed, such as potentially weak abdominals or tight hip flexors and low back muscles, and appropriate corrective exercises suggested. Second, the neural component should be examined. The patterns of muscle recruitment and relaxation might not be altered through exercise alone. Awareness (such as through somatic practices) and imagery are valuable tools in re-patterning poor or inefficient habits. Through the use of imagery, conscious centers of the brain can "see" the task, and then allow the nonconscious centers to make the correct muscle choices and levels of contraction.

This section has provided a general overview of the nervous system, and introduced some applications to training, which will be covered in more depth later in the paper. There is much more detail and complexity to the brain and its relationship to movement, and for more information, the reader can refer to the sources in references and recommended readings.

Part Two: Attention and Performance

Defining Attention

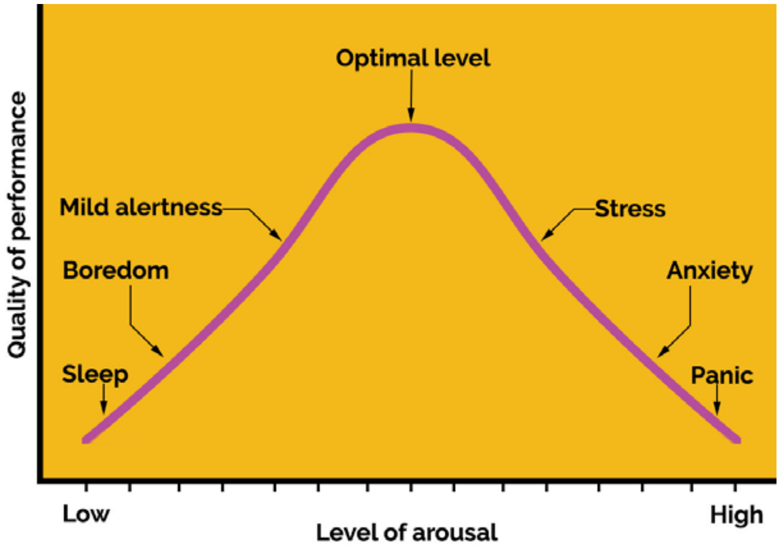
These three systems develop in the very early stages of life, but are not immediately integrated, that is, they act independently. Therefore, the muscles that achieve balance have different responses at different ages, shown in the chart on page 4.

A term commonly used in today's culture is *multitasking*. It is common to see someone walking down the street, looking for a favorite store, avoiding cars, and texting on the phone all at the same time. It would seem that the brain can simultaneously manage multiple thoughts and activities and do them well. However, the brain actually has to move rapidly from one mental task to another. Researchers use the term *task interference* to refer to thoughts competing for attention. If two activities can be accomplished at the same time, and each could be done by itself, then one or both of them need little or no attention, called *automatic action*. One clear example of this idea is the difference between adults and children dealing with balance. Adults can balance on one leg and perform a cognitive task like counting backwards. When children attempt these two tasks at the same time, they fall over. Consider the attention required by dancers to alter or correct alignment problems. Let's consider alignment as the primary task, and a simple or complex movement as the secondary task. If a dancer can maintain alignment corrections doing slow, simple movement such as pliés or bending at the knees, but reverts to old habits doing more complicated movement, it suggests that the dancer still needs to pay considerable attention to the primary task, alignment. Once the alignment change becomes habitual, the dancer can simultaneously maintain the new habit and do complex dance phrases.

Arousal

Arousal is a person's general state of excitability, reflected by responses such as heart rate. Both low and high levels of arousal result in poor performance, but moderate levels result in the best performance, seen in Figure 3. If dancers are either very tired or very stressed, they will perform badly. That slightly nervous energy the dancer experiences just before going on stage is a good sign.

Figure 3 Levels of arousal



Internal and external focus

Research has suggested that attention is different for the beginner and the advanced dancer. Beginners need to focus on specific movement components, such as pointed feet and external hip rotation in ballet, or which part of the foot is hitting the floor in tap dance and flamenco. For advanced dancers, these components become automatic, and they can direct their attention to other aspects such as musicality, artistic expression, and spatial design. Teachers have different approaches in guiding how students should direct their attention when learning and executing dance movements. Some teachers emphasize focusing on specific movement components, some direct attention to particular muscles, and others draw attention to the overall goal or outcome. Researchers use the terms internal focus versus external focus to describe these approaches. *Internal focus* refers to concentrating on components of the task. *External focus* refers to concentrating on the effects of the movement, or general outcome. If the movement in question were a leap, the teacher might coach beginner dancers to point their feet, or think about the timing of the arms, using internal focus. With more advanced dancers, the teacher might simply suggest getting up in the air, using external focus. No researcher, motor control expert, or master teacher recommends telling dancers to recruit or contract specific muscles. The areas of the brain that deal with movement planning envision the task, and the nonconscious areas of the brain select the muscles.

These ideas are reiterated by the pioneers in somatic practices, such as Mabel Todd, educator and somatic practitioner. She states:

> *When "doing exercises" under instruction we are apt to think that we move or direct the moving of muscles. What actually happens is that we get a picture from the teacher's words or his movements, and the appropriate action takes place within our own bodies to reproduce this picture. The result is successful in proportion to our power of interpretation and amount of experience, but most of all perhaps to the desire to do. In any case, the final response is automatic and not the result of any consciously directed movement of particular muscles. It is the result of a combination of reflexes, no one of which can be selected as in itself "causing" the movement, or pattern of movement.* (Todd, 1937, p. 33)

Another way of describing aspects of focus is about the width of focus, that is, attention can be broad or narrow. *Broad focus* refers to directing attention to a large area of space or several components that need concentration. *Narrow focus* refers to directing attention to a small area or fewer cognitive components. For example, when doing group choreography, dancers use broad focus. When a dancer is catching a leaping partner, narrow focus is used. Figure 4 provides examples of direction and width of focus.

Figure 4 Direction of focus is internal or external; width of focus is narrow or broad

	Width of Focus	
Direction of Focus	**Narrow**	**Broad**
Internal	Feeling in the knee during a turn	Feeling of the whole body during a leap
External	Focus on the waist of partner to be lifted	Focus on the movements of all the dancers on the stage

Attention under pressure

Performance anxiety, also called stage fright, involves a conflict between the desire to perform and fears of being inadequate. This phenomenon has been discussed in the performing arts since the 1960s. Anxiety manifests in several ways: trembling, nausea, racing heart, shallow breathing, and loss of motor control. Cognitive components include excessive worry and negative self-image, and these can be more detrimental than the physical symptoms. Performance anxiety has also been linked to dance injuries. This condition should be taken seriously, and dancers can be taught coping strategies, including planning for success, seeking support, humor, and positive self-talk. Dancers can also use meditation, visualization, breathing techniques, somatic work, and methods of focus. Studies done on performance anxiety suggest that one cause of the condition is the tendency to revert back to internal focus in the performance setting. This reaction is another reason to encourage skilled dancers to use external focus in training, rehearsals, and performance.

Research has also suggested that injury is more frequent as a result of attentional deficits. While the mechanism for this connection is not well understood, teachers should be sensitive to times when dancers have lower attention and potential risks. For example, teachers should reduce complexity and difficulty of classes during periods of increased stress leading to diminished attention, such as right before performances. For dancers, dealing with attentional deficits and developing concentration are paramount to the success of the performer.

This section has provided an overview of attention and described arousal, as well as internal and external focus. It has discussed attention under pressure, and its relationship to motor deficits and injury. Finally, there are suggestions for both teachers and dancers to enhance attention for skill acquisition and performance.

Part Three: Motor Control and the Sensory Systems

In order to improve motor control, it is necessary to understand how the brain deals with the extent of incoming sensory information and determines how to use it. The sensory contributions to motor control include input from the visual, auditory, vestibular, and somatosensory systems. Sometimes the brain does not need the incoming information to execute movement, known as *open-loop.* In other circumstances, the brain requires sensory information to do the task, known as closed-loop.

Open-loop and closed-loop systems

The calypso leap is an example of an open-loop system, seen in Figure 5A. Because of the speed of the leap, there is no time after the leap is initiated to alter the motor plan. *Motor planning* is the ability to organize the body's actions, knowing what steps to take, and in what order, to complete a particular task. Dancers can hear corrections during the leap, but they cannot apply this information immediately. In an open-loop system, movements are typically rapid, instructions from the motor plan include all needed information, and once initiated, the movement continues to completion. If the dancer overturns the leap, this error cannot be corrected mid-leap, even if the dancer is aware of this error. Alternately, in a slow lyrical movement, such as an adagio jazz layout seen in Figure 5B, there is sufficient time to hear corrections and/or receive sensory feedback, and the dancer can make adjustments during the movement. In a closed-loop system, movements are typically slow, and feedback during the movement can be compared to the initial plan in order to make necessary adjustments. Because this section is about the use of sensory systems for motor control, the discussion focuses on closed-loop control. This section will also define and describe the three main systems used for balance: visual, vestibular, and somatosensory, which includes proprioception.

Figure 5A Calypso leap

Figure 5B Jazz layout

Photos by Jake Pett

Visual system

Vision is profoundly important in the execution of movement. In adults, vision is supplementary to proprioception in maintaining balance. However, children rely more on vision when first standing and locomoting. The three balancing mechanisms (visual, vestibular, and proprioception) are not yet integrated in young children, so they rely on vision, which is the first to develop. Additionally, the use of vision varies with circumstance, whether about object manipulation, observing other people, or maneuvering through crowds.

There are two types of vision, *central vision* and *peripheral vision*. Central vision is in color and it is in the middle of the visual field, requiring contrast and adequate light. Peripheral vision receives information outside the middle of the field; it does not need focus and can function in low light. It is very poor at color recognition. Two examples will demonstrate how dancers use these two types of vision. Suppose a dancer is in the musical *A Chorus Line* and must reach for a hat being handed over by a stage technician. Using central vision, the dancer focuses on the hat, sees the hat moving towards their hand, and finally grasps the prop. In the film *Stormy Weather*, the Nicholas Brothers tap dance while leaping from bandstand to bandstand and going up and down stairs. https://www.youtube.com/watch?v=zBb9hTyLjfM They use peripheral vision to gather information about the environment, such as the distance between the bandstands and the height of the stairs, while still focusing out towards the audience.

In dance training it is beneficial to encourage the use of peripheral vision so that dancers are able to work in the low light conditions, such as on the stage or the street, and be aware of other dancers in the performance environment. Dance-specific visual training can encompass working without mirrors and verbal information from the teacher about awareness of other dancers. Constant use of mirrors and blocking out other dancers can lead to overuse of central vision.

Dancers need to use vision during various types of movement execution, including eye-hand coordination, time to contact a moving object, correcting movement based on vision, and use of vision during locomotion. Eye-hand coordination is pertinent any time a dancer is dealing with props, such as costume pieces and set pieces. Time to contact a moving object is essential when preparing to lift a partner while both dancers are moving towards each other in space. Correcting movement based on vision, as discussed earlier, depends on whether the movement is open-loop or closed-loop. Sufficient time must be available during the movement between initiation and completion to allow for processing the feedback. For example, if a dancer is doing a slow extension of the leg to the front (développé devant), and she sees that the leg is shifting away from the midline, there is time for the dancer to correct this spatial direction. Use of vision during locomotion varies depending on the environment. When dancing on smooth surfaces, little conscious thought is needed to make adjustments. When the surface is irregular, vision is needed to determine how and when to change the length of the steps. For example, if there are bumps in a linoleum flooring, dancers will alter the length of their steps so they do not end up balancing on an uneven part of the floor. Additionally, dancers who perform in a variety of spaces must use vision to alter spacing and stride length to adapt to new stages.

Auditory system

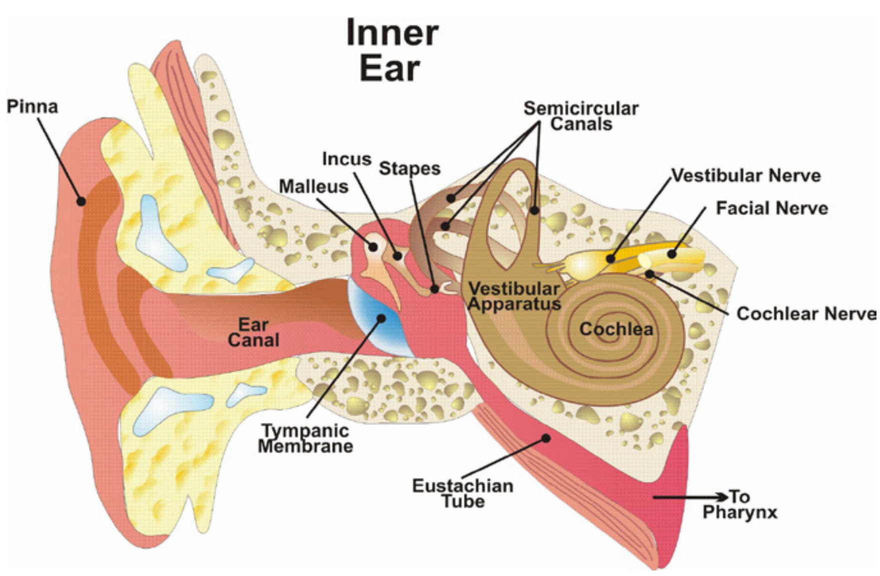
The *auditory system* is the sense of hearing, and dancers rely on this sense to learn about the environment. Sometimes when dancers cannot see other dancers in class or on stage, they can locate others through the sound of their footsteps and even their breathing, such as in Doris Humphrey's 1928 dance *Water Study*. Dancers are among the few athletes, including figure skaters and rhythmic gymnasts, who often time their movement to music. Music can even give feedback about level of arousal, and many have experienced performing where the music sounds slower than normal. Hearing can give dancers feedback about their own movement, such as loud landings, suggesting poor jump landing technique. One effective teaching tool is to ask dancers to execute a combination in silence to emphasize the importance of sounds in the environment and those sounds created by other dancers.

Vestibular system

The *vestibular system* has its receptors in the inner ear, seen in Figure 6. Working with other senses, it provides information about the head's position in space and quick changes of direction in head movements. This system can be useful when a dancer is lifted and his or her position is changed, especially when vision is blocked. The cells of this system are so sensitive that they detect changes as small as the movements of postural sway.

There are situations in which vision and the vestibular system interact, and certain reflexes connect the two sensory systems. The reflexes of the vestibular system are especially important during fast movements of the head, such as spotting during turns, which can help maintain spatial orientation and balance. However, in forms such as modern/contemporary dance and street dance, turns are often done with the head off vertical, and vision can be a hinderance. It can be disorienting to see the surrounding space from an upside-down perspective, and in this case the dancer relies more on the somatosensory system, to be discussed. In most situations, if the visual and somatosensory information conflicts, the vestibular system takes precedent and solves the conflict. For example, if a street dancer is outside at night in very dim lighting and on uneven surfaces, the vestibular system will be essential in maintaining balance.

Figure 6 Vestibular system



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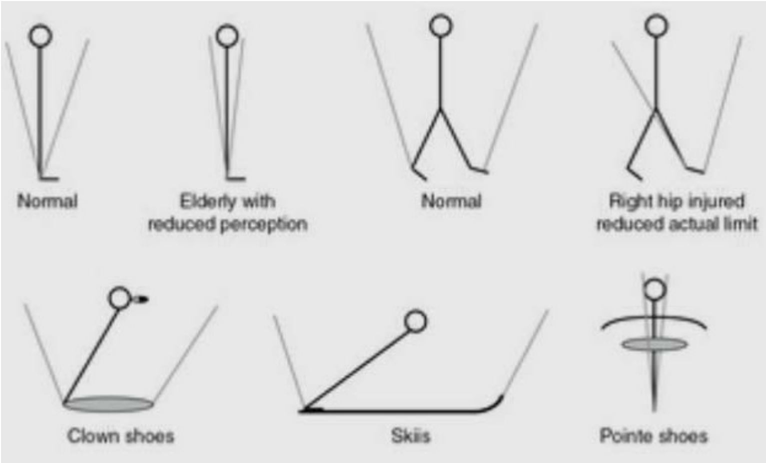
Somatosensory system

The somatosensory system has three parts: discriminative touch (for example, sensitivity to the tactile sensation of the floor), pain and temperature (for example, indicating injury and fatigue), and proprioception (for example, correcting balance, preventing falls, and limb position). Proprioception has receptors in muscles, fascia, tendons, ligaments, and joints throughout the body. The receptors that send information about touch and temperature, residing in the skin and muscles, are rapidly adapting. For example, the sensation of clothing newly donned fades quickly. Some proprioceptors are slow adapters; for example, the pain of an injury does not quickly fade. Slowly adapting receptors help keep the brain informed about important body information.

The main proprioceptors, golgi tendon organs and muscle spindles, were described in the section about reflexes. In addition to their role in reflexes, the GTO's and spindles act together to create smooth, coordinated movement in complex activities. They also play a role in postural control, and in this capacity, the signals are nonconscious, such as with reactions that prevent falls. Receptors in joints fire in extreme range of motion and help detect when joints are going beyond safe limits.

All of the discussion so far in this section has dealt with nonconscious functions of receptors, but there is also conscious perception in certain aspects of the somatosensory system. Dancers can use conscious awareness of limb position in creating clear spatial designs and shapes, and they can create dynamics or movement qualities through control of muscle tension. The term *kinesthesis* (also known as *kinesthesia*) describes the conscious sensation of movement. Perception of sensation plays an important role in limits of stability, which can be perceptual or mechanical. Some of these limits can be seen in Figure 7.

Figure 7 Differing limits of stability: perceptual and mechanical



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Training applications

When teachers understand how motor control is influenced by the sensory systems, they can better design how to teach various skills. They can develop cues to enhance the use of these systems. For example, they can discuss spatial awareness as part of the training, such as describing how to modify stride length to increase or decrease traveling. Teachers can remind dancers to be aware of other dancers around them, and have dancers work away from the mirrors. By eliminating use of music on occasion, dancers can learn to rely more on vision and other sounds. In training dancers for lifting work, begin with lifts in which the dancer is vertical in relation to gravity so that vision is not disrupted. Eventually lifts can be added in which the lifted dancer goes upside down, and reliance moves to the vestibular system. Finally, lifts can be added in which both dancers are moving in space, and visual cues about timing become important.

Teachers can try providing spaces with differing floor surfaces to prepare the feet for varying input. Dancing outside on the lawn can be instructive as well as fun. Moving into the theater for class is also a useful change if this is possible, as it provides many alternatives for sensory input. Dancing in slippers, various shoe types, and bare feet is also important for dance training to give tactile variety. Dance teachers can use imagery, quiet awareness work, focus on breathing, and somatic practices to assist in re-patterning poor habits and heighten consciousness of sensory information.

Figure 8 Use of wobble board to work on balance

Photo by Jake Pett

Balance is an essential part of dance training. Working with eyes closed is an excellent method to enhance the proprioceptive system and to be responsive to challenges to balance. Dancers can try working with eyes closed on various surfaces such as foam pads or wobble boards, seen in Figure 8, and using a variety of bases of support, such as parallel, turned out, plié or knee bends, and relevé or rising on the toes. The brain is extraordinary in its ability to quickly take in information, sort it, and determine how best to use it.

This section has explored motor control and the sensory systems. It defined open-loop and closed-loop, and how dancers use the following systems to inform movement: visual, auditory, vestibular, and somatosensory. Finally, it described how dance training can be improved by utilizing knowledge of these systems and how they function in motor control.

Part Four: Motor Control and Central Organization

Central organization is one of the main ways that motor control is determined. *Central control mechanisms* reside in the brain and central nervous system. These mechanisms rely on open-loop systems in which sensory information (feedback) is not needed to carry out the motor plan, and everything needed to initiate and execute the movement exists in the initial messages to the muscles. An example previously given is that of the calypso leap which cannot be altered in mid-air once the dancer has left the ground. Other examples include quick footwork in tap dance, flamenco, and classical Indian dance, as well as fast falls to the floor in modern / contemporary and street dance. Although this section is focusing on central organization, it should not be overlooked that sensory contributions cannot be ignored.

Central pattern generators

Central pattern generators (CPGs) are groups of neurons that can create rhythmic patterns without sensory contributions. These neurons lie completely in the spinal cord, and do not need messages from the brain to cause the movement. Starting and ending CPGs are conscious choices, but they do not need conscious attention to continue. A simple example is walking. People can walk along a street without conscious thought, but if they see a red light, they need to think about stopping. Similarly, if they are in the crosswalk when the light turns yellow, they will consciously speed up, and if they reach a hill they must climb, they will actively use more muscle effort to achieve the task. In other words, CPGs can be modified by higher brain centers to alter speed or force.

Generalized motor programs

A *generalized motor program* (GMP) is a program that allows the motor system to accomplish a whole class of similar movements. It permits flexibility in doing variations of the program. The term *invariant features* refers to aspects that do not change from action to action within the class. A wonderful example is a class exercise many teachers give to children, asking them to write their names with different body parts, seen in Figure 9. While the body part, size of the movement, and force needed might change, the shape of the letters, that is, the spatial design, is the constant. In dealing with a particular piece of music, there are times that the tempo or instrument might change, but the meter will remain the same, such as 3/4 or waltz time. In this second example, meter is the invariant feature.

Figure 9 Children drawing letters with body parts

Photo by Jake Pett

While it may seem that running is in the same movement class as walking, this is not the case. In running, the time spent in various phases of the movement is very different than when walking, and in fact, there is a flight phase in running that does not exist when walking. Walking and running are two discrete GMPs. This feature is important for dancers and dance teachers to understand. No matter how fast you execute plié / relevé, it does not transform into a jump. The dancer must intend to leave the ground and become airborne. It is important to remember that once a preparation for a fast movement has been practiced, dancers must be given ample opportunity to attempt the full version.

Dancers are expected to reverse combinations to the second side much faster than learning the original phrase. *Bilateral transfer* is the transfer of learning from one limb to the same limb on the other side of the body. One the combination is in memory, the GMP can initiate the second side by recruiting the same muscles on the other side of the body. Here are some ideas for helping dancers develop useful GMPs:

- Walking and running at different speeds
- Walking or rolling across a space while imagining different textures – mud, honey, water, bubbles
- Changing the tempo of a given step or combination to slower or faster
- Varying the position of the gesture leg in a given elevation step, such as hops with the gesture leg front, side, or back
- Varying the shape of the gesture leg in an elevation step, such as leaps with one leg bent, both legs bent, or both legs straight
- Exploring various dynamics (use of muscle force) to experiment with a dance phrase

Dance teachers can be more effective in their instruction by introducing variations in practice once GMPs become embedded in the dancers' movement patterns. This approach will encourage adaptable and versatile dancers.

This section has explored motor control and central organization. It focused on open-loop processes, and how dancers use central pattern generators and generalized motor programs to inform and support dance training. Finally, it described how dance training can be improved by addressing variations in practice and broadening the dancers' skill set.

Part Five: Speed, Accuracy, and Coordination

It is breathtaking to see dancers perform in perfect unison and precision, especially when movement is very fast and demands accuracy, such as Lord of the Dance or the Rockettes. The demands on today's dancers require that they can achieve speed, accuracy, and coordination in complex body designs and spatial patterns. One of the complications of fast movement is that there is no time to use sensory information to make adjustments once the movement is initiated. The question arises, what happens to accuracy as speed increases? In dance, the goal is for limbs to arrive at exact places in space, even at high speed.

Speed and accuracy

The *speed-accuracy trade-off* means that when a person selects speed, accuracy is diminished, and when a person selects accuracy, speed is diminished. It is interesting to note that at slower speeds, accuracy is greater with eyes open than eyes closed, but at very fast speeds, there is little difference because of the lack of time to integrate visual information.

It is not uncommon for teachers and choreographers to practice fast phrases at a slower tempo and gradually increase speed. However, sometimes the faster version is a completely different generalized motor pattern, such as the example of walking and running. This is not to suggest that there is no benefit to the slower practice, as important aspects of the movement can be learned. For example, in the case of jump preparations, dancers can work on alignment, arm organization, and methods to soften the landings. The ballistic attack needed to get into the air will still need to be taught. Children exhibit the same speed-accuracy trade-off as adults.

The *temporal speed-accuracy trade-off* states that with faster movements, timing accuracy actually improves. An example can clarify this principle. If dancers are asked to do a series of jumps in first with no music, the timing of each jump would be very similar. However, if asked to do a series of slow leg extensions with no music, there would be much greater differences in timing from one extension to the next. It is much easier to be consistent when the time for movement is quite small.

Degrees of freedom

Degrees of freedom describe the number of independent components in a moving system, such as a machine or a human body. The degrees of freedom problem examines the dilemma of selecting a particular strategy for achieving the movement goal from the infinite possibilities. The motor system must find a solution based on the organization of the body in reference to the environment and the movement goals. In most instances, when novices start to learn a new skill, they unconsciously reduce the available degrees of freedom to make the learning of the skill manageable. This reduction is called freezing the degrees of freedom. This phase results in stiff, rigid, and poorly timed movement. As the learner progresses, degrees of freedom that were frozen are gradually released. This release is called freeing the degrees of freedom. They are reorganized into new patterns that are smoother, more fluid, and closer to the ideal of the movement.

Coordination

Coordination involves two main aspects of motor control: patterning of movements of the head, body, arms, and legs, and how the body parts relate to the environment. Additional dancers in the space can be considered part of the environment, and remaining in correct spatial and musical connection are all part of coordination. *Coordinative structures* are also known as *muscle synergies*, and suggest that groups of muscles work together. Sometimes synergies develop naturally, such as the coordination of arms and legs while walking. Sometimes synergies develop as a result of training and practice, such as the hand and foot coordination in classical Indian dance. One aspect of coordinative structures is compensation. If a dancer has a hamstring injury, high leg kicks will be accomplished by tucking the pelvis under and possibly even bending the standing knee. Long-term dependence on compensations can be a problem for dancers because they can alter efficient motor patterns.

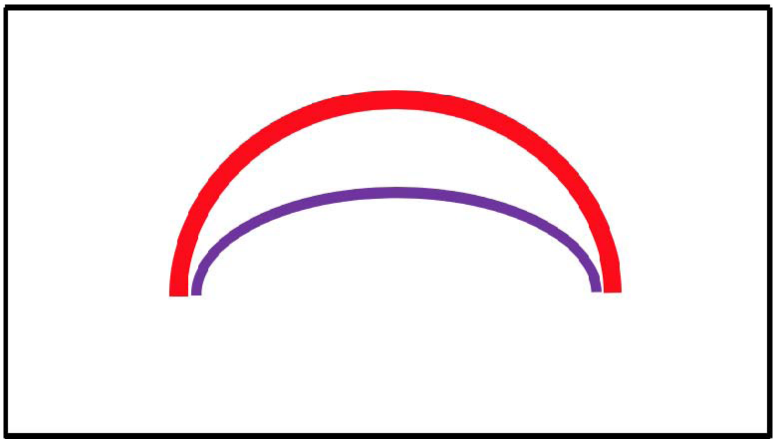
Training applications

There are several different aspects to developing coordination in dance practice, including timing coordination, spatial coordination, and social coordination. The following examples will demonstrate the importance of various types of coordination in dance training.

Timing coordination includes moving arms and legs in different directions at the same time, and the use of *polyrhythms*, which involves simultaneously using contrasting rhythms. In dance, the arms, feet, and legs are often doing different tasks. *Bimanual* is the term for using both hands, and *bipedal* is the term for using both feet. In research involving the hands, when each is doing a different task, the two hands do not remain entirely independent and they affect each other. If this idea is applied to the feet, it may explain why, for example, it is difficult to learn an elevation step with one foot pointed and the other flexed. Dancers need to learn many variations in coordinating limb combinations. They can do left and right arms, or left and right legs, working in organized patterns (*homologous*). They can executive movement on the same side of the body, that is, left arm and left leg, or right arm and right leg coordinating together (*ipsilateral*). And finally, movement can coordinate across the body's diagonal, that is, left arm with right leg, or right arm with left leg (*contralateral*). Dancers often coordinate the limbs in ways that are unnatural in terms of everyday movement, such as an arabesque standing on the left leg with the left arm forward. With rhythm, the term *harmonic* suggests that the various limbs are all using the same pulse, such as the feet moving on a 4-beat count, and the hands clapping double-time. Although these are different, they still have the same pulse. However, if two entirely different rhythms are being used simultaneously, it is called *polyrhythm*, which is far more complex. Imagine beating on a drum or table with one hand sounding out three beats in the same time period that the other hand sounds out two beats, termed a 3/2 rhythm. Flamenco dancers often use a 4/3 rhythm. When teaching dancers polyrhythms, the movement and spatial components should initially be very simple, so that the dancers can concentrate on the complexity of the rhythm.

Spatial coordination includes attempting different spatial designs or locations with various body parts at the same time, such as patting the head and rubbing the abdomen. An example will clarify this concept. First, draw circles in the space in front of the body with both hands. Next, move the hands from the shoulders straight out in front of the body. These are both simple tasks. Now, draw the circle with the left hand and create the straight line with the right hand. This composite action is far more difficult, due to the spatial coordination required. Dancers often construct metaphors to convert complex movements into simpler tasks that are recognizable shapes. Consider a dance phrase in which one arm is drawing a high arc in space and the other arm is drawing a low arc in space in the opposite direction, seen in Figure 10. A metaphor would be to imagine the paths of the sun, and calling the high arc noon and the low arc sunset. This visual image can assist the dancer is creating smooth, coordinated designs easily.

Figure 10 Composite arm movement



Created by Donna Krasnow

Social coordination involves working with others. In any choreography that is not solo work, dancers must be able to work together, which incorporates timing and spatial coordination. It also involves the idea of *entrainment*, the coordination of two dancers to an external rhythm or to each other. It is common to see two people sitting in rocking chairs ending up on the same rhythm. This idea of social coordination encourages group cohesion, and in fact, dancers learn individual skills more effectively when they practice in unison with other dancers. Both vision and sound are important components of social coordination. A subtle sense contributing to social coordination is the sense of touch. In dance formations that feature weight sharing with dancers in physical contact, dancers can use the sense of weight shift of dancers on either side to maintain unison, as seen in Figure 11.

Figure 11 Dancers using sensation of weight transfer to assist unison timing

Choreography Velorio and photo permission by William (Bill) Evans

Speed, accuracy, and coordination are aspects of motor control for dancers, and can be seen in professional companies all over the world. Great dancers spend hours and hours practicing material at slow speeds, and gradually increasing to assure accuracy. Only with determination and patience can these high-level dance skills be achieved.

Summary

This paper has examined motor control, which is how the nervous system organizes and directs the body's muscles and joints to create coordinated movement. It has explored the ways in which the sensory systems and information from the environment are used to achieve dance movement, and how central organization plays a role in this process. Understanding motor control provides teachers with the best means of communication, so that they can develop teaching strategies for their students. Dance training is a complex and enjoyable process that involves many hours of practice. It can be made far more effective through an understanding of the motor control systems.

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Healthy Dancer Canada
The Dance Health Alliance of Canada