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# Perspectives on Perception for Optimal Performance

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To enhance our understanding of the audiomotor performance art that is singing, this column focuses the lens of neuroscience on perceptual-motor processing and the neural anatomy that links our mind and body.[1]

Perceptual-motor processing is the cognitive processing of neural information involving both sensory and motor systems for the purpose of executing tasks according to behavior-outcome goals.[2] Motor behavior and performance psychology are often researched from the perspective of visuomotor integration, such as eye-hand coordination for the purpose of hitting a ball to an external target.[3] However, research in movement methods and singing shows the benefit of studying singing as an audiomotor performance art, or what we might call ear to phonator coordination, for the purpose of singing a targeted pitch that is in turn projected to the intended audience.[4] That is, although we may move in response to music, a singer's primary goal is to make the music—to generate a musical and phonological plan of action supported by postural and respiratory controls.

## PERCEPTUAL-MOTOR PROCESSING

The interdependent aspects of perceptual-motor processing are illustrated in Figure 1 as follows:

- **Sensory input** involves the processes by which information from a stimulus event in our environment or ourselves is received, transmitted, interpreted, and then perceived as a mental representation or image (percept) with the potential to be stored as knowledge.
- **Planning** of voluntary behavior requires accurate definition of our desired task, as well as the ability to recall knowledge and generate a sensorimotor image to guide performance of that task. Moreover, artistic performance requires the ability to alter (mentally manipulate) that image for a phenomenal, one of a kind experience.
- **Motor output** involves the largely unconscious initiation, execution, and mediation (monitoring and correcting) of performance according to the imaged plan of action and past experience.

Although this diagram might lead us to believe these processes occur separately—since 100% of our nervous system is 100% focused on the task at hand—it is actually a rapid, concurrent sharing of stimulus-response signals for the larger sequential process, which occurs over the span of about a heartbeat.[5]

If we consider the neuroanatomic systems involved in singing, motor output would include the postural, respiratory, phonatory, and articulatory systems. Sensory input would include the auditory and vestibular systems of the inner ear for hearing and postural balance respectively, together with the tactile (somatic) system for vibration and proprioceptive position sense.

The perceptual-motor processing loop is also useful for illuminating our understanding of mind-body awareness as a state of consciousness characterized by an ability to integrate sensations from both the environment and ourselves (sensory input) with our immediate goals (planning) and thus to guide behavior (motor output).[6] Moreover, when we get our thinking right—when attentional focus on planning the task at hand yields heightened perceptual awareness (mindfulness), an effortless motor response, and an absence of anxiety—we achieve the ideal performing state Shirlee Emmons and Alma Thomas underscore as essential to optimal performance.[7] That is, an ideal performing state is reported to not only elicit uninterrupted focus and concentration, but also an ability to regulate anxiety and arousal during performance, or homeostasis.[8]

Homeostasis acts as a coping mechanism that seeks to maintain a condition of balance (equilibrium, stability, and constancy) within our internal environment when dealing with changes in stimuli under varying degrees of stress. For example, when singing stimulates a change in respiration rate, that in turn stimulates a response from the autonomic and neuroendocrine systems that regulate respiration and keep us running smoothly. Therefore, a sense of well-being, as a signal from the body to the conscious mind that we are optimally balanced, is essential to optimal performance.[9]

Our exploration of the role of cognitive skills in optimizing perceptual-motor performance will begin with the source of knowledge, sensory information processing.[10] This is followed by the processes for planning voluntary behavior and executing motor output.

## GETTING THE THINKING RIGHT: SENSORY INFORMATION PROCESSING

Perception is a cognitive process by which we take a sampling of the information received from our senses

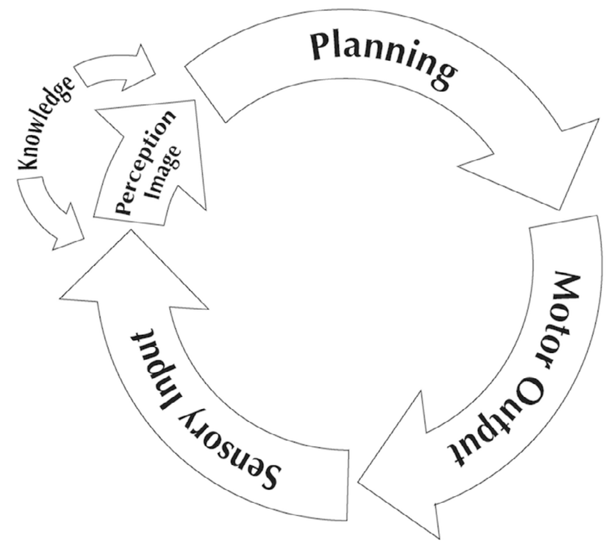


**Figure 1.** **Perceptual-Motor Processing Loop (Courtesy of Alex Johnson).**

and organize and interpret it as meaningful and recognizable experiences with clear locations in space and time.[11] Whether a percept involves a visual, auditory, tactile, or multimodal experience, such as singing a high C, it has the potential to be encoded into our long-term memory as knowledge. As such, it may be recalled as an image (mental representation) of that event.[12] However, perception is not always achieved simply. Only information that is judged unconsciously to be novel and potentially pleasant, or motivationally necessary to our task or well-being, is *likely* to be received and processed, with the potential of being projected to the cortex where it can be perceived consciously, *if* we so choose.[13]

### Selective Attention

The innate ability of our sensory systems to amplify or inhibit (gate) information according to its motivational significance is known as selective attention. We can consciously manipulate this unconscious gating by simply choosing what information we want or need to be amplified for voluntary tasks. We thereby inhibit unwanted information, such as distractions, self-doubt, and judgment. As with all innate abilities, selective attention and its correlates, attentional focus and perceptual acuity, can be developed to a level of expertise.[14] For example, when performing with vigilant attention, the sounds of technicians working back stage are likely inhibited while, at the same time, a critical cue from the orchestra alerts our conscious mind. Moreover, selective attention as a performance skill empowers the singer to voluntarily influence the regulation of the amplification and inhibition of sensory stimulus for the purpose of maintaining an ideal performing state, which is exemplified by optimal arousal and a sense of well-being.[15] Try it!

**Attentive-Listening Exercise.** While standing, preferably with a door or window opened to ambient sound, listen intently to a faint and distant sound. Does your attention to that select information amplify or inhibit the sound? Did your head turn to see the sound you just heard or have your eyes gone into soft focus? Let your attention follow the sound for several minutes to determine its source and location. Perhaps you hear a car or a truck. Is it moving toward you or away from you? As you listen attentively, do you feel appropriately alert? Are you breathing easily? Are you enjoying a sense of equilibrium or well-being?

### Equilibrium and Propriokinesthesis

For most of us going about our daily activities, information arising from below the body's surface to consciousness forms a confluence, or gross propriokinesthesis sense, of our position and movement through space. By virtue of their own displacement, various mechanoreceptors in our skin and joints, muscles and tendons, and inner ear detect the degree (amplitude) and speed (velocity) of displacement of our body parts over time (frequency rate). Taken together, these calculate the force of changes in our position. For example, the vestibular organs of the inner ear detect—and predict—our position relative to the velocity of head movements and the force of gravity.[16] Given the high degree of interpretation required, the ability to calculate our current and future position is called spatial cognition.

### The Vestibular System and Sensorimotor Integration

Sometimes referred to as the great integrator, the vestibular system receives, processes, and projects sensory *and* motor information.[17] This allows it to stimulate head turn reflexes to better position the eyes to see what the ears just heard, and, at the same time, signal corrective postural reflexes in response to those changes in our position, for the primary purpose of maintaining balance or equilibrium (Figure 2).

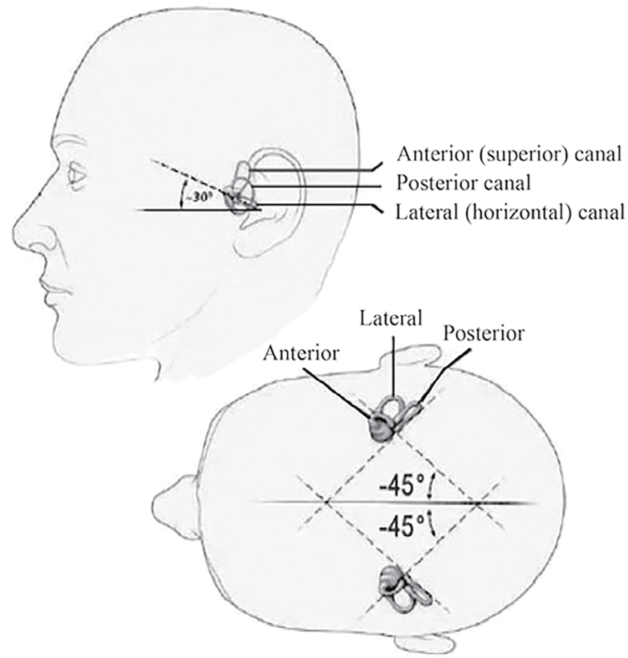


**Figure 2. Orientation of the Vestibular Receptors; https://www.nigeriamedj.com/viewimage.asp?img=NigerMedJ_2012_53_2_94_103550_f1.jpg).**

Similarly, when walking or executing a balance pose, the vestibular system can optimize its own receptivity by reflexively fixing our gaze a few yards ahead of our feet and rotating our head so that the plane of the vestibular organs is parallel with the earth and perpendicular to gravity.[18] We might associate this subtle orientation of the head and fixing of the gaze with the look of intense concentration observed in accomplished athletes and expert singers. The very motion of singing—the bone-conducted vibrations that travel from the larynx to the inner ear—effects rapidly recurring vestibular stimulation, which results in all the benefits afforded by the vestibular system and a state of equilibrium: heightened spatial awareness, smoothly executed postural controls, and a sense of calm.[19]

Gratefully, we are unlikely to lose our balance and fall as we go about our day, as most vestibular activity is successfully mediated unconsciously via direct brainstem controls (Figure 3). Because information is projected

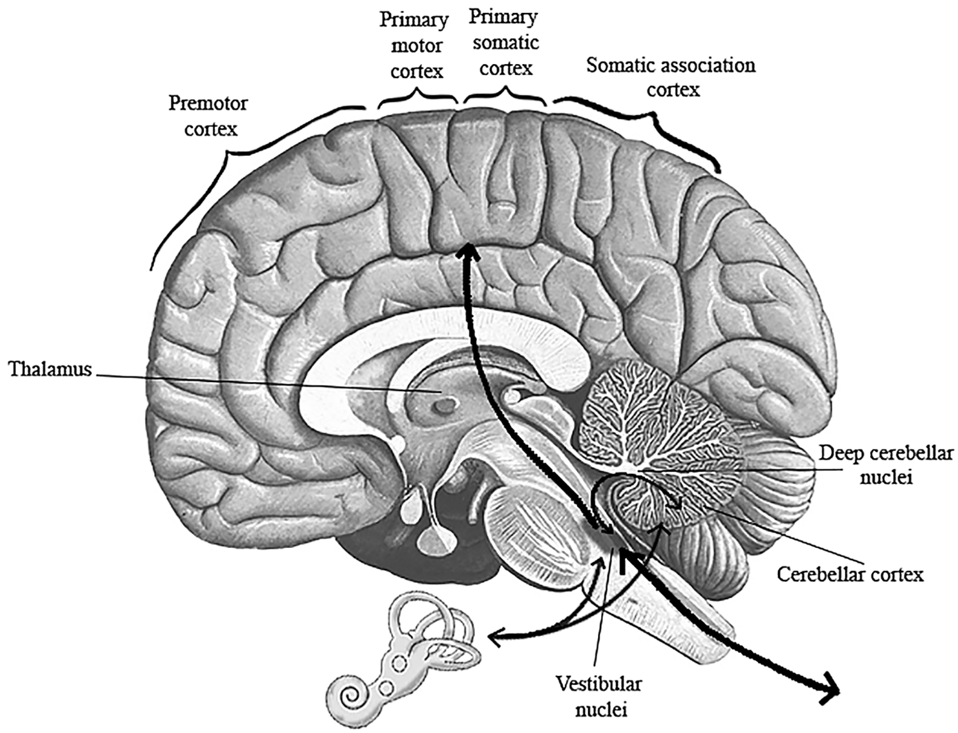


**Figure 3.** Major Pathways of the Vestibular System (Courtesy of Christopher Moore).

to the cortex on a desirable or need to know basis, the conscious sense of motion or physical imbalance, such as when standing on a moving bus or the nausea experienced at sea, is an indication that the unconscious brain needs the conscious mind to pay attention and assist in restoring balance.[20] Conversely, the conscious sense of a desirable state of equilibrium may result in a curious feeling that our head is suspended in space. That is, when the vestibular system is optimized, our awareness of motion is minimized. When the variable acceleration forces of our actions are readily equalized to the opposing force of gravity, we may feel as if we are floating on air. Try it!

**Developing Perceptual Acuity for Spatial Cognition and Equilibrium**

This exercise is especially pleasant to do out of doors or in a room with windows opened to ambient sound, light, and a gentle breeze. If possible, remove your shoes and, with your weight somewhat toward the balls of your feet, keep ankles, knees, and hips flexible to welcome postural responses.

**Step 1: *Exteroception for spatial cognition.*** Sense the spaces before, behind, above, below, and beside you as informed by light, temperature, and sounds near and far. With your eyes in soft focus, the vestibular system signals the eyes to rapidly scan the area to calculate spatial coordinates and in turn signal postural and autonomic reflexes to equalize us—including our larynx—to the force of gravity.

**Step 2: *Interoception for spatial cognition.*** Now that you have amplified your awareness of external space, turn your attention to sensations rising from within. Although interoceptive signals are comparatively vague versus exteroceptive signals, "listen" attentively and take note of your sense of self in space.[21] Do you sense any change in your postural orientation to gravity, including your larynx? With the help of a hand just below the sternum on your epigastrium, sense your heart and breathing rates. While humming, or chanting with your ears plugged, notice the sound and feel of your vibrating bones. Do you sense any postural or respiratory adjustments?[22] Do you have a sense of well-being?

**Step 3: *"Echolocation" for spatial cognition.*** While singing, perhaps chanting *mi, me, ma, mo, mu* on a single pitch at a tempo of about one syllable per second, invite the acoustic soundwaves of your internal space (vocal tract resonances), interacting with those of the external space, to amplify your sense of self in space. A student aptly named this exercise "echolocation." Just as a bat uses echolocation to determine its place in space, we too can use the rhythmic information of oscillating sound waves (acoustic vibrato) together with phonatory oscillations (mechanical vibrato, emitted at a soothing ~4–8 cycles per second), to inform us of our place in space.[23] Is the rhythmic information synchronous and smooth, or irregular? Is it synchronous with your heart rate? Similarly, we may sense the rhythm of attention and intention (motor cortex).[24] It's the rate at which we might tap our finger or articulate phonemes.[25] Synchronicity of neural oscillations is an indicator of autonomic balance and well-being.[26] (While space does not allow for a discussion of neural oscillations, those familiar with bio-feedback or speech and language processing may have interest in research finding a spectro-spatial pattern of delta-beta phase-amplitude coupling relevant to behavior outcomes in temporal tasks, that has been shown in the motor cortex during auditory and visual perception.)[27]

As we progress through the hierarchy of perceptual expertise from early- to end-stage learning, increasingly complex behaviors become automated and can be monitored and corrected unconsciously according to our plan of action and past experience (motor memory). As a result, more feedback information requires less conscious attention and performance becomes intuitive. And when less feedback from a just performed action requires conscious attention, more executive level resources may be devoted to the feedforward creative processes that express the art of singing.[28]

## GETTING THE THINKING RIGHT: PLANNING VOLUNTARY BEHAVIOR

Between sensory input and motor output, there is an intermediate synthesis of perceptual images that, in effect, inverts our perception from processing feedback information (input) to processing the feedforward intentions (planning) that guide behavior (motor output).[29] We experience this planning process consciously as the goal-state sensorimotor imagery of inner singing. A sensorimotor image is a mental representation that is coincident with the generation of the motor plan of action and the activation of its corresponding neural structure (network trace).[30] As the description goal state suggests, it occurs in anticipation of the execution of a behavior and is exemplified in the fluid ease of expert anticipatory control. According to prevailing theories of perception, stimulus events are represented by the particular neurons or neuronal networks that they trigger in the brain.[31] Therefore, the perceptual imagery that we experience when we mentally rehearse or covertly inner sing a melody involves many of the neural functions and networks that would be stimulated if we were to sing the melody overtly (aloud). We could say goal-state imagery is how we mindfully pilot our automation rather than mindlessly run on autopilot.

### What-and-When Planning: The Working Memory and Inner Singing

The working memory involves the temporary, *ad hoc* activation of an extensive network of perceptual and motor memory as well as the capacity to "hold information in mind" for as long as we use it.[32] This is essential for sequencing and cuing the episodic unfolding of sensorimotor events for speech and singing.

To plan voluntary behavior, which involves positioning effectors (e.g., articulators) in the right place at the right time, we choose *what* we will do and *when* we will do it. For example, for speaking and singing, what begins as a nonspecific generalized program for phonating and articulating is then tailored to meet a specific purpose of the moment, such as telling a story to a child or singing a cadenza with a flourish.

With the following audiomotor-imagery exercise, we can readily experience the difference between activating the auditory-vocal cortical network that loops the phonological stores for speech and activating a parallel yet distinct network that loops the tonal stores for the language of music.[33] Just as the contents of the auditory-phonological store can be refreshed and held in mind by mentally rehearsing speech sounds (inner speaking), the auditory-tonal store can be refreshed and consciously monitored through mental rehearsal "based on vocal fundamental frequency control processes" and ongoing articulatory control processes for tuning the vocal tract (inner singing).[34] Try it!

**Audiomotor-Imagery: Inner Speaking to Inner Singing.** Review the first step of the attentive listening exercise to stimulate spatial awareness. With your teeth slightly separated, and your tongue and breathing rate at resting points, mentally rehearse, or inner speak in your mind's ear [do-o-o-o-o-o], repeatedly in rapid succession to refresh the vowel (auditory-phonological information) to "hold it in mind."[35] Now, mentally rehearse (inner sing) $C_4$ and repeat [do-o-o-o-o] in rapid succession while focusing primarily on refreshing the fundamental frequency (auditory-tonal information) to "hold it in mind." Consider how the sensorimotor experience of generating an auditory-phonological image and auditory-tonal image differ. Now co-activate three loops of the working memory for singing: auditory-phonological (inner speaking), auditory-tonal (inner singing), and spatial awareness. Finally, inner sing (covertly) *in real time* an entire phrase from a favorite song (e.g., "Somewhere Over the Rainbow") with the intent to sing aloud (overtly).[36] Did your breathing rate vary from a resting-level point to inhale for the phrase? When you sang the phrase aloud, did you feel equal to the task? Because a sensorimotor image is coincident to a generated motor-plan-of action (as shown in Figure 4), the quality of the image will equal the quality of the performed action.

### Generation of a Motor Plan of Action: If You Can Image It, You Can Do It!

When we feedforward our intentions from our conscious mind (cortex) to our unconscious brain, our motor system (e.g., basal ganglia, cerebellum) prepares a detailed plan of action that is in turn projected to the cortex as a sensorimotor image or mental representation of the to be performed action (Figure 4).[37] This process takes about a second for well learned behaviors.[38]

It might be said that the conscious mind reads the unconscious brain. Because a sensorimotor image is coincident to the generation of a motor plan of action, if we do not have the ability to perform a task, we will be incapable of generating a first-person image of our selves performing that task. For example, what happens if we inhibit effectors (e.g., tongue, intercostals) that would otherwise be capable of singing action? Try inner singing with your teeth clenched, your tongue pressed to the roof of your mouth and holding your breath. Rate the ease and vividness with which you can generate a first-person audiomotor image of yourself singing. Now inner sing without that inhibition, allowing your teeth to separate slightly, and your tongue and breathing rate to return to their resting points. Rate the ease and vividness with which you can generate a first-person audiomotor image of yourself singing. If you can image it, you can do it!

The ability to consciously monitor and even alter planning processes *before* they are executed forms the basis of not only voluntary control but also the expert anticipatory control that effects smooth motor response. It should be noted that, anticipatory control is closely related to ballistic control. In the case of a ball aimed at a target and thrown, we have no control over the ball's trajectory after it leaves our hand.[39] Similarly, we cannot change or retrieve a motor plan of action once the signal to execute leaves the motor cortex. Once we say "Yes!" to an action, the watchful eye of attention (the inner judge) is briefly inhibited or "turned off."[40] At this juncture, to perform in an optimal flow state, we must train our singer's brain to turn the eye of attention to "What's next?" and not look back. After all, unlike a golfer striking a single ball at an external target, singers engage in rapidly executed sequences of tonal and syllabic episodes at a rate of about 1–2 times per second. Try it!

**What-and-When Planning: Streaming Strings of Sound Bites.**

Streaming and improvising with sound bites is a fun and effective tool for developing skills in both pitch memory and attentional focus on feedforward plan-

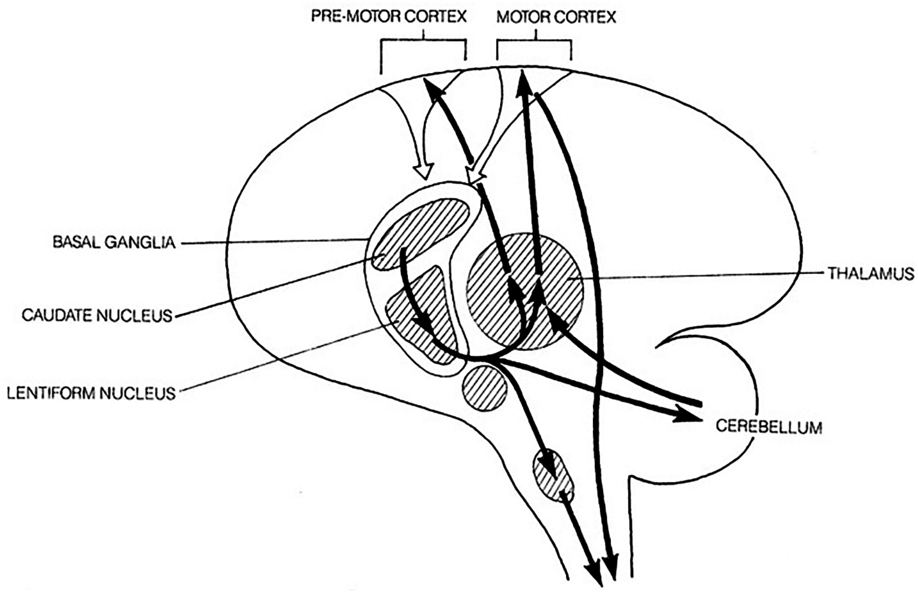


**Figure 4.** **Generation of a Motor Plan of Action (Courtesy of Raymond Kent).**

ning, or "What's next?" In this exercise, *do* and *sol* are tonal mnemonics. Together with visual notation, they cue various musical patterns in manageable sound bites, which may be performed at a rate of about one per second (Figure 5).[41] Once these patterns are learned, we can apply the cognitive skills of pattern recognition and transference to cue a variable musical tale.

**Step 1:** To learn, inner sing (covertly) each sound bite in real time before singing it aloud (overtly). Continue alternating between covert and overt rehearsal until an image for each sound bite can be cued and generated in about one second. This means you will have about a second, or a beat of rest, between each sung episode.

**Step 2:** Once learned, use on-line feedforward cuing to flow from sound bite to sound bite without rests at a rate of about one beat per second. That is, as soon as you say "Yes!" to a sound bite, turn your attention to inner singing "What's next?" The conscious experience will be a streaming string of musical sound bite images formed in the moment just before they are sung overtly. Remember to co-activate spatial awareness to optimize postural and respiratory controls.

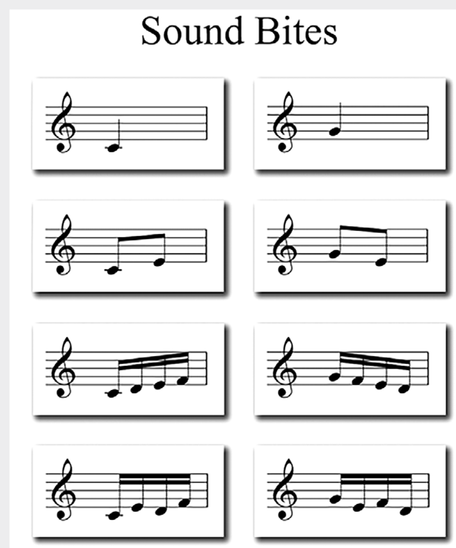


**Figure 5.** **Sound Bites (Courtesy of Alex Johnson).**

**Step 3:** To improvise, begin the sequence on *re* or *mi,* expand to four columns by adding another fifth, or mix-up the patterns by selecting sound bites from alternate rows and columns. The goal is to continuously feedforward intentions using auditory-tonal imagery and say "Yes!" to each sound bite at a rate of about one per heartbeat.

## GETTING THE THINKING RIGHT: MOTOR OUTPUT PROCESSING

Consistent with the *ad hoc* nature of the working memory and the generation of a sensorimotor image, the most workable motor theories present procedural motor memory as generalized motor plans of action that are infinitely variable to the task at hand.[42] This is possible because innate knowledge for reflex acts, such as the ability to grasp an object or phonate, is stored at the foundation, or lowest levels, of the motor hierarchy so as to be trainable (plastic) and flexible.[43] Therefore, the anatomy and function of our motor output processing systems will be presented with respect to our ability to voluntarily adapt our lower level production processes by means of upper level direct and indirect cortical controls.

A reflex is an unlearned automatic behavior that may be influenced by higher level controls and brought under voluntary control.[44] One such influence, as illustrated in Figure 6, is the gamma motor neuron, which transmits a copy of the alpha motor signal to the intrafusal fibers of the sensory muscle spindle in anticipation of action. This "insider information" primes the stretch reflex for a planned action, which enables the rapid and smooth response characteristic of expert anticipatory control.

### Direct and Indirect Cortical Controls

The motor cortex has two pathways by which it can influence local motor circuitry, one direct and the other indirect.[45] As shown in Figure 7, the simple command, "reach out arm" is projected directly to local motor circuity for control of the distal limb via the cortico-spinal pathway. However—and this is essential to understanding how we get our thinking right—upper motor neurons in the cortex also control movement *indirectly,* via the cortico-reticulo-spinal pathway.[46] In this case, the same command "reach out arm" is simultaneously sent to the medial spinal cord via brain stem controls. A major function of these indirect pathways is to provide rapid up-to-the-millisecond mediation of postural and autonomic (cardiovascular and respiratory) controls during cortically initiated voluntary movements.[47] For example, when our arm is extended to maintain the position of a tray, postural contraction of the calf muscle (gastrocnemius) begins well before contraction of the biceps.[48]

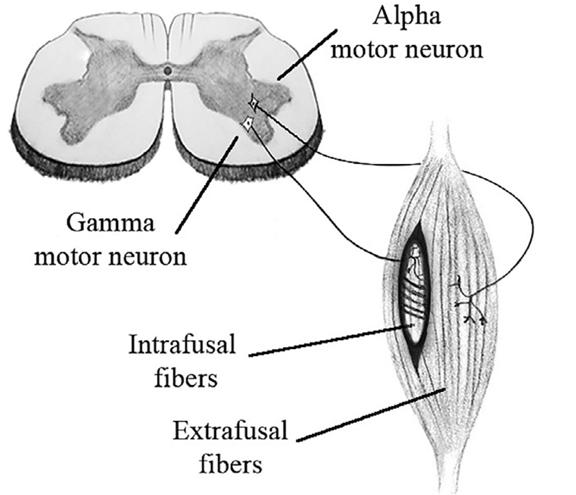


**Figure 6. The Motor Unit and Muscle Spindle (Courtesy of Kelsey Stalker).**

In this way, our dual control system provides for our conscious mind to engage in both the creative processes that generate rich and intentional sensorimotor imagery and the gathering of temporo-spatial information essential for unconscious mediation of motor output. Concurrently, this satisfies our nervous system's overarching purpose to maintain well-being.

## CONCLUDING THOUGHTS

There is no gap between sensory and motor processing. Rather, the integration of cortical intentions and sensory and motor controls exists at each level of the nervous system: at the level of local circuitry to mediate reflex controls; at mid-level controls (brainstem, basal ganglia, and cerebellar), where up to the millisecond information is continuously coordinated and modulated to optimize the plan of action; and at the cortical level, where we experience the continuous flow of goal-state imagery. Direct and indirect anticipatory controls empower us to take meaningful action with the assurance that our behavior systems are equal to the planned task at hand. All we have to do is know what we want, then say, "Go," and let go.

## NOTES

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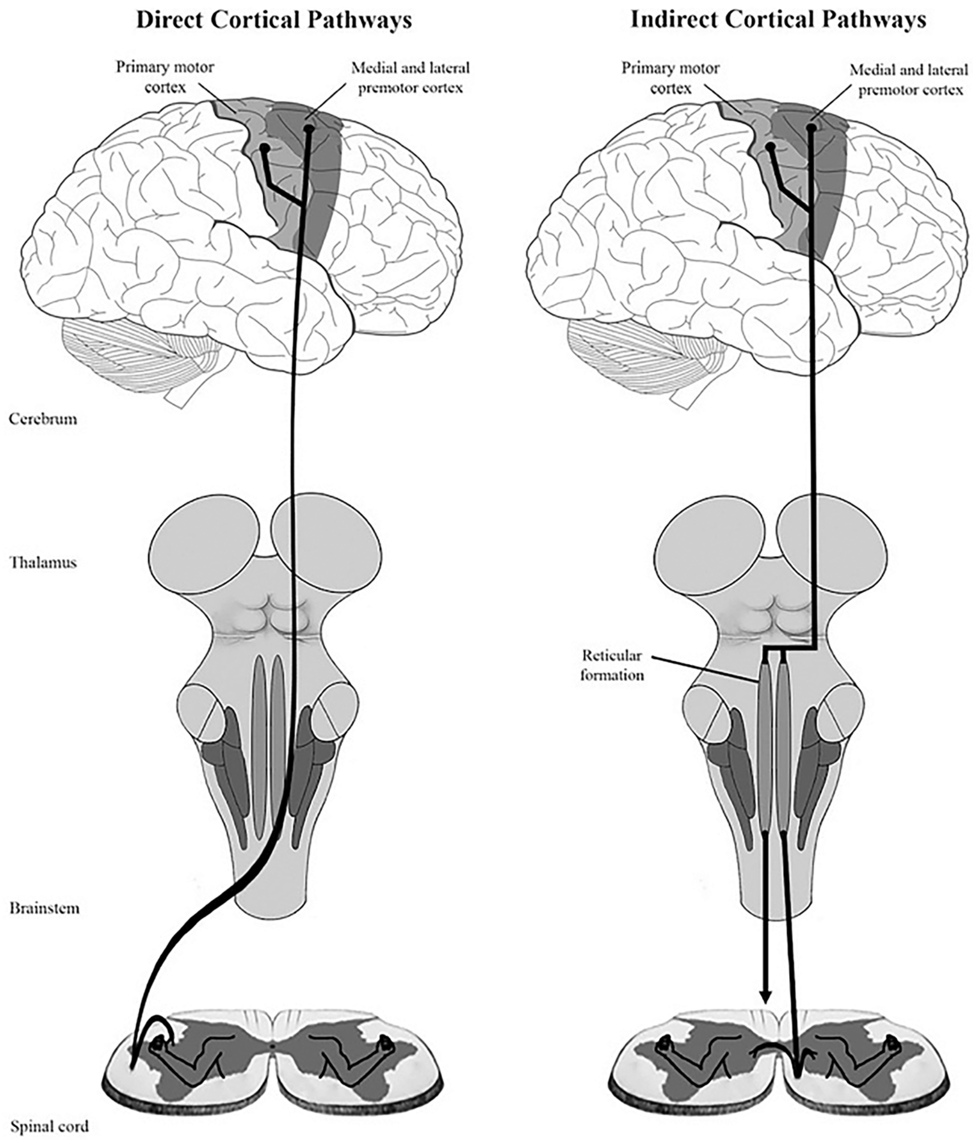


**Figure 7.** **Direct and Indirect Cortical Controls (Courtesy of Christopher Moore and Myslin/Grays 728/Wikimedia Commons/public domain).**

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