Dancing Round the Homunculus: Movement in the Brain

…the representations of different muscles were intermingled even at the level of individual neurons. Muscles of the fingers, wrist, hand, arm, and shoulder had overlapping representations in the primary motor cortex. The map seemed designed to integrate *the control of body parts rather than to segregate the control of body parts.* (Graziano & Aflalo, 2007)

…The proper locus of mind is a complex, multilevel, continually interactive process that involves all of the following: a brain, operating in and for a living, purposive body, in continual engagement with complex environments that are not just physical but social and cultural as well. "The Meaning of the Body" Mark Johnson.

My soul is like a hidden orchestra; I do not know which instruments grind and play away inside of me, strings and harps. timbales and drums. I can only recognize myself as a symphony. "The Book of Disquiet" Fernando Pessoa.

Summary:

- Learning to sing can be viewed as learning the physical coordinations that facilitate free, resonant and expressive singing
- We can consider what is known about the way the brain organises movement in the body to ask what approaches to singing might effectively help us improve these coordinations.
- The powerful concept of the "motor homunculus" lent weight for a long time to the idea that movement was organised "by the muscle", or the body part, but…
- Movement seems to be organised in complex coordinations, by synergistic neural networks.
- These neural networks are activated in the pursuit of *tasks*.
- Intention-led tasks coordinate and constrain a huge range of possible movement to achieve *goals*
- Singing instructions implying the operation of individual muscles *may* be difficult to follow
- We can ask what the task of singing is.
- Singing teachers may wish to find intentions that inspire networks of coordinated movements to improve singing, and avoid language that suggests the assembly of new coordinations, piece by piece.

Words and Neuroscience.
What can we sensibly expect from thinking about the brain in singing? It is easy to over-extend the findings of neuroscience. This article confines itself to ideas that are broadly agreed and have survived at least a decade. Any conclusions drawn are limited in scope and tentative in nature.

Though we might, then, expect relatively little, perhaps there is something, and something worth having. Anything we *do* lift from these findings will at best be simply *metaphorically informative*. No definitive conclusions are available for the singer or teacher of singing, as no direct research has yet considered the role of the brain in learning to sing.

A survey of current neuro-scientific research does suggest, with a reasonable degree of consensus, a picture of the way the brain organises movement. This picture could help us form strategies for teaching and learning. It could help us structure our teaching and language in a way that works *with* it, rather than battles against it.

We note that the terms commonly used to describe brain-behavior relationships define, and in many ways limit, how we conceptualize and investigate them and may therefore constrain the questions we ask and the utility of the "answers" we generate (Koziol, Budding, & Chidekel, 2011)

If the concepts with which we teach are in line with expected brain-behaviour relationships, we may get better results. The value of considering this relationship is nothing of the "do this with your brain to get this from your singing" kind. In fact, the findings suggest the opposite, bringing further support to the crucial role of imagination and intention.

We start here by looking at a powerful image. An image that has influenced thinking, in and out of neuroscience, about how the brain and body interact. An image that is now thought to be misleading.

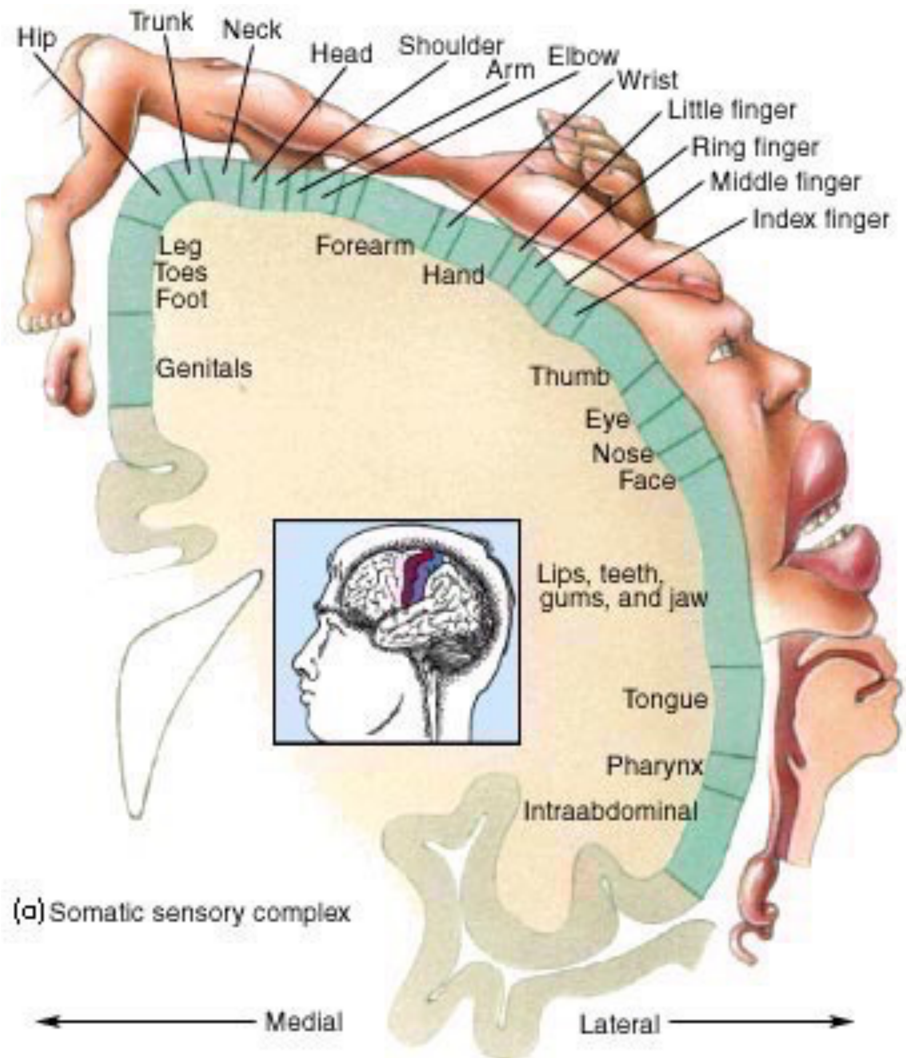
A body in the brain.
A popular conclusion drawn from some of the early findings of neuroscience was that there was a one-to-one mapping relationship between brain and body. It had been found that, in parts of the brain responsible for movement, there appeared to be discrete areas that reliably correlated to motion in certain parts of the body. This is known as a somatotopic relationship:

Early experiments with cortical stimulation in human surgical patients revealed a somatotopic organization of motor cortex, giving rise to the enduring concept of the motor homunculus. (Harrison & Murphy, 2014)

This idea of a homunculus, a miniature representation of the body in the brain, rapidly caught on, especially when the unusual step was taken of employing an artist to represent it:

Penfield and Boldrey set out to illustrate "the order and comparative extent" occupied in the sensorimotor strip.' To represent the topography of their observations, the authors departed from the rigorous textual description of the effects of stimulation of the brain and achieved an extraordinary conceptual leap: an artist, Mrs H P Cantlie, was employed to draw a sensory and motor homunculus…
(Schott 1993)

Here is one such picture of the motor homunculus:



This strangely horrid being shows the locations in the motor cortex (the area of the brain responsible for movement) in which different parts of the body are mirrored. The picture draws body-parts to a size which indicates how richly represented they are. Thumbs, for example, more useful and used than elbows, have more neuronal presence: the thumb is therefore startlingly large in the motor homunculus.

For a long time, this image, to some extent, shaped thought about how the brain organises movement. It led to the idea that the area containing the representation of a particular body-part would in some sense "operate" that part.

This idea, however, of a one-to-one, brain-to-body operation of parts, is not currently understood to be the case. A more complicated picture has emerged.

Fuzzy, multiple representations.
A traditional view of the motor cortex in the primate brain is that it contains a map of the body arranged across the cortical surface. This traditional topographic scheme, however, does not capture the actual pattern of overlaps, fractures, re-representations, and multiple areas separated by fuzzy borders (Graziano & Aflalo, 2007)

It is now understood that a particular part of the body might be *multiply* represented. Boundaries between parts are *vague*, and different parts of the body can be *intermingled*. Representations may even be *fractured*, spread across several parts of the brain.

The motor homunculus view of the primary motor cortex…implies a one-to-one correspondence between certain cortical neurons and the muscles they control, but this is somewhat misleading. Current research indicates that a given muscle is controlled by multiple spots on the cortex and that individual cortical neurons actually send impulses to more than one muscle. In other words, individual pyramidal motor neurons control muscles that work together in a synergistic way to perform a given movement.
(Marieb, Nicpon & Hoehn 2007)

Synergy replaces addition.
This new topography is mirrored by a new understanding of the way the brain organises movement. Instead of an "additive" process, where say, in order to *point*, the "arm area" of the motor cortex activates in conjunction with the "finger area" to produce it, movement is rather organised (or represented) in the brain by *suites of*

behaviour, or tasks. In order to expedite these tasks, large networks of neurons activate and work together, across disparate areas of the brain.

Addition…

Such results indicate that the process of moving multiple fingers is not simply the sum of activating multiple separate M1 territories, each controlling a different finger;
(Scheiber 2001)
(M1 here refers to the primary motor cortex)

…is replaced by synergy…

Recent research suggests that the nervous system controls muscles by activating flexible combinations of muscle synergies to produce a wide repertoire of movements…task-level motor intentions are translated into detailed, low-level muscle activation patterns
(Ting & McKay, 2007)

The brain organises movement on the basis of *task:* tasks serve our intention.

What is more surprising, and notable for the teacher of singing, is that *different* tasks operate the *same* parts of the body *differently*:

Neurons discharging for a specific motor act typically do not discharge during the execution of similar movements aimed at a different goal, for example, a neuron that discharges during finger movements for grasping an object does not discharge during similar movements aimed at scratching. (Rizzolatti, Cattaneo, Fabbri-Destro, & Rozzi, 2014)

A finger used to *grasp* is regulated by a different part of the brain when that same finger is used to *scratch*. Perhaps a tongue used to sob, or yawn, or being directly "placed", is activated differently from one used to communicate.

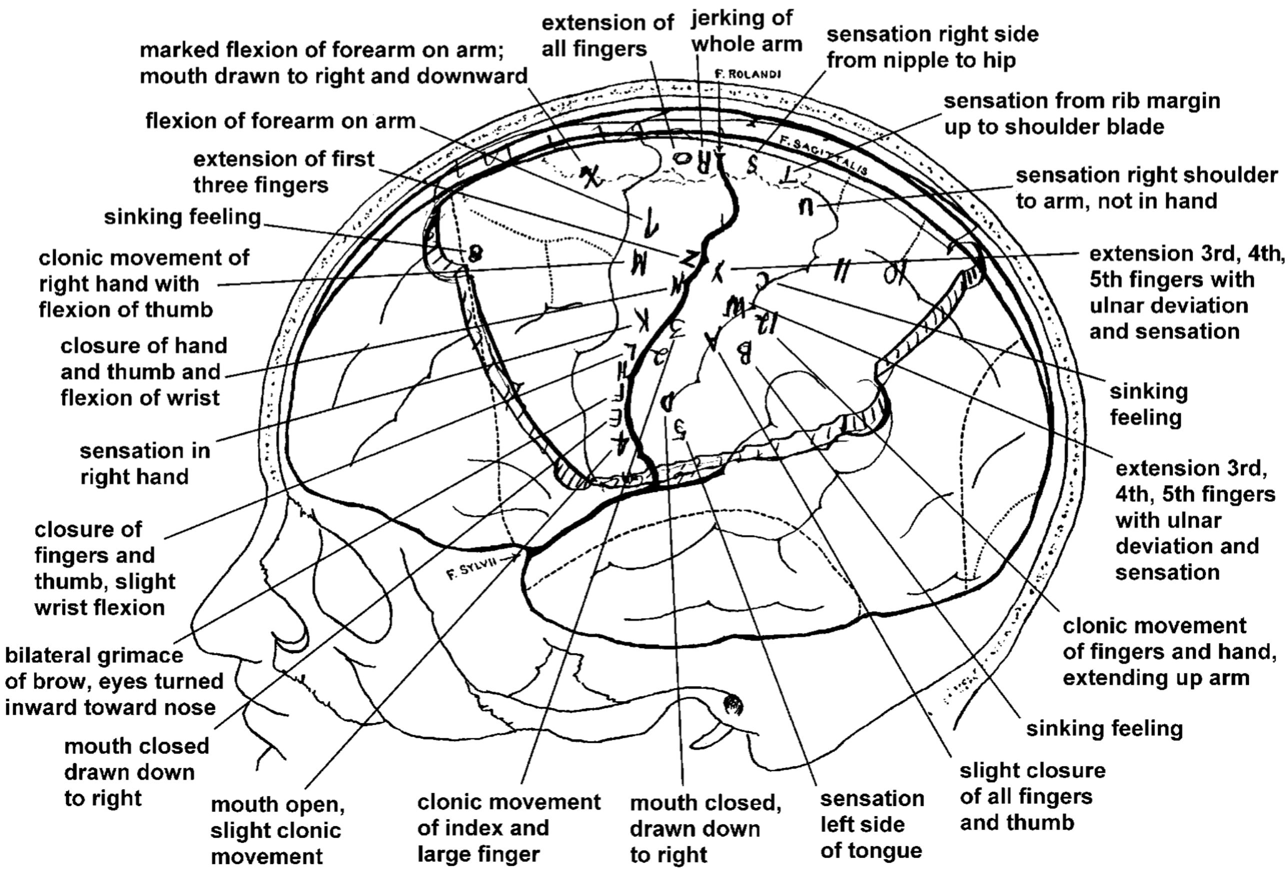
A "Task-Led Movement" Homunculus.
The current view then, is that the body is represented in the brain in terms of task-led movements, rather than individual muscular operation:

There is now general agreement that the primary motor cortical organization is in term of movements (and motor acts) and not in term of muscles and joints (Rizzolatti, Cattaneo, Fabbri-Desto, & Rozzi, 2014)

Our results indicate a movement-based, rather than a muscle-based, functional organization of motor cortex
(Brown & Teskey, 2014)

Particular kinds of *coordinated movements* are re-presented in the brain, rather than the brain playing a sort of "keyboard of muscles".

When the motor homunculus is replaced with this understanding of the brain, things are rather different:



(Scheiber 2001)

Were this to be fully pictorial, *actions* would be drawn in different areas of the brain, rather than body parts. Observed activity in the brain is not representative of the activity of individual muscles, but of complex *tasks*. These tasks have *goals*, and require extensive coordination of multiple muscles to attain them:

…neural activity reflects many features of motor performance from high-level goals to low-level details of motor execution. Second, this complex representation of motor action in MI is not surprising when one considers the large number of cortical and subcortical regions that project and influence motor cortical activity as well as MIs important role for influencing brainstem and spinal circuitry to control movement (Scott 2003)

Constraining Complexity.
This *task* guidance constrains the immense number of possible coordinations possible in the human body:

Humans have a complex body with more degrees of freedom than needed to perform any particular task. Such redundancy affords flexible and adaptable motor behavior, provided that all degrees of freedom can be coordinated to contribute to task performance (Todorov & Jordan, 2002)

It is perhaps worth seeing again Kent's reminder of the complexity of speech, quoted first in "The Meaning of Exercises":

As commonly noted in introductory texts in speech science, speech production involves more than 100 muscles located in the trunk, neck, and head. To illustrate the control problem of speech production, suppose that each muscle can have the binary states of either contracted or relaxed (of course, muscle activation is much more complex than that, as it involves gradations in degree and duration of contraction within individual muscles). Even with the severe simplification of two activation states for each muscle, the number of possible patterns of motor activation is 2^100, or more than 1 nonillion. (Kent 2015)

One can imagine how finding an appropriate task or intention for a singer might radically guide and constrain the number of potential patterns of muscular activation possible, and increase the chances of successful learning.

Learning in the Brain
Here is a summary of the general principles underlying the organisation of movement in the brain, as currently understood:

Decades of cortical stimulation experiments have revealed four general principles of motor map organization: 1) fractured somatotopy—individual movements are represented multiple times and are highly interspersed with adjacent movement representations across discrete cortical regions, 2) interconnectivity— corticospinal neurons from adjacent cortical areas are densely interconnected via intracortical afferents, 3) area equals dexterity—movements with a greater degree of dexterity are more *easily evoked in response to stimulation and occupy a larger proportion of the map, 4) plasticity—motor map topography is highly dynamic and can rapidly change in response to a variety of internal and external pressures.* (Monfils, Plautz, & Kleim, 2005)

These principles are worth drawing out:

- The representation of movement in the brain is highly complex. Movements are multiply represented. Representations are not neat, but muddled with each other.
- Movement draws on complex, networked connections.
- A movement of great dexterity has a greater neuronal presence in the brain and so takes up more space.
- The neural networks underlying movement are plastic, and can be developed, replaced and grown.

Monfils continues:

The process by which motor skills are encoded by the motor cortex invokes all four of these principles. The fractured somatotopy facilitates the formation of novel muscle synergies during training through changes in the pattern of interconnectivity. (2005)

Motor skills are learnt, encoded, in a manner reliant on *all four* principles, including complexity. New skills can be learnt, and are encoded in the brain (rather than in questionable "muscle memory"), but they are learnt as reconfigured movements, rather than lego-like new-assemblies of individual muscle actions.

motor skill learning is associated with a reorganization of movement representations (Kleim, Barbay, & Nudo, 1998)

What's here for the singing teacher?

As mentioned above, anything we derive from these findings will be *informative* at best. The information and ideas might inspire us to think in novel ways, and see if we can find new and helpful approaches.

We can perhaps say that current research roughly agrees that:

- Movement is organised in the brain as tasks or behaviours, such as grasping, pointing, swallowing and so on.

- There is no one-to-one relationship between a given muscle and a particular part of the brain: a given muscle is activated differently in the brain for different tasks.

These ideas could guide the language of our teaching.

We could choose our words in a way that takes account of complexity. We might look for the *intentions* that underly good singing and seek to inspire them in the singer. We might *avoid* language that implies a one-to-one correspondence between brain and body. We could encourage coordinated actions, rather than imply a model of individual muscular control.

Elucidating focus and meaning.
The findings here might also help us understand the experimentally verified results on *focus* and *non-speech oral motor exercises* discussed in the previous two articles. The three articles together seem to circle some central understanding.

- In "Effects of the Focus of Attention on Learning", we saw how self-directed attention, attempting to manipulate one's own physicality to advantage, was not the most successful strategy to improve performance. Learning was more effective if attention was *external*, on the *intended effects* of an action.

- In "The Meaning of Exercises" it was noted that exercises to improve speech were only effective if they had speech as their aim. Physical exercises, apparently highly relevant to the physicality of speech, seemed not to help, unless communicative intent lay behind them.

- In *this* article, a broad picture has been sketched, from current research, of how movement and the body are organised in the brain. The picture is one of complex, coordinated neural networks that serve tasks and intentions. Muscles are not individually represented in the brain: coordinated movements are.

We might now suggest that the problem with an internal focus in learning could be that it represents an attempt to crudely re-coordinate a movement that is highly complex, and exists in the brain as a synergistic network. Adopting an internal focus of self-directed manipulation is akin to thrusting a spanner into subtle, entangled works.

We might also wonder if non-speech oral motor exercises do not work because they omit the *task-led* intention, on which principle the brain organises movement. If there is no *intention to speak*, one might imagine that a large portion of the relevant neural network is not enlisted, and so relevant learning cannot take place.

Techno-physical Language and the Homunculus

If we wanted to find language for our teaching that *suggests intention*, respects *complexity* and remains *task appropriate*, how does techno-physical language fit?

In describing certain teaching instructions as techno-physical, I have suggested that the language offers direct information about the body of the singer to the singer. It is implied or inferred that the singer acts directly on this information.

It might be helpful to give a few examples of instructions framed in this kind of language:

- You are over-extending and tensing your jaw as you sing. Massage and release that tension. Loosely move your jaw from side to side as you undertake some vocalises. Now sing a phrase of music, maintaining a loose jaw as you do so.
- You need to raise your soft palate, to make more space. Lift the back of the mouth, and maintain a feeling of stretch.
- You are singing with your mouth nearly closed: open it more as you sing. Try holding this pencil between your teeth to show the approximate degree of opening needed. Now sing again with an equivalent degree of openness.
- Your singing suffers from tongue root tension. Keep the tip of your tongue just below your lower front teeth. Remain aware of the tongue's position as you sing. You will also be able to detect some tightness underneath your jaw. Encourage a free release and widening there. Sing again whilst maintaining that freedom.
- Your cheeks and eyes should have a sense of brightness and openness as you sing. Rub your cheeks and get a sense of lift. Keep your zygomatic arch energised whilst vocalising.

All these instructions offer possibly reasonable information to the student. The singer is invited to become aware of, and explore, their physical use in order to improve their singing. They sing again, directing physical change.

Addition or Synergy?
The first point to note is that these techno-physical instructions *seem* to imply a one-to-one relationship between body-part and brain. They appear to suggest to the student: do *this* with *these* muscles.

If that were what was taken from the instructions, we can imagine a potential conflict. If the body *is* organised through coordinated complexes of task-oriented movements, these instructions seem to work against that. In the unlikely event that this kind of language were used repeatedly over the longer term, inferences might be absorbed and held dear by the student, and these inferences might be at odds with what is possible. They might expect to be able to "operate themselves" variously and separately. Individual points of fixation could emerge: "I must remember to raise my soft palate", "I must open my mouth more…". The task of "opening" or "raising" could replace the task of singing.

This, of course, may not be the whole story. If in fact the "task of singing" continued, with intent and motivation, whilst, say, the jaw was actively loosened, might that build a new neural network in which singing began to take place with a looser jaw?

The teacher may also be seeking to nudge and inspire new and appropriate "neural networks", or muscular coordinations which serve a communicative intent. The techno-physical instructions are then just a "staging post" on this road to good singing.

Bad task/good task.
We can also turn things on their head and ask: if the brain *does* organise movement in task-oriented suites, what "task" were the tense jaw, the lowered palate, the half-closed mouth, the tight-tongue root, the dead eyes, attempting to perform?

These physical actions were then the results of *intentions*, and were directed by the brain in the service of that intention. If we could change the intention, would the ill-effects disappear without the need for direct interference? Changing intention demands a meta-technical approach that calls on the imagination.

As well as considering altering inappropriate intentions, we might consider the relevance of other "tasks" that are sometimes referenced in the singing lesson. These include the (after-)swallow, the beginning of a yawn or the sob. A limited physical recreation of these tasks might be suggested as a way to "find space" or prepare the body for singing. In the light of the "task oriented" relationship between brain and body, we can ask whether this seems appropriate. Can you actually have just the "first bit of a yawn"? Does imitating sobbing activate a helpful network, even if one element of the physicality might be helpful? Does the "after-swallow" light up a relevant, complex coordination? These are open questions.

Conclusions:
What might we safely take from the findings of neuroscience, and consider when thinking about our teaching?

- We could take the fact that intention is important to movement.
- We might have respect for the complexity underlying the coordinations involved in singing, and more circumspection when suggesting conscious interference.
- We could examine potential solutions for singers on the basis of the respect they pay to the relationship between brain and body, as currently understood.

It also appears to me that this most "modern" of sciences reminds us that we can, should, trust the role that *imagination* plays in our singing, our teaching and our learning. The centrality of task, intention and meaning suggest these might be "baked into" teaching and singing in a way for which purely techno-physical language cannot completely account. Intention can *only* be conjured through the use of imagination and interaction.

The use of imagination forms a large part of what I have called "meta-technical" approaches to vocal pedagogy. Meta-technical language might avoid possible pitfalls of the homunculus, and promote new, complex coordinations in ways that may be more powerful than individual muscular directives.

Meta-technical approaches do not, of course, preclude specific and detailed knowledge on the part of the teacher. The teacher will know *exactly* what they need and expect to hear and see from a singer. They will be possessed of a high degree of technical knowledge. They are probably fluent in the language of anatomy, physiology and acoustics. Our question here though is what language works best to *facilitate change* in the singer. These two languages may not be the same.

This "Singing Words" series examines the use of language in singing from a variety of perspectives. These first three articles suggest that language implying direct action on the body to improve performance may not be as effective as common sense would suggest.

Mark Johnson, a prominent philosopher of embodiment, describes the complexity of mind-body relationships. Great singers, highly aware of the subtleties of their craft, often profess ignorance as to "how" they do something. Perhaps we should respect this symphonic mystery, even as we seek to master it.

Alex Ashworth
Paris, September 2017.

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