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The Dancing Brain

by Ivar Hagendoorn

How can watching one dance performance, whether classical ballet or the newest modern choreography, be so engaging—even thrilling—and watching another leave us indifferent? Dutch choreographer and researcher Ivar Hagendoorn argues that contemporary neuroscience points at the answer. The limbs move, but it is the brain that dances.

I can still recall how thrilled I was more than 10 years ago after attending my first dance performance, by the Netherlands Dance Theater. How could watching a group of people moving about on a stage be so fascinating? Ballets like *Swan Lake and The Nutcracker*, or at least fragments of these on television, had not particularly appealed to me. At this performance, though, attended at the urging of a friend, I discovered that dance has more to offer than girls in tutus pretending to be princesses.

Then another friend recommended the work of the American choreographer and artistic director of the Frankfurt Ballet, William Forsythe. As it happened, the following week I was in Paris, walking along the Seine, when I spotted a poster announcing a performance by the Frankfurt Ballet that very night. The moment the curtain went up, I forgot everything around me. My thoughts seemed to have been translated into movement. What happened on stage seemed an embodiment of how my thoughts moved, connected, and organized themselves.

Yet a few weeks later, watching a performance of a work by a choreographer whose name now escapes me bored me so thoroughly that it was difficult to concentrate on what was happening on stage. What was so different about this performance?

In the process of completing a Master's degree in philosophy at that time, my natural reflex was to look for books and articles in philosophy that might answer these intriguing questions. It soon became apparent that there was little literature specifically on dance. Much had been written about the visual arts and some about music, but with the exception of the French poet and philosopher Paul Valéry and some scattered remarks by French philosopher Maurice Merleau-Ponty, no well-known philosopher had anything to say about dance. The few existing articles seemed dated, both in terms of the dance they discussed and with respect to the contemporary philosophical tradition of my teachers, a mixture of poststructuralism and phenomenology. The only course seemed to be to learn enough to write the article I wanted to read.

Reading and thinking for several years about what we find interesting when we watch someone dance brought me no closer to understanding what I saw on stage. At some point it struck me that this was the wrong track. Everything we see, hear, feel and do is mediated by the brain. To understand what fascinated and literally moved me in watching dance, we have to look to the brain.

HOW SLOW BRAINS COPE WITH FAST MOVEMENTS

An article in *Nature* by vision researcher Romi Nijhawan of the University of Sussex shows the consequences of neural processing delays for the perception of moving objects. Once a light particle hits the retina, it takes 50 to 100 milliseconds to be transformed into an electrical impulse and reach the visual cortex. This interval may seem negligible, but in this short time a car traveling at 65 mph will cover 7 to 10 feet. Several scientists have proposed that to make up for this delay the brain somehow extrapolates the moving object's trajectory. By shifting the percept—that is, the object's neural representation—forward, its perceived position would coincide with its actual position. Nijhawan suggests that this extrapolation takes place at the starting line of the process of perception—in the retina. Although this is still debated, many scientists hold that some kind of prediction takes place at various stages of visual processing, including the earliest.

In the French neuroscientist Alain Berthoz's *book The Brain's Sense of Movement*,[1] the theme is that both perception and action are essentially predictive. In his view, the brain acts as a simulator, creating mental models of the body and the world, models that it constantly updates with newly arrived information from the senses.

Some of the best examples of the predictive nature of motion perception come from sports. Sports psychologists showed in the early 1980s that a tennis serve is too fast for an opponent to decide after the ball has been hit in which direction it is going, to his forehand or backhand (and this was before the "power serves" of today). Players nevertheless frequently manage to return the ball. They do so by reading from the movements of the serving player where he is going to hit the ball, so they move in that direction even before the racquet touches the ball.

In a recent elegant study, the psychologists Michael Land of the University of Sussex and Peter McLeod of Oxford University showed how cricket players solve the same problem. The researchers measured the batsmen's eye movements as they prepared to hit an approaching ball. They found that the eyes monitored the ball shortly after its release by the bowler then made a predictive movement to where they expected it to hit the ground, waited for it to bounce, and then tracked its trajectory for 100 to 200 milliseconds afterward. Using a combination of statistical measurements and physical calculations, Land and McLeod showed that "information provided by these fixations may allow precise prediction of the ball's timing and placement."

From my brain's viewpoint, watching a dancer on stage is virtually the same as a tennis player's watching his opponent's serve. But how did this help me begin to understand my fascination with dance?

THE BEAUTIFUL AND THE SUBLIME

In his analysis of aesthetic judgment, 18th-century German philosopher Immanuel Kant made a distinction between the beautiful and the sublime. Beauty, according to Kant, is the feeling we experience when we discover a harmonious order in art or in nature that appeals to our mind's own drive towards creating order. This feeling may be instantaneous, as when we look at a perfectly symmetrical sculpture, or the result of careful analysis, the way a Bach fugue becomes more beautiful the more we listen to it.

Sublime also refers to a feeling—or, better, a state of mind—but one that is characterized by initial discord rather than harmony. Faced with an immense object, a skyscraper or the Grand Canyon, or a powerful phenomenon like a raging storm, our senses are overwhelmed, unable to comprehend the object or phenomenon in its totality.

According to Kant, this causes an initial feeling of displeasure or even fear. Shortly after this moment of disorientation, the self regains its composure as it succeeds in framing the information that overflowed the senses. It is at this moment that a feeling of pleasure sets in, as the self realizes that it has survived and, by implication, is more powerful than the vast object or event.

When reading Kant alongside the work of Berthoz, Nijhawan, and other neuroscientists studying perceptual anticipation, I realized that this reasoning may also apply to our perception of movement. If the brain fails to predict correctly the unfolding of a movement, we are taken by surprise. We often give out a sigh if a tennis ball hits the rim of the net, or if we see someone stumble. If the movement should continue to elude us, we become intensely aware of a "presence" (the movement) that cannot be wholly represented neurally or internally. The brain struggles to keep up with the movement, but before a motion percept (the internal representation of a movement in our brain) has been created, a buildup of new stimuli is already queuing to be processed. It is at this moment that the state of mind Kant described as sublime has a chance of arising. The brain responds to the flood of motion stimuli by focusing attention on the object's movement, blocking other stimuli, and increasing processing in the relevant brain areas. In my article "Some speculative hypotheses about the nature and perception of dance and choreography," I have outlined some of the possible neural mechanisms involved in this chain of reactions.[2] Essentially the responses are the same as when the brain prepares the body for action, such as returning a tennis serve.

By reversing the argument, we can also account for beauty in the Kantian sense of harmony between mind and object. If the movement trajectory predicted by the brain coincides with the actual movement, we are filled with pleasure, which we ascribe to the movement that gave rise to it by calling the movement beautiful or graceful. In summary, when our expectations are fulfilled, when the brain's simulations are correct, we delight in grace or elegance; when they are challenged, we are pleasantly alarmed.

This speculative account offers possible leads for research. It would be interesting to measure the brain's responses while subjects watched a live dance performance (using EEG) or one on tape (using fMRI) and ask them afterward to describe their subjective experience. My reference to the Kantian notions of beauty and the sublime only serves the goal of showing that some neural mechanisms can be related to aesthetic concepts. Actual experience is a combination of feelings, and beauty and the sublime are but aspects of a rather more indeterminate experience. For instance, we may find something interesting, yet might hesitate to call it beautiful.

The idea that the appreciation of dance has something to do with the interplay of expectations and their fulfillment has antecedents in other fields. For example, the same interplay has been proposed as an explanation for music and for humor. Indeed, what I here call the sublime may be similar to what some people describe as "chills" or "shivers down the spine" at certain moments during particular pieces of music. Neuroscientists Anne Blood and Robert Zatorre recently investigated the neural mechanisms of this phenomenon in a neuroimaging study at the Montreal Neurological Institute of McGill University. They found that the intensity of the "chills" correlated with increased activity in brain regions associated with emotion and arousal. Interestingly the map of activation overlaps considerably with the one that, based on a survey of the literature, I myself have sketched for the perception of dance. This may also explain why music and dance mix so well: A buildup of expectation on an auditory level can find its realization on a visual level. The final moments in many ballets are either a concurrence of exaltation in both sound and movement or the opposite, a slow fading away.

APPARENT MOTION

How does the brain anticipate movement when watching dance? An article from 1983 by cognitive psychologist Jennifer Freyd showed that still photographs of an object in motion—for instance a falling glass—convey information about its dynamics. This phenomenon is called "implied motion." What is more, watching such "action stills" activates the brain regions associated with perceiving motion, as was recently shown by Zoe Kourtzi and Nancy Kanwisher of the Massachusetts Institute of Technology. Of course, this will not surprise dance audiences, who know that a great dance photo somehow captures the performance. But cognitive neuroscience tells us how: The camera freezes the movement, but in such a way that it appears to continue, creating a sensation of movement in the viewer.

We experience motion not only in dynamic single images but also when a sequence of still frames is rapidly displayed. This is the principle behind film, of course, to which the vintage term "motion picture" is still applied. Consider a simple film consisting of two frames, one with a dot to the left, the other with a dot to the right. If the two frames are shown sequentially, the dot appears to move from left to right and back. Scientists believe this illusion occurs because the brain chooses the shortest path to connect the two images. However, as shown in a classic study by Freyd and Maggie Shiffrar, if the dots are replaced by images of a human body in two different positions, the brain chooses an anatomically possible route to connect the two positions. This suggests that the brain's implicit knowledge of the movements that the body is capable of making somehow influences perception. An intriguing thought! This is corroborated by a recent neuroimaging experiment by neuroscientist Jennifer Stevens and her collaborators, which showed that motor areas in the brain become active when people watch two rapidly alternating body positions, but only if the connecting movement is physically possible and the interval between the two frames long enough for the unobserved movement to have been made.

Laboratory experiments like these bring out capabilities that the brain evolved to solve everyday challenges. In dance, as in other areas, sometimes a movement is so quick that the brain processes the beginning and end positions more quickly than the movement connecting them. Sometimes, too, part of the dancer's movement is blocked from view, for instance, because a limb disappears behind the body or because the body as a whole disappears behind one of the stage props. The brain will then interpolate between the positions it did perceive and retrospectively infer the connecting movement. *Enemy in the Figure* (1989) a stunning ballet by William Forsythe, features a wavy-shaped wooden panel positioned diagonally in the middle of the stage. In combination with a mobile light pushed along by the dancers, it offers a fascinating visual spectacle. Sometimes dancers disappear behind the panel, leaving only the shadows of their movements visible, at other times one side of the stage is brightly lighted while the other is shrouded in semi-darkness. This led Anna Kisselgoff, dance critic for the *New York Times*, to write that "[the dancers on the dark side of the stage] could be barely made out but their movement was sensed. One could regard them as images caught in the web of distant memory: present but not visible."[3]

Research discoveries about how the brain "fills in the blank" between movements, using only anatomically feasible actions, lend support to theories that propose a common framework for perception and action. According to this view, perception is constrained by the properties and limitations of the observer's own motor system. To name one rather peculiar finding in this respect, psychologists Günther Knoblich and Wolfgang Prinz of the Max Planck Institute for Psychological Research in Munich, Germany, recently showed that people are able to recognize their own drawings from a set of samples, even when they were blindfolded when drawing them. This strongly suggests that action planning somehow contributes to perception.

MOTOR IMAGERY

Everybody knows what it is like to imagine an object. You do not even have to close your eyes to picture an elephant or the Eiffel Tower, though blocking sensory stimuli helps. This is what is called visual imagery. Motor imagery is the similar process of imagining a movement. But there is a key difference between visual and motor imagery. In the former you are a spectator, whereas in the latter you are an actor. You perform the movement virtually, in your mind.

The precise nature of motor imagery is debated. According to the French neuroscientist Marc Jeannerod, motor imagery corresponds to the covert activation of the motor system. Motor areas of the brain are activated, but the actual motor command is inhibited. The inhibition is likely controlled by the prefrontal cortex. In a much quoted article from 1986, the French neurologists François Lhermitte, Bernard Pillon, and Michel Serdaru showed that some patients with damage to the prefrontal cortex compulsively imitate movements performed in front of them. This suggests that the mechanisms that normally inhibit motor output are impaired in these patients, and therefore motor images are instantly translated into motor commands.

Motor imagery is peculiar. Experiments have shown that it takes people about as long to imagine walking somewhere as it would to walk there. What is more, it takes longer when they imagine carrying a heavy box! It is unknown whether people also get tired from imagining movements, but their breathing does speed up slightly when they imagine themselves running.

We engage in motor imagery whenever we prepare, intend, mentally rehearse, describe, or listen to a verbal description of a movement: for instance, when someone gives us directions. In fact, mentally rehearsing movements enhances actual performance, as sports psychologists have shown. Intuitively it makes sense that the same motor areas are activated regardless of whether you imagine or actually perform a movement. But could it be that, when watching movement—let us say, dance—the brain also engages in a form of motor imagery?

Some years ago, French cognitive neuroscientists Jean Decety and Julie Grèzes did a positron emission tomography (PET) experiment in which people observed a series of hand and arm movements. Participants in the study were instructed either simply to watch the movements or to watch so that they would be able to recognize or imitate the movements after the PET session. This allowed the researchers to investigate the influence of each task on motion processing. It turned out that motor areas were activated no matter what the instructions, but the activation was stronger when participants watched to prepare to imitate the movements.

In another study, Giacomo Rizzolatti's group at the University of Parma showed that observing human movements activates the same muscle groups and motor circuits in the brain as actually executing the movements. So maybe watching movements can be tiring after all. "Why do you look so exhausted?" "I went to see a dance performance."

If motor areas are activated when we watch movements, then we could say that when watching dance, the brain dances. Some caution is warranted, however; the movements in the French study lasted for as little as four seconds and involved only the arms and hands. The results are intriguing, nonetheless. Anna Kisselgoff's review of William Forsythe's *Enemy in the Figure* may have been closer to the truth than she realized.

MIRROR NEURONS

Assuming that the brain engages in motor imagery when we are watching human movement, how and where do motor and visual information come together, and how does knowledge embedded in the motor system influence how we process visual motion?

In 1996, Italian neuroscientist Giacomo Rizzolatti and his colleagues at the University of Parma discovered a group of neurons in the premotor cortex of a monkey that become active both when the monkey performs an action and when it sees another monkey take similar action. These so-called mirror neurons have become the object of intense speculation and research. For one thing, they could provide a neural bridge between action and perception. If they do, they could also provide part of the neural basis for imitation and the understanding of intentions, the latter because by mentally simulating another's actions you can perhaps infer his intentions.[4] That the area in monkeys where the mirror neurons were discovered may correspond to Broca's area in the human brain—one of the brain regions associated with language—added to the excitement. Could mirror neurons somehow be associated with the evolution of language from gestural communication?[5]

Over the past few years, neuroimaging studies have yielded tentative evidence that a similar mirror system exists in the human brain. Marco Iacoboni and his colleagues at UCLA found that if processing in Broca's area was temporarily disrupted with transcranial magnetic stimulation (application of a magnetic field), imitation was impaired—but simple execution of a motor task was not.

In 2001, I was invited to contribute to a television documentary on mirror neurons, for which I created a short dance duet. (Here I am getting a bit ahead of my story by revealing that my explorations of dance and the brain eventually led me into choreography.) The duet began with one dancer copying the movements of the other dancer, then gradually shifted to the dancers changing lead and copying each other's movements but transferring them to another limb, and ended with the dancers taking general cues from each other that were communicated in movement. The piece therefore symbolized a possible route from imitation to gestural communication, but it also enacted it. Although the concept was set and rehearsed in advance, the actual performance was improvised.

HOW TO ENGINEER AUDIENCE ATTENTION

It may sound like a truism to say that choreographers draw the audience's attention primarily to the dancers' movements, not, for example, to the costumes they are wearing. But it also reveals something about the brain and dance. Attention refers to the various processes by which the brain selects among internal and external stimuli. Attention can be "caught" by a sensory event or actively directed at events happening inside or outside our brain. By orienting the senses to the source of a sudden change in the environment, by filtering the information that reaches the senses, by searching for specific clues in the environment, and by preparing for the occurrence of an expected event, attention modulates perception.

Now, catching attention is one thing, keeping it another, especially because the brain exhibits what is called "inhibition of return," a biological bias against looking back to a previously attended situation. This may occur because when the brain first catches sight of something, it extracts all the available useful information. It follows that to catch our attention something has to stand out. To keep our attention, it either has to be more prominent than what might distract us from it or provide for ongoing novelty by altering its appearance, intensity, location, and so forth. Motion therefore has high potential for catching attention.

Under normal circumstances, the brain is likely to focus on the most promising incoming signals, while ignoring all other input. Once an object and its motion characteristics have been detected, attention is likely not to stick with motion but either to shift to something else or focus on other features to try to identify the object: "Is it a fly or a wasp?" Once the object is identified, attention may turn to something else ("It's a fly.") or focus exclusively on the movement ("It's a wasp!"), in which case all other stimuli are temporarily ignored.

It follows that if attention is to focus on movement and movement alone, the brain's natural tendencies in perceiving motion should be enhanced. If the brain is inclined to turn to other features once an object's motion characteristics have been identified, the movement should be such that this tendency is suspended, while at the same time other features (color, patterning) are played down. The brain will then quickly turn away from these features and back to the movement. So if you ever wondered why in many dance performances the costumes are plain and simple, this could be the answer.

How can movement itself be made interesting enough to hold our attention? Choreographers intuitively know the answer. One way of emphasizing movement is to build up and play with the brain's natural tendency to form an expectation of what is coming next. The human body provides an excellent device for this kind of play and by implication for bringing about a sensation of movement. In dance, at any moment the potential is there for the movement to stop, expand, contract, or continue in any other direction. Dance demands an agility of perception equal to the agility of the dancer. The dancer controls a wide range of parameters he or she can vary: speed, direction, the number of limbs involved, rhythm, flow, and so on. By contrast, racing is almost entirely about speed, rather than movement, while in gymnastics the emphasis is on the agility of the body and perfection in the execution of a limited number of movement exercises.

PRINCIPLES OF AESTHETIC EXPERIENCE

Of course, there is more to dance than movement alone, just as there is more to music than sound. In 1999, neuroscientists Vilayanur Ramachandran and William Hirstein published an influential article, “The Science of Art: A Neurological Theory of Aesthetic Experience,” in which they advanced eight supposedly universal principles for the perception and appreciation of art:[6]

1. Enhancement of features that deviate from average (referred to as the “peak-shift effect”);
2. Grouping of related features;
3. Isolation of a particular visual clue;
4. Contrasting of segregated features;
5. Dislike of unnatural perspectives;
6. Perceptual problem solving or deciphering ambiguous scenes;
7. Metaphor;
8. Symmetry.

In the temporal arts, such as music, dance, and cinema, I suggest we could add another principle: the elicitation of patterns of anticipation.

The main principle is the peak-shift effect. Ramachandran and Hirstein claim that exaggerating the essential features of an object will create a quicker and stronger response in the brain of the observer. This is what cartoonists aim at when they draw a caricature, but it may also apply, for example, to Van Gogh’s sunflowers, which by their color evoke the experience of seeing a sunflower more than a naturalistic rendering would do. It may be more difficult, however, to point at a peak-shift effect in something such as Renaissance art or 17th-century landscape paintings, just as it may be difficult to define the essential features of an object. I therefore suggest that an artist does not necessarily exaggerate an essential feature, but exaggerates a feature that then becomes essential in the final creation.

Even though Ramachandran and Hirstein draw their examples from the visual arts, we can apply their principles to dance. Contrast, for instance, can be achieved by the opposition of group and individual, left and right, sitting and standing, and so on. In many Balanchine ballets, the contrast between male and female dancers is enhanced through the costumes: The women wear white pants and black tops, whereas the men wear black pants and white shirts. The perfect synchronization in much classical ballet, as well as in many modern dance performances, can be said to create a peak-shift effect in the grouping of related features. The feet, eye, and finger movements in traditional dances from India are an example both of the isolation of a particular visual clue and of metaphor in the cultural meaning of the gestures.

A problem with this approach to dance analysis is that the moment we move from a simple laboratory experiment to a full dance performance—whether a 10 second solo or an evening-long group piece—so many mechanisms interact that it becomes difficult to untangle the web of connecting lines of explanation. The opening moments of Balanchine’s *Symphony in Three Movements* may serve to illustrate this. Sixteen women are lined up on a diagonal, vigorously swinging their arms. Then suddenly a man jumps onto the stage from the wings with a ferocious leap. In this small fragment, we recognize the interplay of various principles I have described: group vs. individual, male vs. female, left vs. right, contrast in direction and use of space (the male dancer does not walk onto stage, he jumps), and breaking our expectation—even if we know the male dancer is going to jump on stage, it still catches our attention and inadvertently we will look to the side.

Perhaps the best example of a radical disruption of our expectations is at one of those unfortunate moments in a ballet when a dancer falls. Instantly, a sigh goes through the audience, while those who were focusing on something else wonder what happened. What is more, because we know that falling hurts, we can empathize with the dancer, a feeling that has been hypothesized to be mediated by mirror neurons.[4] But here is the interesting part: A choreographer who understands this can put it to creative use by having a dancer intentionally drop to the floor. One of ballet's popular legends is that when one of the dancers fell during the rehearsals for *Serenade* (1935), Balanchine liked the effect so much that he decided to incorporate the fall in the ballet.

This way of analyzing dance also allows us to explain why certain dance performances are boring—for example, because they do not hold our attention by varying from our expectations. Compare your own experience, or what you read in a dance review, with how I have described the processes of attention and expectation. Remember, too, that expectations work not only on the micro scale of individual movements, but also on the more global scale of dance phrases and even whole ballets.

FROM IDEA TO PRACTICE

In 1995, I met William Forsythe, the choreographer and artistic director of the Frankfurt Ballet whose work had made such an impression on me when I had first discovered dance. He encouraged me not just to do research on dance but also to give my ideas a physical reality. It took a while to overcome my qualms, since I am a mathematician and philosopher by education, and at the time was working as a quantitative analyst for an investment bank. Yet I had felt the desire to choreograph since I first saw a dance performance.

When asked how I can choreograph without formal dance training, I respond that what matters is to get the dancers to do what I want them to do. Demonstrating a movement sequence and having the dancers imitate it is but one of many ways of achieving that goal. I make extensive use of cognitive strategies for generating movements and creating a hierarchical or sequential structure within a series of movements. For example, "change the leading movement" means that after the dancer moves, let us say, the left leg, she will move the right arm and subsequently the head, the left shoulder, the hips, and so on. In developing these strategies, I take into account what is known about the workings of the motor and visual systems and the principles of aesthetic experience outlined above.[7] So "change the leading movement" plays with the tendency of the brain to extrapolate a motion trajectory by abruptly breaking off a trajectory and continuing with another limb.

When I started reading about brain science, I bought some popular science books. I quickly found myself yearning for more. Before long, I was reading graduate neuroscience textbooks and then scientific journals. *In Cognitive Neuroscience: The Biology of the Mind*, by Michael Gazzaniga, Richard Ivry, and George Mangun, I read the neurological explanation of the childhood game of trying to pat your head while rubbing your stomach, an example of what is technically known as dual task interference. Our difficulty in performing this task, or in rapidly switching between patting with one hand and rubbing with the other, is probably due to the competition in our brain between the two motor tasks, one of which involves the left hemisphere and the other the right. It seemed clear that this example was a specific case of a more general class of movements and, as such, could be used as a strategy for producing movement in choreography. So the next time I was in the studio with one of my dancers, we explored some extensions of the tasks investigated in the laboratory experiments, such as drawing a line with the right foot and a circle with the left arm or using three limbs instead of two.

This is just one example of applying scientific findings and laboratory experiments to dance. To give another, when reaching for an object such as a spoon, you transform its location from a visual frame of reference ("next to the plate") to a frame of reference relative to your body—roughly speaking, the distance between your hand and the spoon. What is true for objects is also true for parts of the body. If I extend my arm, I can refer to the position of my hand relative to my body but also think of it as being at a point in space. In itself, this is not a dramatic observation, but to return my hand to its previous position, I can either move it back to my body, keeping the body fixed in space, or move my body to my hand, keeping the hand fixed in space, or move both toward each other. The same idea can be applied to movements involving two limbs. I can scratch my arm by moving my finger along my arm or by moving my arm along my finger, a technique I have called "reversals." In everyday life, this is what we do, for example, if a glass is filled to the top: Rather than bringing it to our mouth, we bend forward to sip from it.

When improvising, dancers can use these ideas to create a variation on a choreographed movement sequence. As "recipes" or techniques for generating movements, they are not specific to my work, but can also be found in other dance forms, everyday movements, and martial arts—what else is the movement following a feint other than a sudden change of the leading movement? These techniques, too, do not tell the whole story. I always say that my work arises from the tension between this formal approach, based on my scientific research, and my own aesthetic ideas and preferences.

JUDGING THE RESULTS

Choreography is not just about inventing movements, it is about evaluating the perceptual and emotional effects of a particular movement or spatial configuration. Choreographers continue adjusting a certain movement or position until it matches the effect they had in mind (or until the day of the premiere). The same is true for dancers as they watch their movements in the studio mirror or on video or rehearse a movement until their bodies' proprioceptive feedback informs them that the movement "feels right." In doing so, both choreographers and dancers are guided by the brain mechanisms involved in perception, action, and emotion. This is why the British neuroscientist Semir Zeki says that, in a way, all artists are neuroscientists. They investigate the properties of the brain and reveal its capabilities.

The logic of the present argument may also explain why people's experiences of a given dance performance differ. Having seen a fascinating performance, we expect to be as thrilled the next time we see a piece by the same choreographer. Indeed, this is why we want to return, to get another dose of that good feeling. Conversely, if we were bored, we are less inclined to go again. What we have seen has not only raised (or downgraded) our expectations of what we will feel, it has also entrained our perceptual expectations.

When creating a new work, choreographers can either try to replicate the perceptual and emotional effects of the previous work or explore a different direction. Both approaches have their pluses and minuses. If a choreographer continues along the lines of previous work, new audiences may still be thrilled and so may part of the old audience. Some people, however, may be disappointed: Their perceptual expectations were met, but their emotional expectations were not. This is why many sequels disappoint. But seeing the same piece again may in fact be more engaging, even though we are now familiar with it. We may attend to different aspects or get excited in anticipation, or maybe the performance was simply better at triggering our responses. As to our choreographer, should he decide to explore a different path, he may not only alienate part of the audience, he may also quite simply fail in that the piece does not live up to his own expectations. That is the risk of any experiment, whether artistic or scientific.

Of course, this is not the only reason why people differ in their aesthetic judgments. Appreciating something cognitively and enjoying it emotionally are not the same. Each person's individual experience of a dance performance is the product not just of perceptual processes, but also of their interaction with memories, associations, and personal preferences. As I like to say, with a nod to my former career in finance: "Past performances are not a guide to future experiences." Time may distort the memory of past performances. Experiences, tastes, and preferences may change over time. But then again, these memories and preferences are also laid down in the brain. Their content may change over time or differ among individuals, but the brain processes that connect them are the same.

Back in the laboratory, neuroscientists are probing the neural mechanisms of human motion perception and motor control, moving beyond studying simple finger movements to more complex stimuli and motor tasks. In effect, they are becoming choreographers of certain movement sequences. If choreographers and dancers performed in research laboratories and neuroscientists analyzed dance performances, we might learn more about both dance and the brain. But whether you are dancing yourself or watching a dance performance, even when your limbs do not move, your brain will dance.

EPILOGUE: COMING FULL CIRCLE

In the spring of 2004, a dream will come true: At the invitation of William Forsythe, I will create a new work for the Frankfurt Ballet. Little did I know, on that memorable day in Paris more than 10 years ago, that one day this company, which has had such a profound effect on me, would literally perform my thoughts.

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