The Dancer in Nature

by

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ABSTRACT

A rich body of science has grown up around the art of dance. It includes study of a dancer's relationship to Newtonian physics, dance medicine, the role of the spine in balance, and the emerging study of the neuroscience of dance. The thesis integrates personal narrative and descriptions of dance performances with scientific discussion of the art form. Greater scientific understanding of the art of dance is needed in order to improve teaching practices and decrease injuries to dancers.

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Dedication

A small offering to the memory of Kevin Granata,
who was kind and interested, and gave generously of his time.

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The Dancer in Nature

Simple Machines

The rough-and-tumble choreographer Elizabeth Streb watches from the shadows in the auditorium of the Institute of Contemporary Art in Boston, while two of her dancers struggle on stage below like competitors in a three-legged race gone wrong. The name of the dance, "Tied," is literal, and deeAnn Nelson and Fabio Tavares rush away from each other again and again, only to snap to a midair stop when they reach the ends of the cord connecting them waist to waist.

Streb seems oblivious to the sold-out crowd, which groans sympathetically each time one of the dancers crashes to the floor or gets dragged by the other. Her spiked, dyed-dark hair sticks up from a face dominated by glasses with thick, plastic frames. She is tall and lanky, wearing a T-shirt and baggy pants. Her 57 years don't show unless you're close enough to see the lines on her face. Her hands are softer than you would expect from a woman known for running full-speed into walls.

Strings play the music of tragedy. Tavares slides, his face down on the floor, as Nelson hauls in cord as if he were a ship's anchor. Soon, another leap. Nelson grunts as the cord catches her body, and she is down again.

The name of the show, "Streb vs. Gravity," is also literal. In the arena of forces, a projection declared before the dances began, "the heavyweight is gravity."

"I'm disappointed that we humans can't fly yet," Streb told choreographer Garry Reigenborn in an interview for the New York Academy of Sciences. "... My battle cry is that we can at least try to defy physics." She won a MacArthur "Genius" grant in 1997 for her efforts to teach dancers to fly, but sometimes Streb's talk of flying gets lost in her love of the sound of flesh against floor.

In an earlier dance, called "Crash," the dancers dove into the floor as if it were a lake. They flung themselves fearlessly into the air, the projector cataloguing the impact of their bonecrushing landings, displaying calculations of acceleration due to gravity, and the compression in their joints as they made contact with the earth.

From the audience, I get the bravado loud and clear. I see the fighters facing off across the ring. But watching Streb's face in the shadows, I have no idea if she thinks she is winning or losing the match.

This is not the dance I experienced in high school. The members of Avant Garde, DeLand High School's varsity dance team, did not look like warriors battling implacable natural laws. They were high-school royalty, and the toned muscles of their backs rippled smoothly as they transcended the awkwardness I felt in my own body. Words tangled through my poetry notebook as I tried to express longing, joy, sensuality and confusion. Then, as I sat in the dark and noisy school auditorium, I saw these girls, bathed in light, expressing all I wanted to say with a simple motion of the hand. I watched but could not imitate, my face pressed against the glass of grace.

My sister Rose joined Avant Garde when she got to high school. For years, I had loved watching her dance. Mostly self-taught, she spent hours in our living room choreographing to Tori Amos songs. We often compared notes on our arts. I learned the need for technique in writing from watching her coordinate arms, legs, the mood of a song and its beat. I admired the determination and love with which she danced, unfazed by having started later than the other girls, not intimidated by the private lessons many of the other girls' families could afford to send them to. When I saw her onstage with Avant Garde, my pride for her brought tears to my eyes.

Then I began to learn the price of the grace I admired. I saw the dancers' callused feet and bruised knees. Rose's lower back started spasming during shows. Encouraged to push herself, she danced through the pain. From the audience, I could never tell when she was hurting, since she always kept the performer's smile on her face. Her back injury later forced her to drop out of a show with the community college dance team. Now, six years since the injury appeared, it remains an obstacle to practicing the art she loves.

Streb designs dances that pull this dark side of dance into the spotlight. She makes sure the audience knows what her "action hero" dancers have to face. Her choreography reveals the force hidden in their movements, and the risk of moving at all. At the same time, she seems to invite the kind of injury my sister suffered, courting disaster even as she reveals a dancer's heroism for facing it.

From where I sit, "Tied" and "Crash" underline Newton's crushing Third Law: "To every action there is always opposed an equal reaction." Newton explained it this way: "Whatever draws or presses another is as much drawn or pressed by that other. If you press a stone with your finger, the finger is also pressed by the stone. If a horse draws a stone tied to a rope, the horse … will be equally drawn back towards the stone."

On a visit I made last October to Streb's studio in Brooklyn, called the SLAM Action Laboratory, Newton's Third Law ruled like a tyrant over every dance, even the ones that weren't about one body straining against another. I walked into the "laboratory," a warehouse that used to be a mustard factory, and saw Nelson suspended from the ceiling, a harness belted to her pelvis. Dancer Ami Ipapo lifted and lowered her by working the controls on an industrial hoist, and Nelson's body swung in circles, the cord that held her up winding and unwinding around a pole in the center of the dance floor.

Streb called this "flying," and talked about putting Nelson on "new ground" – the pole, not the earth, became the floor. But Nelson's face turned redder and redder, and she grunted, gasped, and cried out, until dancer Terry Dean Bartlett asked if he could let her down.

"How come?" Streb asked, looking up placidly from the choreographic notes she had been scribbling. "What's going on?"

"She's been hanging upside down for 15 minutes," he said.

"Oh," Streb said. "Of course."

Nelson, once released from the harness, came over to where I sat with Streb. She panted, her face, neck and chest still pink from increased bloodflow. Short and well-muscled, brown hair sharply cut to stay out of her face, Nelson looked too thick and

powerful to have been the "prima ballerina" for anyone but Streb. She pulled down the waistband of her pants and showed me the raw welt the harness left on her right hip.

As her body pressed down against the harness, the harness pressed back up into her hip. Whichever direction Nelson's feet may have been pointing, her blood was never confused about which way was down.

Later, Streb told me her dances "are about surviving in a mean world riddled with physical truths."

"What are you really doing in normal dancing?" she said. "It's … geared to make me impressed – it's an issue of demonstrating privilege. The dancer has a straight back – it's aristocratic. … My dances are working class – so it's hard. … It may not look elegant, because I want to show that it's not elegant."

She sometimes calls these inelegant movements "experiments," though they are experiments in the sense that a child may experiment with a hot stove. They are experiments in classical physics, exploring the consequences of crashing, jumping, colliding and flinging a (human) projectile. Her experimental equipment are a series of contraptions she engineers and builds: the hoist that lifted Nelson; an arrangement of swinging concrete blocks; a human-sized hamster wheel; and "Tip," a hollow half-wheel that rocks back and forth on its round side while Streb's dancers balance on the flat surface above. They are simple machines – wheels, levers, pulleys and pendulums – that Streb uses as a sort of physics class for the hard-headed.

At the Boston show, it's time for the finale. The speakers play the theme from the movie *2001*, and the human-sized hamster wheel is revealed. Screens rise away from a picture window behind the wheel and sunlight floods the dark auditorium, while glittering shards of it dance over Boston Harbor, spreading out wide and blue just beyond.

The dancers board the wheel in inadvisable ways, leaping on and off as it spins. They flatten themselves inside so it seems only centrifugal force holds them in place. They run on top of the wheel, or cling flattened to the outside through full rotations.

A crowd gathers on the other side of the window, peering into the darkness at the strange sight, becoming part of the show for the audience inside. Streb couldn't have

planned it better – the confusion and wonder on their faces testify to the craziness of the whole idea of Streb, and also to her appeal. Though she presents herself as a rebel against the forces of nature, and uses her art to highlight the effort in humanity's struggle, the sight of the wheel against the backdrop of sun and ocean and wondering humans drives home the point that Streb's dancers only accomplish what they do with nature as a partner. For all that I feel sympathetic pains each time a dancer smacks against the floor or a moving object, only the predictability of the laws of classical physics makes Streb's work safe at all. Nature is her partner, not her enemy, and her dancers triumph only so much as they are parts of nature moving exactly as predicted, as simple machines obeying simple laws.

Dancing with the Floor

Kenneth Laws curls his lip when I mention Streb's name to him. He is a physicist retired from Dickinson College in Pennsylvania whose passion is studying the physics of dance. I tell him I've been to see Streb, and Laws bursts out, "That isn't dance!"

Laws is in love with the form and discipline of ballet. The affair started in 1975, when he was 40. When his children wanted to take ballet at 5 and 7, Laws didn't want to be left out. He started taking classes, too, and became deeply involved with the Central Pennsylvania Youth Ballet. He soon found himself standing in the wings offstage, tears streaming down his face, overwhelmed by beauty. By the time he was 50, he was taking eight to ten ballet classes a week. By now, he has taken more than 5,000 classes.

Streb offends Laws' aesthetic sensibilities by being rough and dangerous, and by tossing out ballet's concern for smooth, graceful motion. But once the aesthetic disagreement is out of the way, the two seem cut from the same cloth. Both look to Newton's laws as the core of beauty in dance. Both work to reveal it.

It wasn't until he had been dancing a few years, Laws said, "that I suddenly looked around and realized that a dance studio is really a physics laboratory." Laws' two

loves merged, and he has since become the man to see for anyone interested in physics and dance.

He has published three books and more than 30 articles on the subject. When he began, he worked with Lisa de Ribere, who has danced with the New York City Ballet and the American Ballet Theater. As I sit with Laws in the library at Dickinson, he points across the street to the cupola where he and de Ribere performed those experiments with makeshift materials. To learn how de Ribere built up the torque needed to perform turns, Laws had her dance on a plate he made from bands of conductive material. He wrapped her feet in aluminum foil, so they could connect the bands and complete the circuits. When de Ribere's foot was flat on the plate, electricity flowed. She also held a cord that pulled out from its spool when she turned. By measuring how much the cord unwound, and how much electricity flowed, Laws studied how de Ribere used contact with the floor to accomplish turns of different degrees.

As with all of Laws' work on dance, the experiment was not designed to come up with new laws to add to the body of theoretical physics, but about seeing how existing laws come into play. Though dance, and particularly ballet, has a long tradition of rigorous training to develop technique, Laws is interested in how those techniques harness physical forces. He gets insight into the beauty behind the tradition, but also into the realities of training. Laws says he has often observed dance teachers giving students physically impossible instructions.

One example is the tour jete, a formidable high speed move which calls for a dancer to launch into the air and flip 180 degrees. The dancer kicks his left leg up, jumps, rises, and spins, landing on his left leg, right leg extended straight behind him in an arabesque. According to Laws, a dance teacher might tell a student, "Square your shoulders and hips! The turn is most brilliant when you rise straight up and then start to turn right at the peak of the jump!"

When Laws began to analyze this instruction, he realized there was a problem. Without an outside force at work, it's impossible for the body to begin turning in mid-air. Instead, he concluded, the move must be an illusion. The dancer must begin his turn on

the ground, when he is able to push against the floor and be pushed by it in return. Then he conceals the turn until the height of the jump.

Laws benefited from his analysis by being the first in his class to manage a tour jete, in spite of the disadvantage of his age. Many students now achieve that understanding through trial and error, Laws says, and this is an invitation to injury. A student who tries 100 times to fling himself into a tour jete, without understanding the physics at play, is much more likely to be hurt than a student who knows exactly what must be done with his body and gets the move right after only 10 or 20 tries.

Streb's studies the physics at play in a dance by slamming a dancer into the wall or the floor. Laws shudders at this, but he too finds significance in how a dancer contacts the surfaces around her.

Laws sees Newton's Third Law in action like this: when a dancer jumps, she pushes against the floor and the floor pushes back at her. She can only get off the ground by cooperating with it. If she dances alone, Laws says, the floor is the only thing that can push her in the directions she wants to go.

"Your interactions with the floor become inherent, absorbed in the body automatically," he says.

There is a photograph of Cynthia Harvey, formerly a principal dancer with the American Ballet Theatre, taken mid-jump by famous dance photographer Martha Swope. Harvey is several feet in the air, head and arms flung back in a gesture of absolute freedom. She is on the way down, and her right leg leads toward the floor to catch her when she finishes the leap, while her left leg rises behind her toward the sky.

The picture captures a moment both an artist and a mathematician would love. She holds a position of angles and perfect lines. Her legs align to a 45-degree angle with the floor, and her arms are parallel to her legs. Her legs are the diameter of a semicircle formed by the skirt of her pink dress. Her face is a mix of triumph and exhilaration.

Though the move clearly requires an athlete at the top of her form, no hair is out of place on Harvey's head. She wears the severe bun of the ballet dancer, white earrings dangle from her ears, and her eyelashes have been lovingly curled. She embodies the aristocratic image Elizabeth Streb criticizes in ballet. Instead of the image Streb creates

for her dancers - desperate warriors up against inexorable larger forces - Harvey represents the gentle illusion of a woman who can float free of physical laws. Harvey represents a triumph of humanity. *We can fly after all,* her face in the picture seems to say, *it's not even very difficult.* But Laws, who co-wrote *Physics, Dance and the Pas de Deux* with Harvey, would say Harvey's freedom depends on how Harvey pushed against the floor as she left the ground.

To feel the way my body interacts with the floor, I try an experiment Kenneth Laws suggests. I stand straight and start to let myself fall. I am supposed to resist the urge to step forward to save myself, instead watching other reactions my body uses to keep from falling.

I shift my weight forward, rising onto my toes and becoming unstable. The muscles in my feet tense as I start to tip, fighting the shift that threatens to send me over. Several times, I can't resist taking the step.

I begin to fall when I shift my weight so my center of gravity is no longer above my feet. The position of the center of gravity is the secret to all balance. It is how ballerinas stand on the tiny surface area of their toes. So long as the weight of an object is centered so the downward force on that weight is above a surface in contact with the floor, the object is stable. The principle is true for any object, including a person, though it is more complicated in irregular shapes.

When I finally do let myself fall, I get the result Laws predicts. My body bends forward at the waist, and my arms spin forward. I practice several times. Moving that way consciously, it gets easier to avoid a fall.

To keep from falling, what I need is to move my center of gravity back to where it was, above my feet. However, as Laws explains it, only a force from the outside world can do that. Gravity can pull me down, or the floor can push me up, but I can do neither on my own.

I saw the importance of the floor as a dancer's hidden partner at the Somerville Theater in Davis Square, where the contemporary dance troupe BoSoma was performing. While the main theater is gorgeous, built with the opulent decorations that were popular when going to the movies was an elegant thing to do, it's decaying. The balcony seats

were difficult to open, and, as I took mine, I looked down at the stage and wondered about the floor.

A few days later, Audrey Lavallee, who dances with BoSoma, told me she couldn't manage to dance the choreography as planned on that floor, and, instead of going barefoot as she customarily does while performing, was forced to wear ballet slippers. Not only was the floor rough and splintered, threatening direct damage to her feet, its expanse was unpredictable, returning differing amounts of force as she moved across it. For certain parts of the dance, she says, she was forced to improvise through sections of choreography she wasn't able to perform with that floor.

"The floor," Richard Wood says, "is [a dancer's] instrument." There's a very individual, personal relationship with the floor.

Wood and his partner, Peter Colao, run Wooden Kiwi, a business devoted to building dance floors. Wood is thin, wears an earring, and tends to ramble. His partner, despite an easy, jovial manner, cuts straight to the chase.

Colao brings over a square foot sample of floor. He shows me the surface, smooth enough to slide on, but not so smooth that a dancer can't keep her footing. I stand on it and feel it responding to my weight.

He says he and his partner think of a dance floor like a drum head or a diaphragm. Attaching the perimeter of the dance floor to the existing subfloor, the rest of the floor is left "floating" - responding to a dancer's feet with a predictable sort of give. Colao says they think of elasticity both at any given point and over the area. The goal is to make a floor that behaves with the same elasticity throughout, with no hard or soft spots. "We try to make it as consistent, understandable and predictable as possible."

These men have put dance floors in most of the venues in Boston, it seems, including Green Street Studios in Cambridge, a well-known dance space dedicated to supporting local dancers and choreographers. While they say they have no standard dance floor design, they hand me representative bits of foam and wood. Each bit of floor, Colao says, is fit together and cushioned so there isn't any tilt when a dancer steps on a seam.

After seeing BoSoma at the Somerville Theater, I saw them again at Green Street Studios, where the soft, clean, rhythmic slap of the dancers' feet, hands and bodies on the

floor were part of the beauty of the show. There, I saw a precision in them that escaped them in the old theater in Davis Square. The floor as representative of Elizabeth Streb's old enemies, the laws of physics: It holds a dancer, responds to her, and pushes in answer to her cues, as the principal dancer in plain sight, the hand of nature holding the dance in its palm.

Killing the Body

Laws is an old man, and his body is beat up. The physicist had back surgery last October from which he still has not recovered, leaving him unable to dance, though not unable to talk about the art form he loves.

I meet him in his office at Dickinson College, a clean, modern building encased in an ancient-looking facade in the small Pennsylvania town of Carlisle. He stands and is unable to straighten, taking a good foot off what would have been a tall frame. The steel-blue eyes and strong features I had noticed in photographs from when he was younger are hidden in the depths of an old man's beard. I want to cry for him.

Laws is bent by the very forces he studies, plus the decay that is so much a part of living. After 70 years of standing against gravity, any body begins to break down. For dancers, whose fight against gravity is more strenuous than most, their bodies often collapse much sooner.

In Laws' books, helpful diagrams detail the equations and models he used to calculate the forces a body harnesses and interacts with in a dance. After reading through several of these descriptions, one thing becomes clear. The models are oversimplified. They are a set of lines and angles, and not nearly enough of them. The figure in the stylized diagrams looks more like a clothespin doll than a woman. When a physicist says "body," he doesn't mean flesh and blood. He is usually talking about a formless blob of matter in a frictionless environment that behaves according to ideal laws. This is not the way a dancer experiences physics. Physical forces are making her pulse race, her pores

sweat and her adrenaline pump. And physical forces, when they become an enemy, will sometimes break the complicated machine she uses as the medium for her art.

No one knows when ballerinas began dancing en pointe – balanced on the tips of their toes – but it was sometime at the beginning of the 19th century. Marie Taglioni, a ballerina famous for grace and weightlessness, rose onto her toes for *La Sylphide* in 1832.

In the years since, pointe work has become a staple of classical ballet, requiring ballerinas to learn delicate balance, power and control. As pointe work has gone from being the exception to the rule, its demands have grown, from what were probably motionless poses in Taglioni's time to the traveling spins in today's ballet.

Pointe work can seem brutally unnatural. The dancer rises to balance on the ends of her toes, her feet curving forward under the weight of her body, to create a long, aesthetically pleasing line for the leg. With the help of a little technology – special pointe shoes, stiffened with glue around the toes to hold the shoe in shape – and a lot of control, the dancer walks and spins and turns in a position no one would choose for convenience.

Even the most accomplished ballerinas show the strain of difficult pointe work. Sofiane Sylve, a principal dancer with the New York City Ballet, visibly wobbled through one performance of the Rose Adagio in Peter Wright's *Sleeping Beauty*. The French ballerina, known for her grace and fuller figure, danced the title role of Aurora. The choreography called for her to stand en pointe in attitude, with one leg lifted behind her, waist-high, and bent at the knee. While in that position, each of her five suitors took her hand in turn and rotated her in a complete circle. Each time a suitor released her, Sylve barely clung to her balance, moving her arms from side to side to keep herself from falling. By the time the last suitor released her, Sylve dropped out of the pose as if, in a half second more, she would have tumbled to the floor.

To me, the most amazing thing about pointe work is not that it can be done at all, but that something so difficult and unusual for the body could have become an expectation for every accomplished ballerina. Dancing en pointe can yield a gruesome list of physical ailments, including cuts, bunions, bruised toenails, and deformations of the bones in the feet. Though pioneering University of Utah dance kinesiologist Sally Fitt held that it was insanity to start pointe work before the age of 12, a girl who shows

special promise may be rushed to start as early as 9, before her bones have hardened enough to hold their shape under the strain of the technique. The result, as Chicago Dance Supply pointe shoe fitter April Lewis puts it, can be "shoes that mold your foot." The dancers with the most talent, ironically, are the most likely to be tempted to start pointe work at an age when it runs the greatest risk of damaging them.

Even if the dancer starts pointe work at exactly the age recommended, she still regularly places her weight on the points of her toes, which did not develop to be used in that way. The day after day effort has its effect. Professional dancers train incessantly. While any repeated motion can cause injury – such as the types of finger movements that can cause carpal tunnel syndrome – a dancer constantly repeats especially stressful movements.

Though many dancers still suffer shortened careers due to injuries, a growing number of experts are calling for an approach to dance that they say will allow dancers access to the most challenging moves, without breaking them apart in the process.

"Even though dancers do extreme things, they need adaptation to do it," University of Califonia Santa Cruz dance professor Ruth Solomon says. Though Solomon is a dancer in her own right, and has performed on and off Broadway and with the Jean Erdman Dance Theater Company, in recent years her work has led her to focus on dance medicine. Working with Lyle Micheli of Children's Hospital in Boston, Solomon made an extended study of the Boston Ballet that showed the value of preventive dance medicine. The marked decrease in injuries at the ballet through the course of the study influenced companies across the country to provide dancers with care before injury happens. Much of Solomon's teaching is now aimed at counteracting the idea that it's all right to be in pain while dancing.

Solomon agrees with Fitt's assessment that pointe work devastates when started too young. Another cause of injury, she says, is the desire for 180-degree turnout – the ability to stand with the heels together and the toes pointed outwards in opposite directions. Though 180-degree turnout is thought to be an aesthetically appealing ballet position, Solomon says, "I have never seen a dancer in which the 180-degree turnout was good for the body. … They can force it, but it's not anything they can do naturally."

According to Solomon, the fall of the Soviet Union brought a wave of dance teachers to the United States who had been trained to accept no turnout less than 180 degrees, causing an increase in injury. Dancers can force turnout by stretching ligaments rather than muscle, which is dangerous because ligaments do not return to their original position once stretched. They can increase their appearance of turnout by turning the knee and ankle in addition to the hip. Torque on the knee and ankle adds stress to those areas in addition to the existing stress of bearing weight. Over time, the combined, more powerful stress, can cause trauma to the foot or knee.

This leads to other, unforeseen results: microtrauma injuries, caused over time by small, repeated unsafe movements; spectacular injuries, such as broken ankles or compressed vertebrae; and shortened careers. Solomon says she tells dancers, "It's your body. You're going to live with it for the rest of your life. [Your teachers and choreographers] are not."

Rhonda Ryman, whose master's thesis work at York University in the 1970s was one of the early attempts to unite science with dance, also spoke passionately about the risks dancers assume by attempting to force themselves to achieve desired positions.

Ryman described the history of the arabesque. In an arabesque, a dancer lifts one straight leg behind her and holds it there, a move that requires well-developed lower back muscles. A hundred years ago, when a dancer performed an arabesque, Ryman says, the leg was typically lifted until it was perpendicular to the body. Now, the leg is often lifted to 180 degrees, parallel to the body, leaving the dancer doing a standing split.

Some dancers, according to Ryman, do have the flexibility and muscle to pull off a move like that. Others don't. These others, when required to do this move, sometimes find ways of twisting the hip to simulate the appearance of a true arabesque. Sometimes, the cheat they discover is harmless, and other times harmful. "You don't know that until a few years later when you crack a vertebra," Ryman says.

But "to gain range of motion and gain the facility to do the kinds of things a dancer has to do, you don't have to do damage," Solomon says. "You've got to believe that, and a lot of people don't believe that."

The key to safety, she says, is to recognize the individual differences in dancers' bodies, and be aware of them when training and choreographing. Though the idea may sound obvious, Ryman explains that it's a revolution in a field where, for a long time, there were few differences in dancers' bodies because dancers were selected on the basis of having specific body types.

"Teachers are not prepared to accept those [individual] differences very readily," Solomon says.

According to Ryman, some of the reason for this lies in how dance is communicated. It has always been difficult to produce a thorough written specification for all that goes on in a particular dance move such as the arabesque, and video was not available until recently. For most of the history of dance, teachers have passed on information about the technique of the arabesque by consulting their own muscle memories and comparing it to what they see in their students. Considering that method, Ryman says, it is natural for teachers to expect their students to perform dance moves exactly the way they themselves perform them.

To give a dancer a chance at a long career, Solomon says, practices must change so teachers and choreographers work within the capabilities of an individual dancer's body, and that dancer knows what her capabilities are. "It all comes down to knowledge," she says. But the line between improving and training the body to achieve greater heights and burning the body out in a blaze of impossible glory is a battleground for dance experts.

Elizabeth Streb's dancers often seem to be surviving injuries rather than dancing.. I write to ask her about Streb vs. Gravity. Who wins? She writes back, "Streb wins. Anyone who willingly walks into Gravity's vectors and can take the intense hits ... wins. That's just the way it is. Bruised, Battered, Triumphant. That's us." A general intent on Pyrrhic victory, Streb makes her dancers adapt to her brutal routines.

The adaptation seems possible - Streb does, after all, have a company, though she admits her worker's compensation premiums are very high - but Solomon wonders if it is worthwhile. "She is so articulate, and she can justify everything she does, but it makes no sense to me. Her dancers get killed, no matter what they say."

Solomon recalls a residency she did at the University of Wisconsin, when she shared a group of dancers with Streb. Solomon says she was preparing the dancers for an upcoming show. They appeared on Tuesday night for rehearsal, having had a class with Streb the day before. "They couldn't walk, they couldn't bend over, they couldn't do anything," Solomon says. "... and for what? I'm not sure what they learned. ... There was no reason to beat them to a pulp like that."

When Solomon talks about Streb, her voice rises. While making it clear she respects Streb's intelligence and artistry, it is also clear she finds Streb's swashbuckling risks unconscionable. "When it translates to the movement, it's got to have more of a point than, 'How much damage can you do to the body without dying?'"

Both the development of classical ballet technique and choreography like Streb's reveal a trend dancers have begun to notice. "Just as the level of difficulty in dance technique has increased with time, so have the physical demands of a performing career," noted dance teachers Andrea Watkins and Priscilla Clarkson write in their book, *Dancing Longer, Dancing Stronger*. There's a lot of temptation for dancers to push to the point of stress fracture trying to force a spectacular extension.

But Solomon is not saying dancers shouldn't take risks. "I don't know what safe movement is," she says, "because I don't think a dancer or a choreographer should 'stay safe.' I think they should move intelligently."

What is that intelligent motion? My sister Rose offers one example of what it's not. As an adult, she says, she monitors her body while stretching, remembering that gentle progress is most likely to give her lasting flexibility. But with her high school dance team, she says she often felt a competitive spirit between herself and the other girls. Whose split was the most impressive? Who could stretch the farthest? Rose says she was often tempted to bounce in a stretch or force the last inch for the sake of impressing the other dancers.

"Most dancers will do anything to produce a result," Solomon says.

Rose says she wishes she'd had the training to adapt her stretching regimen to the current requirements of her dance routines. If she'd known to stretch her back and neck

more carefully before performing a dance that called for a back somersault, she says, she might not have injured her lower back.

If you'd gone to college for dance, you would have learned this stuff then, I tell her. You probably would have had class with a Ruth Solomon or an Andrea Watkins, who would have taught you how to take care of yourself. But it would have been too late then. You would already have been dealing with this injury.

As I speak, I know why writing about dance matters to *me*, someone who can hardly walk down the street without twisting her ankle. As a writer, the instruments of my art are pen and paper, computer and imagination. I have a good chance of being able to write until I die, never stopped by old age or injury. But a dancer's instrument is the body, and any mistake barely conceals the threat of a dead career.

Is it over? I ask Rose. Once you get injured, are you done?

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I sit down for coffee one day with Matthew Grierson, a medical student at Harvard who recently won awards for the dance he choreographed about the doctor-patient relationship. The coffee shop is loud and crowded, and it is hard to spot Grierson when I walk in, since he hunches in a corner over a laptop computer. He has a slight frame, large dark eyes, and a careful voice.

"Lots of dance medicine comes from fixing problems created by teachers of young dancers," he says.

But though Grierson is aware of the potential brutality of dance, he sees another side as well. In dance, he says, "a lot of personal research goes on." The dialogue between a dancer and his body, he says, made him realize there's not a lot of difference between dance and medicine - each is a way of coming to terms with a body's capabilities and learning what can be done in a life.

By way of explanation, he opens his laptop and plays a copy of *Outside In*, an award-winning dance movie by the British choreographer Victoria Marks. He tells me nothing of what to expect, and so, as the music begins, I sit with my hands in my lap,

peering into the laptop screen. The dancers sit in a row, and the camera focuses on each one in turn as they pass an invisible object down the line. Each dancer uses face and gesture to express his unique relation to the object. The faces and gestures are so interesting that it is only when the camera pulls back that I realize many of the dancers are missing legs and arms.

"Next comes the legless tango," Grierson whispers excitedly. I'm repulsed by his words, but the sight is different. A man with no legs balances on the palms of his hands, tracing the pattern of a tango on the floor. Opposite him, a woman with no obvious disability mirrors his steps. They approach one another, and the dance begins, replete with the usual tension and sexuality of a tango. The man is agile, and, after a few moments, I realize he is using his body in a way a man with legs could never use his. He swings in one motion over a barrier. He vaults and climbs. His body is both light and forceful as he leaps into the woman's arms.

"Being willing to modify movement for specific dancers is an important skill," Grierson had told me a moment before, but I hadn't had anything as spectacular as this in mind. The dance company, he explains now, is CandoCo. After losing limbs, he says, these people are questioning everything, and now dance has helped them redefine their identities.

I see that a dancer can adapt his art to the strengths of his particular body, the instrument of his expression. The body is plastic - changeable. The ballerina can train herself to rise onto the tips of her toes, and a man can learn to dance on the palms of his hands.

Quick Reactions

The intelligence of the body's motion is often barely conscious, the stored result of years of training, layered over natural instincts. Muscles make a thousand tiny corrections to hold a balanced position. Muscle memory and reflexes direct those corrections.

April Lewis fits pointe shoes at Chicago Dance Supply, running the dancers through a set of tests to make sure they are ready for the physical stress of adapting to the

strange new way of carrying the body's weight. Though she recommends a dance teacher always help a student decide when the time is right to go en pointe, she says she often catches problems with a simple glance.

When a student comes in for a fitting, Lewis positions her before a barre and mirror, and asks her to stand in parallel, with both feet facing the same direction, and lift to releve, standing on the bottoms of the toes. "They'll do whatever their muscle memory tells them to do, and that'll tell on them," she says. If they are well-prepared for pointe work, Lewis will see their heels in a straight line with the rest of their legs. If not, she will see a curved line as the ankles bow out or in.

Lewis's examination goes far beyond the feet. "We look up as far as the top of the head looking for proper alignment," she says. Among other things, Lewis checks to see the neck is held long, shoulders square, stomach pulled up, and the tailbone dropped. Though proper alignment may sound simple, it actually takes well-trained muscles.

As dance scientist Rhonda Ryman writes, a human body is never passively in balance. Kenneth Laws can compare the human dancer to various inanimate objects balancing or rotating for the purposes of his models, but in real life, the dancer is not a model, and there is a difference between the balance of an inanimate object and the balance of a dancer. The realities of a living thing assert themselves – the bone and blood and muscle. Ryman analyzed the body's musculoskeletal structure to describe an ideal upright posture. Even in that perfect posture, though it is desirable for the bones of the skeleton to balance on top of each other as much as possible, muscles must always be engaged to hold the body up. Ryman points particularly to the head, the weight of which requires constant support from the neck muscles. The tilt of the pelvis forces the spine to curve, preventing it from being a straight pillar of support.

In other words, no upright body position is completely ideal, completely relaxed, completely free of strain. The reflexes of the spine prove to have a big role in keeping a dancer in the lovely, straight, poised position for which ballet is known.

Kevin Granata studies spinal reflexes in the theoretical mechanics lab at Virginia Tech. A slim, gentlemanly figure, Granata leads me downstairs to the lab in Norris Hall, which I will tour as he goes out for a run. His graduate student Greg Slota is stocky, with

a carpenter's hands and love of woodworking. While enthusiastic about work in the lab, Slota is at his best when talking about the machines he helped Granata design to test the ways of the spine. The lab is full of contraptions - machines for measuring how a person is able to maintain balance and stability under various types of duress. Slota is familiar with the details of constructing each one. He built many of them to specifications after a trip to Home Depot and a raid on discarded devices already in the lab.

In one study, Granata's team examined how subjects were able to keep the spine straight under stress. They used one of Slota's contraptions to hold a test subject's lower body immobile while he was linked by a length of elastic to a motor that tugged his upper body in random directions. The idea was to throw the person off balance so that changes happened too quickly for him to think out his response to each jerk from the motor. The reflexes took over, and Granata's team was able to measure what the reflexes do to keep a person in balance. By hooking their subjects up to a device that recorded electrical reflex responses by means of electrodes, they were able to determine how the reflexes are affected by various degrees of muscle tension and flexibility. To see how muscle stiffness (such as that experienced by someone tense or by someone exerting the muscles consciously) affected the situation, they tested some subjects unencumbered, and some while hooked to a weight that required them to keep their back muscles engaged. They found fewer electrical responses from the reflexes when the muscles were already active. Their results support Kenneth Laws's suggestion that the looser a person's body, the better his reflexes can make small adjustments to balance and the lower his chance of injury.

Slota's baby is the wobble chair, a contraption he personally built and programmed. It is designed to isolate the trunk, so the upper body's capacity for balance can be measured. It resembles a pogo ball on a board. The subject sits on the pogo ball, and a display in front of him shows with a bull's eye diagram whether he is evenly balanced. Try to maintain balance, the subject is told, but the chair is constructed so he cannot maintain this balance without muscular exertion. The researchers can then adjust and tilt the chair to make it more and more difficult for the subject to stay upright, and, in doing so, they can test the limits of the trunk's ability to keep the body stable.

To get a fuller understanding of how the spine holds the body upright, Slota says, the team tests people who are fresh and well-prepared, as well as people they fatigue first through exertion or vibration. Since they don't want to test subjects to the point of injury, researchers conduct experiments in a limited range and construct computer models that can tell them the rest of what they need to know.

Later, Granata shows me what his team learned from the computer models, balancing a pen on his desk. If you wanted to hold this pen up, he says, one way to do it would be to attach a bunch of rubber bands to it and anchor them to something solid. Then, if you knocked into the pen, the rubber bands would hold it up. This type of stability is known as steady-state recruitment, since the rubber bands, the source of the stability, are equally in play at all times. The problem with this, Granata says, is that if this were a proper model of the spine, the spine would vibrate all the time in response to whatever came its way. "I don't think you want your spine vibrating," he says.

Most models of the spine assume steady-state recruitment, Granata says. In the last several years, Granata started to study the extent to which reflexes keep the spine erect. Regular nerve signals must travel to the brain and back, taking too long to allow a person to consciously maintain balance. Reflexes, on the other hand, bypass the brain, sending signals through the spinal cord. When Granata began experimenting, he expected to find that they were a negligible term of the equation.

However, he found something very different when he started running experiments. "Without reflexes, the spine is unstable … The feedback delay is destabilizing," Granata says, meaning by the time a regular nerve signal arrives at the brain, the reaction it suggests is no longer the appropriate reaction. If a person reacts accordingly anyway, he further destabilizes the spine. As a result, it is necessary to depend on the reflexes to hold the body upright in the case of most small challenges to balance. Reflexes respond to the positioning of the body at any given moment. So, to model the spine and include the role of reflexes, it is necessary to make a complex system that allows for time delay and many points of input.

What previous models of the spine did inadvertently, Granata says, is bundle the effects of reflexes in with stiffness. Beginning to separate them, as his model does,

uncovered a relationship between the speed of the reflexes and muscular stiffness. When the reflexes slow, the body tightens the muscles surrounding the spine, presumably to hold it steady and allow more time to react. The stiffer the spine, however, the more prone it is to injury, just as a stiff object is more easily broken than a flexible one. The stiffer the spine and the more injury-prone the person, the slower the reflexes. "I don't know which comes first, the chicken or the egg," Granata says.

So, when a dancer is standing en pointe, she holds herself up through the active balance of a living thing, making physical laws work in her favor and adding her muscular strength. When she begins to move, she artfully moves out of her moment of equilibrium and into a type of fall, only to sweep back into equilibrium. Moving into and out of equilibrium, she uses a staggering number of physical and biological forces to stay on the razor's edge of losing her balance.

When Streb's dancers launch themselves off Tip, they somehow perform thousands of corrections that keep their bodies on a stable path into the judo-style breakthrough that will allow them to break their fall, rather than into a collision course that would break a bone. Granata compares the set of corrections to the reams of programming that go into keeping a spacecraft on course, and in a stable trajectory. The question that comes out of this, the million-dollar question, really, is, how does the dancer accomplish all this? How does she negotiate these forces, often without being explicitly aware of them?

Mind Control

Alone on a dimly lit dance floor at Green Street Studios in Cambridge, Josie Garthwaite dances "Solo for Two," accompanied by the voice of a single opera singer. The dance exhibits Boston choreographer Irada Djelassi's favored style: a muscular, technical display.

She stretches her arms up toward the ceiling, following the singer's voice as it rises. She balances on her toes. Then, as the voice begins to fall again, she lowers herself toward the floor. She bends at the knee and, keeping her upper body straight, brings her

shoulders backwards and all the way down in one smooth, controlled motion. She never comes off her toes.

Later, I ask Audrey Lavallee, another member of the company, if I saw that right. Was it an illusion, or did she really drop backwards, bent only at the knee? No illusion, Lavallee answers. She brings her knees forward past her toes, so they counterbalance the weight of her body, and she keeps her upper body as stiff as she can.

I can believe there is a place Garthwaite could position her knees that would counterbalance the weight of her body, but how can she find it? And how does she not struggle to find it again each time, wobbling for stability in front of her audience?

Scientists would like to know more about the dancer's brain, but have found it's difficult to watch. Daniel Glaser, of University College London, described his attempt to access the dancer's brain to Peter Tyson of TV's *Nova Science Now*.

Glaser's main interest is in studying how people see, so his experiments on dance were geared toward comparing the brain activity of a person who knows a dance to that of a person who does not know the dance. A control group of non-dancers balanced a group of ballet dancers and a group of capoeira dancers. Ballet and capoeira were selected for their well-defined technique and rigorous ranking methods.

The experimenters matched dance clips that showed technical dance moves using similar parts of the body. Then, each group watched the clips and the researchers measured how their brains responded.

Glaser found the dancers' brains responded more strongly to the clips than did those of the nondancers, and the ballet dancers responded more strongly to the clips of ballet than to the clips of capoeira and vice versa. The more familiar a person was with a dance, the more likely it was that their brain activity would center in the motor cortex rather than the visual cortex. Glaser found that dancers watching dances they knew experienced strong activity in the intraparietal sulcus, which he calls the "visual-motor integration cortex." They also showed activity in the dorsal premotor cortex, an area he says is responsible for complex motion planning.

Though Glaser says he designed the experiment the way he did because he is primarily a visual neuroscientist, he also talked about the problems with attempting to

study the brain activity of dancers in motion. He told Tyson: "... the technique that we use to look at people's brains involves a large brain scanner, and in order to get clear images, people have to remain very still. Obviously, in this case, you can't have people doing cartwheels themselves, because you can't do a cartwheel in a brain scanner."

While the capoeira and ballet dancers' brain activity varied in response to ballet versus capoeira, the nondancers' activity did not. Glaser told Tyson, "... for [people not trained to do either kind of movement] the brain areas don't care whether they are seeing ballet or capoeira. That means we've matched the stimuli very well – they are using the same body parts – and your brain is indifferent to those two if you're not an expert."

In other words, Glaser's study set up a hierarchy of brain reaction. To the person unfamiliar with dance, the brain seems to register bare facts, the same for each dance. It responds to a motion of the leg, for example. To a dancer, who approaches motions of the leg with more precision than the layperson, watching any dance caused a stronger awareness of the planning that went into the movement. To a dancer whose body knows the dance she watches, much more of that body knowledge is activated by the images coming in through the eyes.

Larry Parsons, who studied the neural basis of dance with a team of scientists from the Research Imaging Center at the University of Texas Health Science Center, well understands the problems of studying the brain of a moving body. In his group's study of tango dancers, a major obstacle was finding an experimental design that allowed the dancers to both move and stay still.

Parsons and his team had dancers lie flat in the scanner while tracing the steps of the tango on a plastic grid placed at a slight diagonal angle under their feet. While they pretended to dance, both with music and without, the scientists observed which parts of their brains were active.

How much is dance like any other, simpler body movement? the team wondered. What similarities could they find between a person drumming fingertips on a table and a person dancing the tango? On one hand, dance seems complicated and otherworldly: Garthwaite's amazing move seems to be outside the range of most humans. On the other hand, it is only one of many ways to move the body.

Though Parsons and his team found evidence suggesting dance uses more neurons than simpler movements, they also found it uses neurons in areas similar to those activated by those movements. "Dance can be a very complex coordinated performance," Parsons says, "more so than simple finger or foot tapping." He says he thinks his findings so far suggest that when the brain guides the movements of a dance, it is recruiting many independent supporting systems into one changing, interacting system.

When they tried to break down these systems, they found some areas of the brain seemed to respond to the melody and harmony of the music, while others coordinated the dancer's alignment of her body to that music. Several systems seemed to organize the body's movements into regular patterns, coordinating limbs with each other and sequencing their movement, while several more kept track of the body's position in space and the position of one leg with respect to the other.

Though the researchers say more study is needed to confirm the patterns of systems they identified, their work so far shows how many fine adjustments the brain makes for even the most elementary dance: basic tango steps, legs only, danced with music or without.

Parsons and his team are interested in studying natural, complicated movements like dance, because it provides a chance to study, all at once, rhythm, how the body moves through space, the coordination of the body as a whole, and its ability to synchronize to external stimuli such as music.

These two studies may only hint at what happens in the brain of a dancing person. For now, our best knowledge is experiential. When I watch Garthwaite control that incredible backwards arc to the ground, I am floored. My brain doesn't identify with the movement – it stands in awe. For Lavallee, who sees Garthwaite perform this movement regularly at rehearsal, and understands what it requires the body to do, the response is technical, aware of each moving part. My reaction and Lavallee's reaction could both be measured scientifically.

Garthwaite, on the other hand, remains a mystery. While Glaser could measure how she responds to Lavallee dancing, for example, and Parsons could contrive a pared-down way of testing basic steps, neither one can touch what happens in her brain the

moment she defies gravity and floats to Earth on a cloud of voice. The scanners are not big enough, and she cannot be still enough, for us to look in on the workings of a dancing mind.

It may seem, then, that she has escaped the laws of physics and simply willed herself down. What we are really seeing is how dance calls forth a triumph of nature we have yet to fully unlock: the mind's power of controlling the body.

The Triumph of Nature

Elizabeth Streb reveals the effort inside grace. For a long time, I thought the dancers I watched and worshipped had a magical, inexplicable talent to use their bodies in an unnatural way. That view lacks respect. There was beauty in my impressions of those high school dances, the creamy fabric swishing around long legs raised with pointed toe while an arm rises to a graceful arc. But these impressions missed the beauty a dancer sees.

As I came to study the science of dance, I feared doing disservice to the grace I loved. I worried I would be the dreary-eyed audience member at a magic show who mumbles the secret of a trick to her neighbor, stealing wonder. Instead, I found wonder revealed in layers. The first is the simple wonder of the dance itself, the envy and awe I feel watching a woman using her body as an instrument of art rather than as a clumsy tool. Beyond that are the laws Streb reveals. They push and pull the body, the invisible but essential part of the dance. A living body bears up against those forces, choosing how to approach gravity like a surfer chooses how to move through the ocean current. There is another wonder in the body's mechanics.

Finally, in a transcendent dance we see the transcendent power of the mind. For the moments of the dance, all movements are intended. The body is not a falling object, moved by impersonal physical forces, nor even a living object equipped with muscles to resist those forces. It is a living work of art, a sculpture held in place by the dancer's mind.

Though each of the people I talked to about the science of dance studied it from a different angle, all were motivated by two things: an interest in uncovering the natural beauty within the mechanics of dance and the body, and the desire to make dance safer for dancers through understanding the stresses the art places on them.

An artist refines the beauty of nature. I understand this as a writer, manipulating my natural language and urge to express in order to get the impact exactly right. The dancer works with her anatomy and gesture and controls it, so everything the audience sees is intended. In art, accidental gestures that carry feeling and meaning are studied and transformed into experiments whose results can be duplicated for the benefit of a thousand different audiences.

A scientist refines natural movement in a different way. By reducing what is left to chance, the scientist hopes to isolate a single phenomenon, and therefore increase the precision of human understanding. The scientist plucks bits of order from the mouth of monstrous chaos, revealing the elegant beauty of pattern as they work to know.

A scientist studying dance is really studying how a person is able to refine nature. The science of dance asks how to accomplish the extraordinary within nature. The miracles of science are practical miracles: bridges that don't fall down, devices that work as expected. Laws, Solomon, Ryman and the others are giving dancers the understanding they need to move their bodies more predictably, and, therefore, more safely.

The dancer Doris Humphrey, who was an early professor of dance at both Bennington College and Juilliard, wrote about dance as "the arc between two deaths." She said dance was a balance between two principles, the power of stability symbolized by the Greek god Apollo, and the power of movement symbolized by Dionysus, Greek god of drunken abandonment. In a dance, according to Humphrey, a dancer moves from stability to movement and back again, and the excitement of dance lies in the play between the two forces.

In the same way, at one moment a dancer both wants to defy nature and moves in accord with it. The beauty of dance is in the way the dancer fluctuates between tension and harmony.

At times, I rail against the forces that move me, and at times I flow with them. Always, I am an active part of my environment, my muscles holding me straight, and my mind trained on consciously deciding how or where I am to go. Always, I am subject to the laws of physics, the body and the brain. As scientists become more involved in the study of dance, they show more and more how the dancer moves in accord with nature all the time, and how the most incredible moves trace to the facts of physics and anatomy.

I asked Ruth Solomon if she thinks safer moves are more aesthetically pleasing. She laughed and said, "They are to me."

I know what she means. As I walk up stairs now, I'm conscious of the angles of my knees and angles, and of each delicate bone in my feet. My studies have left me full of wonder over the body, but also a little squeamish about its fragility. Just as I cringe watching a carpenter operate a circular saw, hoping she knows what she's doing with that tool, I hope as I watch a dance that the dancer's not ruining herself for what I'm seeing.

Elizabeth Streb becomes an antihero for me, stridently calling attention to the core of force within dance, but risking her dancers uncomfortably for that attention. Matthew Grierson broke his collarbone practicing one of Streb's dances. Stories like that frighten me.

When Rhonda Ryman began studying the science of dance, neither her dance teachers nor her science teachers could understand what she was doing. Even the subject of her experiments, Canadian ballet star Vanessa Harwood, known for the form and power of her jumps, had no interest in Ryman's scientific results. The science of dance has grown up a lot since then, and since Kenneth Laws wrapped Lisa de Ribere's feet in aluminum foil. But it still lacks coherence, as I saw when I discovered most of the people I talked to hadn't heard of each other.

The sum of what I've learned, practically and generally, amounts to common sense. It's important for a dancer to care for the instrument of her art. The scientists I spoke with have done much specific work, analyzing particular moves and looking at how they can be learned and practiced safely and with intelligence.

I would like to see that attitude spreading much farther, so a young dancer doesn't have to wait to get to college to encounter the revelation that her body is her own

responsibility, and she should pay attention to how it feels. And I find myself, as always, learning from my sister Rose's art. The effect of strain and force is injury. I saw it as I struggled to write this through the pain of confusion, fear, loss and frustration. When I had injured myself so much I could barely face the computer, I talked to my sister one more time.

Is it over? I asked. Once you get injured, are you done?

If you're really in it for the art, she said, and you know how your body works, you can hobble across that stage and it'll still be dance. That's what it means to pay attention to a dancer's individual body.

Dance, in the end, isn't about being beautiful or graceful, or having a perfect body. It's about conscious and careful devotion to an art. That devotion, practiced intelligently, will lead a dancer to nature, and to the nature of her own self.

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