Chapter 12
Motor Control and the Injured and Healthy Artist

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12.1 The Origin of Art

The origin of art is probably related to the origin of symbolic thought (Lorblanchet 2007). The human being, like other animals, is able to partly modify his environment and the objects contained therein. By modifying objects, human beings are able to increase the information contained in those objects (Schneider 2006; Koch 2014). These objects acquire information that they would have never been able to acquire by themselves by being exposed to the forces in the environment. Modified objects become tools that can be used by their creator and by other humans. The information contained within these objects is thus also transferred in part to other humans. Human beings can also create abstract objects, like words and symbols, which also can be used to transfer information. Some of these words and symbols can be used to describe the laws of nature, and thus there is a relation between art and science through the action of the creative mind.

Art is present in all aspects of life. Virtually all man-made objects that we interact with during normal life have a specific artistic stamp—the bed we sleep in, the shower we use, the clothes we wear, the plate and glasses we use to eat breakfast, the vehicle we travel with, the building where we work, the novels we read, the music we listen to, etc. Every man-made object in a city, town, or village has an artistic

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component. An artless existence is simply unthinkable. Art is part and parcel of the human existence. There is no human being that is untouched by art.

12.1.1 Lessons from Artists

In the area of neurophysiology, much progress has occurred from working with injured patients. Correlating damaged areas of the body with loss of function has led to many insights about function. The disadvantage of this approach is that documenting a lesion will only tell you that a specific area of the nervous system plays an important role in a specific disease, but not clearly what that role might be. To use an image: if you remove a transistor from a radio, and hear a screeching sound when the radio is turned on again, this does not mean that you have removed "the screech inhibitor."

The advantage of doing clinical and experimental research on high-level performers like elite athletes, dancers, musicians, circus artists, singers, etc., is that these performers have become experts in the mastery of their chosen discipline. As soon as something is "not quite to right," they are able to describe pain and loss of function that interfere with performance. These verbal descriptions and practical demonstrations are usually very accurate and precise (valid and reliable). Since high-level performing artists function at the extreme limits of human capacity, they can be a unique and useful source of information for the clinician and the researcher who wants to understand how the human body can work at an optimum level. We will recall that Nikolai Bernstein not only studied skilled workers but also elite pianists, for instance, documenting with kymocyclography that keyboard musicians could play hundreds of notes per minute (Kursell 2006).

The interest in the injuries of artists has a long history. The first textbook that mentions injuries in musicians is Bernardino Ramazzini's 1713 treatise, *Diseases of Tradesmen* (Ramazzini 1933). With the advent of the pianoforte in the nineteenth century, composers started taking advantage of the properties of this new instrument to create musical pieces that required increased speed, power, and sound intensity. With increasing performance requirements came increasing injury rates, and a few physicians started to develop an expertise in the treatment of these ailments (Poore 1887). Some of these injuries would now be recognized as tendinopathies, and others, known as musician's cramp, now fall under the heading of focal dystonias. Different medical approaches were devised to address these various ailments and obstacles to enhanced performance. For example, it was well acknowledged by piano teachers and students that the fourth finger had less mobility and power than the others and, eventually, physicians invented an "ingenious" solution to this problem: tenotomy (a surgical procedure) of the secondary tendons of the ring finger. A few surgeons specialized in this technique and traveled by invitation to practice their art on those who wished. The long-term results were less than convincing, however, and this practice was eventually abandoned (Sataloff et al. 2010). The famous Romantic piano composer, Robert Schumann, developed a hand injury that prevented him eventually from practicing his instrument. Current research indicates that this condition, affecting his third finger, may have been a focal dystonia (Garcia de Yebenes 1995). Indeed, in the early 1830s, Schumann created the Toccata in C Major Op. 7, an extremely difficult piece that can nonetheless be entirely played without the use of the third finger of the right hand (Alltenmüller et al. 2005).

The rapprochement between artists and health professionals has led to interesting discoveries. For instance, the technique of indirect laryngoscopy was invented by a professional opera singer, Manuel Garcia, who used a dental mirror to examine the vocal cords of his students. Garcia eventually presented his findings at the Royal Society of Medicine in 1855 (Sataloff et al. 2010). In the second half of the twentieth century, there was a major increase of scientific activities in relation to health, disease, and performance of the professional artist. There are presently annual conferences devoted to arts medicine in North America, Europe, and Asia. Some cover all of the performing arts, and others are more focused, for example, on the injuries of musicians or dancers. Scientific journals dedicated to health and disease in music, voice, and dance have been in existence for over a quarter of a century. Indeed, the effect of music on the brain is an area of research in neurology that has increased by many orders of magnitude since the early 90s.

The visual arts field also has not been left out, as more researchers are exploring the links between visual perception and artistic creation in the areas of painting and other visual arts (Conway and Livingstone 2007; Pinna 2011).

12.2 How Artists Learn and Train Depends on the Type of Discipline Considered

Let us take the example of dance. In dance, students will acquire very specific skills in classroom situations. For instance, ballet students will typically start training when they are 8 years old or even earlier. A teacher will demonstrate how to perform ballet movements correctly and the student will attempt to reproduce these movements, while the ballet teacher corrects the student until the proper movement has been achieved. In the case of ballet, the quality of movement is of the utmost importance. It is not simply a question of standing still with the feet turned out and of bending the knees. This action must be done in a very fluid and controlled way that appears effortless and flawless. The dance student must learn to minimize jerkiness by the fine control of the equilibrium of the posture of the body and the smooth activation of the muscles. The student first learns to do this on both legs, and then on one leg (the supporting leg), during which the other leg (the gesture leg) will describe different patterns in space. These patterns have different names and form part of the ballet vocabulary. There are a few variations in terminology, depending on which ballet method is used (Vaganova, Cecchetti, Bournonville, etc.), but in essence the similarities are greater than the differences. Learning in a ballet class depends a lot on visual cues and the ubiquitous presence of the mirror, which helps the student to self-correct the attempted movements.

The comparison of the ballet dancer's movement with those of others in the class can be stressful. Because of the values of perfectionism that are part and parcel of ballet, the student will always perceive herself as imperfect: too tall, too short, too fat, too slow, etc. One of the challenges of a good dance teacher is to convince the student that she must strive to be the best of what she is and not a failed copy of which she is not.

Eating disorders are commonly associated with the word "ballet," even though research has failed to demonstrate that anorexia and bulimia are more prevalent in ballet schools than in the general population. The scientific consensus at this time is that eating disorders are influenced by genetic and epigenetic factors, and family dynamics, but are triggered by specific psychosocial events and interactions (Treasure et al. 2010). An example of trigger would be a boyfriend or a dance teacher telling the student that it would be desirable for her to lose weight. One of the central aspects of certain eating disorders is that the individual has a distorted visual image of herself. This distortion is in fact an enhanced visual perception of the body that is associated with the notion of being overweight (Keizer et al. 2013). Any minute bulge of the skin will be detected with the eyesight of an eagle. The action–perception issues associated with this medical condition have recently started to attract the attention of researchers (Guardia et al. 2010).

One of the challenges of teaching ballet is that even though the ballet teacher demonstrates exactly the same sequence of movements to a dozen different pupils, each of these students will perceive what has been shown and explained differently. This perception will be based on the psychological and physical properties of the student (Gibson 1987). Thus, a sequence of movements will be seen as doable, partially doable, or not doable. This will depend on the state of the components of fitness of the student: coordination, flexibility, strength, endurance, power, etc., but also on the genetic potential of the student, similar to that of any other individual, to acquire the required performance level (Bouchard 2012).

One aspect, which differentiates ballet from sports training, is that there is no individualization of the training program. No block of time is set aside in the weekly schedule so that the student can work privately to improve her own specific motor skills. The dance student is never assessed individually to identify her training needs. Corrections are usually given "on the fly" within the framework of the dance class.

12.2.1 The Challenges of Effortless Appearance

Another aspect that differentiates dance from most sports is that the motor actions need to appear effortless. Let us take, for example, a "grand rond de jambe en l'air." The dancer starts the movement standing on one leg, with the other leg extended in front of her, parallel to the ground. Keeping the knee straight, the dancer will then gradually bring the gesture leg outwards towards abduction, and then bring the leg backwards, always staying in the same horizontal plane. At the beginning of the movement, the sole of the foot is facing the ground, and, at the end, it is facing the ceiling. What happens is that, as the leg travels from forward to backwards, the leg rotates so that the load is transferred, apparently without any effort, from one group of muscles to another, along the upper arc that is part of the cylinder of continuous muscles that extend from the thigh to the ankle. Naturally, all the muscle groups must be co-activated to maintain the shape of the leg, even though the greatest muscle activation will be provided by a band of motor units that are supporting the mass of the leg at any given time.

The appearance of effortlessness must also be maintained during ballistic movements. As the dancer performs a "grand battement devant," the leg must be shot high up in the air as fast as possible, yet the rest of the body must appear completely immobile. Rapid movements are more challenging because they require more kinetic energy. Kinetic energy is related to the mass and the square of the speed of an object. So if the leg is travelling at a speed of three units, the mass will be multiplied by nine, whereas if the leg travels at a speed of ten units, the mass will be multiplied by 100, which is an order of magnitude higher than a movement three times as slow. The body of the dancer must not only be able to generate such high kinetic energy but must also be able to control, as the movement is taking place, the exact trajectory of the leg according to the demands of the piece.

Naturally, the dancer must be able to simultaneously mobilize all necessary forms of energy to stabilize the rest of the body and give this appearance of perfect immobility of the trunk and the standing leg. All dance students have different characteristics (power, flexibility, endurance, etc.), and so the movement solutions chosen by the dancer must be "good enough" to accomplish the task according to the demands of the teacher, and not necessarily "optimal." As the student learns to handle movement of all her body parts as an integrated whole, less energy will be wasted to stabilize limb trajectory and body shape, and more attention can be focused on decomposing a global movement into the smaller details that make the dance piece more interesting for the spectator, including the possibility that the movement is voluntarily jerky, if wished for by the choreographer.

12.3 Differences and Similarities Between Artists and the General Population

The professional artist needs to be performing at the highest skill level. His employability depends essentially on this characteristic. Artists have to be different from the rest of the population. The saying that "it's the little differences that make the big difference" applies especially well to the arts world. The artist can be seen as an ideal model of what can be accomplished by the human body with specialized training. Motor coordination will develop slowly based on exercise and experimenting with the task at hand. At the early stages of training, the artist will be overwhelmed with the excessive number of degrees of freedom related to the task: playing this note versus that note, landing on this space and not another, putting the hand here instead of there to catch the ball, etc. Sensory feedback given by the outcome of a determined movement will permit self-corrections and stabilization of the intended task. Overcoming peripheral indeterminacy by coordination of movement will lead to relative stability of goal-directed performance, accompanied by a sense of self-confidence (Bernstein 1967; Reppa et al. 2012).

When the artist has achieved mastery of his given discipline, the motor impulses used to control movement will have become more efficient and will be used to guide the passive elements (bone, water, fat, cells, etc.) of the limbs and digits in the direction of the intended goal. The inertial properties, reaction forces, and interaction torques of these passive elements then cease to be a problem, and in fact become part of the solution of the required movement. All this is accomplished by online constant afferent feedback from the mechanoreceptors (Bernstein 1967; Silva 2012). The information that arises from the periphery is also transmitted through the body by mechanical waves that travel at the speed of sound through the various tissues of the organs. These waves travel much faster than that of neural transmission. To what extent this mechanical information can be utilized by the central nervous system (CNS) is as yet unknown. Certainly, most of the cells of the human body, including neurons, are equipped with primary cilia (Anderson et al. 2008). Many of these primary cilia have a role in mechanical perception at the cellular level (Tobin and Beales 2009). The existence of such primary cilia may also explain in part the favorable effects of strength and aerobic training on health and disease (Trilk and Phillips 2014).

12.4 Circus Disciplines

In contrast to dance, voice, and music, up until now, the circus disciplines have not attracted a lot of attention on the part of health and fundamental researchers, and the existing studies are mostly of an epidemiological nature (Shrier et al. 2009; Wanke and Hamilton 2012). This may be in part due to the fact that many circus injuries are also commonly found in various sport disciplines, and thus the transfer of basic and clinical knowledge can be made more readily.

Still, the unique blending of motor and psychological skills with the goal of activating an artistic effect on the audience adds a new layer of complexity to the accomplishment of the circus movements. Contrary to his athletic counterpart, the circus artist cannot afford to be in a psychological cocoon, oblivious to the reactions of the spectators. Quite the opposite, the successful circus artist must be able to reach out and connect with each person in the audience.

In this section, we will review the main circus disciplines and the motor control issues that arise within each of them. Circus disciplines can be classified into five main families: aerial disciplines, equilibristic disciplines, acrobatic disciplines, juggling and object manipulation, and clowning disciplines.

Fig. 12.1 Aerial hoop. (Photo: Lionel Montagnier, artist: Alexandra Royer in Sequence 8 by Les 7 Doigts de la Main)

12.4.1 Aerial Disciplines

Aerial disciplines require specific abilities and motor skills. They require a predominance of upper body work and pulling against gravity. The construction of these movements could be addressed by motor control levels A and B, as proposed by N.A. Bernstein (Bernstein et al. 1996). Examples include aerial hoop (Fig. 12.1), static trapeze, flying trapeze, swinging trapeze, and vertical rope. A high level of proprioception and spatial orientation is required. These disciplines present a significant level of danger and risk, and psychological issues including the fear of falling.

Fig. 12.2 Hand balancing. (Photo: Louis Ducharme; artist: Samuel Tétreault)

12.4.2 *Equilibristic Disciplines*

Equilibristic disciplines require, in contrast, the ability to push against gravity. Constant postural corrections are required on the part of the stabilizing muscles. These might correspond to Bernstein's levels B and C1. Examples include hand balancing (Fig. 12.2), tightwire, high wire, slack rope, rola bola, and hand to hand. The perfect balance that is required is not immobility but rather a dynamic balance (active correction of posture and the ability to perform a task while maintaining a stable position). Psychologically, this type of discipline requires from the artist the ability to sustain concentration at every instant.

Fig. 12.3 Chinese hoop diving. (Photo: Valérie Remise; artist: William Underwood in TRACES by Les 7 Doigts de la Main)

12.4.3 Acrobatic Disciplines

Acrobatic disciplines require explosive movements (fast-twitch fibers are more in demand than slow-twitch fibers) and are characterized by a predominance of lower body work. These might be assigned to Bernstein's levels C2 and D. Examples of these disciplines include Chinese hoop diving (Fig. 12.3), Korean board, Russian bar, and Chinese pole. Spatial orientation and proprioception are very important, and there is a high level of risk, so fear of injury needs to be addressed.

12.4.4 Juggling and Object Manipulation

Juggling and object manipulation requires excellent hand–eye coordination skills. These skills would be an example of control level D according to Bernstein. There

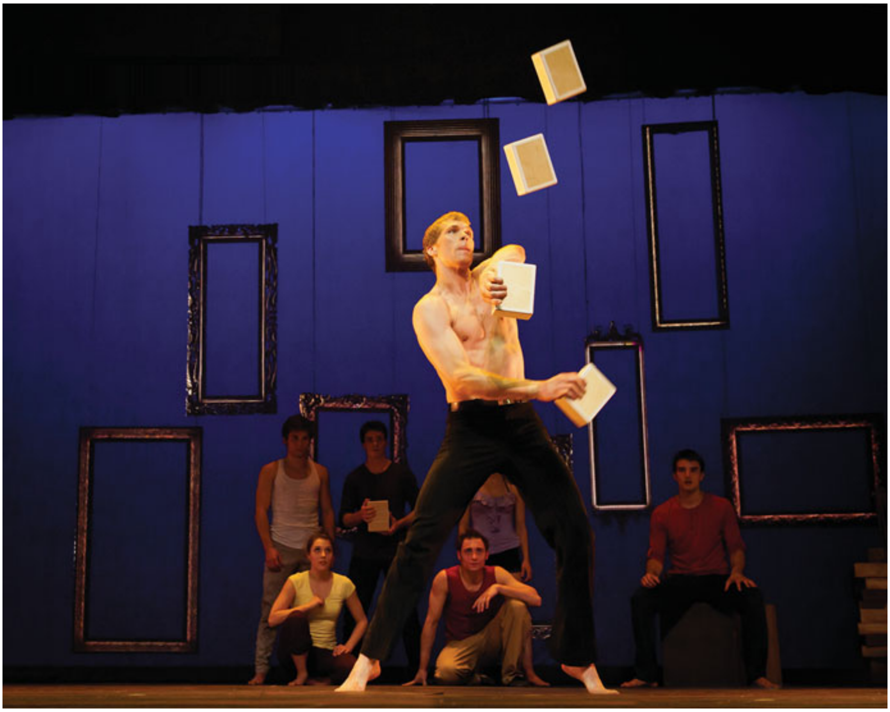

Fig. 12.4 Cigar box juggling. (Photo: Sylvie-Ann Paré; artist: Eric Bates in Sequence 8 by Les 7 Doigts de la Main)

is a high demand on upper limb dexterity. Examples of these disciplines include cigar box juggling (Fig. 12.4), club juggling, and diabolo. Juggling can also be done with partners. A large amount of practice is necessary to accomplish juggling acts. Jugglers tend to have mathematical and musical types of mind (patterns, precision, timing; Polster 2003). Indeed, the first recorded mathematician-juggler is believed to have been Abu Sahl al-Quhi, a mathematician living in Baghdad in the tenth century (Buhler et al. 1994).

12.4.5 Clowning Disciplines

Clowning disciplines find their origins in the grotesque characters of ancient cultures and in the early forms of theatre such as commedia dell'arte. Both classical and contemporary circus clowns very often combine their specific artistic performance with other circus disciplines and therefore there are no specific motor control skills or body types required.

12.5 Training in the Circus Arts

Learning is more a question of differentiation rather than a question of enrichment (Gibson and Gibson 1955). There is no reason to believe that artists use different strategies to learn than other human beings. Based on experience, coaches are adept in identifying those individuals with enhanced motor-perceptual skills that are "trainable" within a specific discipline. The existence of individuals with distinct or exceptional qualities is well-recognized, and even if there are many competitive descriptive frameworks that address this (see, for example, Gardner 1983), satisfying explanations from a neurophysiological, biomechanical, and biochemical point of view are still lacking. Naturally, some disciplines, like contortion, require a genetic and epigenetic makeup that is truly exceptional. Identifying to what extent these super-flexible individuals are similar or different to the majority could enhance our understanding of the interaction between gene expression and training with regard to flexibility in the general population, and could lead to insights about injury prevention in sports and in the workplace.

While the artist trains, he or she compares qualitative differences (Verri and Poggio 1989) such as bigger than, farther than, faster than, etc. For instance, when a juggler tries to catch a ball that is thrown in the air, the optical flow to his eye is compared with previous experiences of watching movable objects transiting in every manner possible. The immediate perception he has of his own body will tell him instantly if he has even the remotest possibility of catching that ball. This is based not only on the relative speed and direction that the ball is traveling but also on his training and how his body perceives the state of health of his limbs (injury in the shoulder, etc.). Eventually, these tasks will become well-learned habits that the circus artist can count on to be accomplished nearly automatically, whether the artist is immobile, or traveling along a well-known trajectory. When confronted with the new situation, more areas of the brain will be solicited to be able to compare known experiences versus the necessity of inventing new tasks. As the circus student becomes a professional, the possibilities afforded by the environment and its objects will be modified because the artist's capabilities have been modified. This training process entails an updating of the brain's active operative representation (modeling) of the external world (Bernstein 1967). Whether this process is qualitative or quantitative is presently the object of much debate (see, for example, Ostry and Feldman 2003). When exposed to the same array of objects (ropes, balls, ladders, etc.), a nonartist will perceive different affordances from a circus artist.

General principles of circus training include physical preparation in strength and flexibility, basic acrobatic classes and biomechanics (floor and trampoline), decomposition of complex movements into simpler ones, progression using educative movements, use of safety lines and crash mats, repetition until patterns and sequences become integrated, consistency, and endurance.

Psychological issues are also very important, as the artist must learn to plan near into the future the complex movements related to his or her discipline. "Death defying" acts have always been part and parcel of the traditional circus trademark

Fig. 12.5 Swinging trapeze. (Photo: Yann Boyenval; artist: Danica Plamondon in PSY by Les 7 Doigts de la Main)

while in the contemporary circus arts the focus is less on sensationalism and more on the artistic research and individual expression. Commonly, especially during the first half of the twentieth century, many aerial artists boasted about their capacity to work without a safety net. Current research is now looking into these and other psychological skills (Shrier and Halle 2011). Learning to master the fear of death is intimately tied with the human capacity to plan ahead (Bernstein 1967).

12.5.1 Training in Aerial Disciplines

Morphological qualities include a smaller and lighter body type, good flexibility, and good lines, and the proportion of slow-twitch versus fast-twitch fibers depends on the type of aerial discipline. Psychological skills include being comfortable with heights, courage, a high tolerance to pain (for instance, caused by the friction of the rope or twine), the capacity to visualize complex sequences of movements and thereby their mechanics, risk management (security), and rigging knowledge. Action and perceptual skills include hanging and suspension postures (from hands, knees, feet, heels, etc.), spatial orientation without contact with the ground, swinging on a trapeze, for example, (Fig. 12.5) and tempo movements, feeling the “dead point” (moment of weightlessness), and flipping and twisting movements.

12.5.2 Training in Equilibristic Disciplines

Morphological qualities are believed to require a preponderance of slow-twitch muscle fibers, and the ideal body type will depend on the discipline. For example, good shoulder and elbow flexibility is required for hand balancing or hand-to-hand actions (Fig. 12.6). Psychological skills include attention to details, being meticulous, having the capacity to concentrate over long periods of time, patience and perseverance, calmness, understanding the biomechanics of balance, and the capacity to visualize shapes and postures in terms of balance structures. Motor control skills include consciousness of the base (anchor) points and extremities, consciousness of body alignment, posture and muscle tone, proprioception accuracy, standing and balancing postures using different body parts as anchors (hands, feet, head, knees, etc.), dynamic balance (active correction of posture), isolation of movement within a fixed shape, and steady movement.

12.5.3 Training in Acrobatic Disciplines

Morphological qualities include a shorter, muscular body type with fast-twitch fiber predominance. Psychological skills include a courageous and daredevil spirit, the capacity to visualize complex sequences of movement and their biomechanics, greater attention to the whole and less detail-oriented, and risk management (security). Motor control skills include jumping and landing from and to different surfaces, spatial orientation and fast movement combinations, quick trajectory and velocity corrections, initiating and stopping rotation, explosive movements, and flipping and twisting movements such as those seen in Fig. 12.7 on the Korean board.

12.5.4 Training in Juggling and Object Manipulation

No specific morphological qualities are required for this discipline (body type, flexibility, muscle type). Psychological skills include patience, perseverance to the point of obsessiveness, a mathematical/musical mind type, and the capacity to visualize complex patterns of intricate upper limb movement (Beek and Turvey 1992). Of note, there is a predominance of male jugglers. Motor control skills include a high level of hand–eye coordination and dexterity; relation with objects in space and time; throwing, catching, and manipulating objects of different shapes and weights using different body parts; and consistency in highly repetitive movements.

Fig. 12.6 Hand to hand. (Photo: ODC Photo; artists: Sebastien Soldevila and Émilie Bonnavaud in La Vie by Les 7 Doigts de la Main)

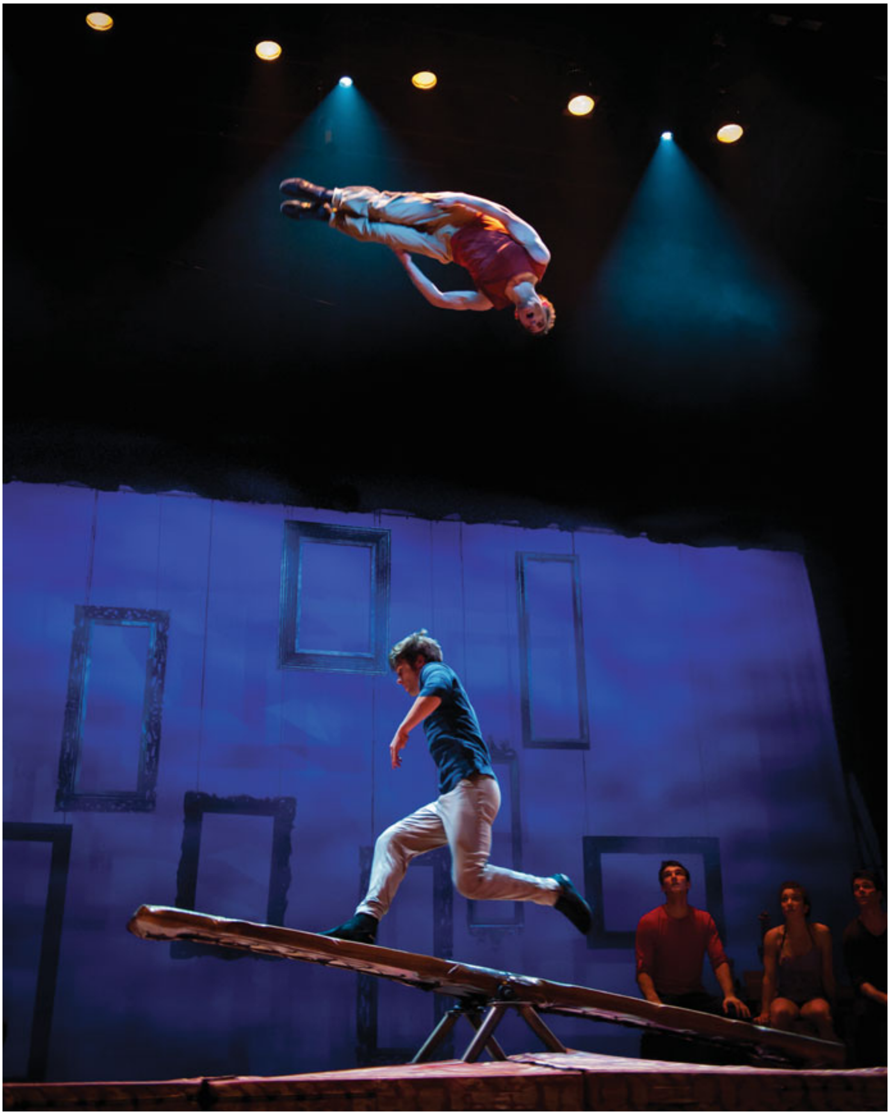

Fig. 12.7 Korean board. (Photo: Sylvie-Ann Paré; artists: Maxim Laurin and Ugo Dario in Sequence 8 by Les 7 Doigts de la Main)

12.5.5 Training in the Clowning Discipline

What mostly defines the clown artists is found on a psychological level: A great sense of humor and self-derision is an essential personality trait to any good clown. Clowns often provoke laughter by exposing their own flaws and vulnerabilities, appearing

Fig. 12.8 Russian bar. (Photo: Lionel Montagnier; artists: Eric Bates, Tristan Nielsen and Alexandra Royer in Sequence 8 by Les 7 Doigts de la Main)

clumsy or failing in what they attempt. They are a mirror for what we usually do not want to see in ourselves or try to hide from others and therefore clowns need to have an acute sense of observation for their own behaviors and those of others. It is not rare to see some of the funniest clowns on stage being rather moody or even depressed off stage.

12.5.6 Partnering and Group Disciplines

In terms of morphological quality, a “flyer” (the acrobat who is being carried, thrown, and caught) will usually have a shorter and lighter body type, while the “base” or “catcher” has a taller and stronger body type (Fig. 12.8). Psychological skills include the capacity and interest for teamwork, capacity to put one’s trust in someone else and to be trustworthy, verbal and nonverbal communication skills, and the capacity to visualize movement sequences involving the simultaneous movement of others. Motor control skills include the capacity of throwing and catching people using different body parts (hands, feet, shoulders, back), giving and taking weight and counterweight, letting go of the automatic reflex of balancing yourself (flyer) and letting the “base” balance you, developing synergistic movement with someone (synchronized “tempo”) to combine pushing actions, high adaptability, and requiring quick adjustments (the other person is a variable you cannot control).

12.5.7 *The Live Performance Has Specific Issues of Its Own*

The artist has to deal with psychological factors like the stress of performing in front of the public, the fear of failing or falling, mishaps, and last-minute changes. Outside factors include the conditions of the show: lighting, musical cues, different stage sizes, floor types and ceiling heights, etc. This is where experience and training allow the artist to transcend the acrobatic elements and motor skills and to reach a sense of freedom in his artistic expression.

12.6 Basic Considerations About Motor Control and Injury

In the past 150 years, much progress has been made in the area of motor control. In particular, the area of synergies and their origin have been the object of many publications and discussions, including the proper definition of the word itself (Latash 2012; Turvey 2007). The creation of a neologism that captures exactly "what is meant" might contribute usefully to the standardization of motor control terminology. For the moment, let us consider that there may be three kinds of synergies: inorganic synergies like those of the lattice that unites the molecules of a rock, organic synergies characterizing the structure and metabolism of living things, and action synergies, which are the goal-directed movements of living things and their interaction with the environment. The last two categories may be corollaries of each other. Action synergies are driven by the demands of the organism and its interactions with the environment. The similarities between the goals of a unicellular organism and those of a complex animal like a mammal are obvious. All living organisms need to consume molecules to generate energy, need to gain access to sources of energy, need to maintain their structural integrity, and need to reproduce themselves (Pross 2012). Indeed, it may even be hard to draw the line between metabolism and structure. For instance, the cytoplasm also contributes to the mass, shape, and structure of the cell, through both osmotic and hydrostatic pressure (Myers et al. 2007). Another consideration is that all living organisms are constrained by physical factors like pressure (the pressure of water or of the atmosphere), temperature (molecular agitation and the threat of loss of information), electromagnetic waves, mechanical waves, and gravity.

What the CNS seems to learn are correlations between changes of body sensation and visualization of body movement, so that a given dynamic image of the change of the body configuration is associated with a change of body perception. The unit of control of the CNS is probably not the muscle, but rather the motor unit. Muscles do not seem to exist as far as the controller is concerned. The controller would seem to recruit, through threshold modification, the number and location of the motor units necessary to accomplish the required task. The elementary component of movement confined in the organism is most probably the motor unit and its feedback loop (motor loop). It is through this motor loop that the animal probably perceives part of the environment, and notably deformation of matter, which is interpreted as "force." It is thought that similar loops are related to the existence of consciousness in humans and animals (for a review, see Dehaene 2014; see also Tononi 2008; Koch and Tsuchiya 2012; Koch 2014).

Injury is a structural breakdown of the normal components of the organism. This breakdown can affect the metabolism, the external or internal mechanical structure, the communication system, and any or all of the above. Inflammation, a common component of injury, will create localized changes in pressure, volume, and temperature. These localized inflammatory changes will disrupt the organic synergies of the animal or human. For instance, thermodynamic measurements indicate that native proteins are only marginally stable under physiological conditions (Voet et al. 2012). These localized inflammatory changes may also disrupt action synergies.

Injury can also be accompanied by structural hypermobility, hypomobility, or both. The coexistence of both is not at all rare: For instance, in the case of a severe injury to the knee, the joint may have not only an increased mobility because of a partial ligamentous tear but also a decreased range of motion because of a torn meniscus.

The existence of organic synergies is not trivial. The proper way that each mechanical part of a living animal will interact is already included in the way that the animal is constructed. This greatly simplifies motor control, as movements that are forbidden and movements that are permitted are already built into the biomechanical structure of the animal. For instance, the knee is constrained to mostly perform flexion and extension, and the healthy artist does not have to think about producing "impossible" movements. Indeed, if an injury affects the normal length or tensile properties of the ligaments, fasciae, etc. of the knee, the artist, because of his enhanced training, will become very worried because he can instantly tell that "something" is not quite right, and that he cannot count on his knee or leg to perform flawlessly. Quite often, the instability can be very subtle, and there is a real risk that the injury will be dismissed out of hand by an examiner who is not used to dealing with dancers and circus artists, for instance.

This does not contradict the fact that action synergies are probably controlled only at the most distal part of the motor arc (or motor circle), the muscle activation threshold of the muscles of the body (Feldman 2009). According to Bernstein, "the co-ordination reflex is not an arc but a closed circle with functional synapses at both ends of the arcs." Recent studies have supported this point of view (Mattos et al. 2013).

Naturally, the bones that meet at the knee joint have, in reality, six degrees of freedom, like every other bone of the body, if viewed on a sufficiently small scale. The debate between those who see the helical axes of the knee as more ligament-controlled or more muscle-controlled (Blankevoort et al. 1991; Zatsiosrky 1998) is probably artificial, as the tensegrity (Ingber 2008; Swanson 2013) model, based on the concept of pre-stress within biological entities (cells, organs, etc.), apparently reconciles these seemingly opposing viewpoints.

12.7 Injuries in the Artistic Disciplines

The causes of injury in the artistic disciplines are very similar to those in sports. Injury is usually multicausal. Let us take yet again the example of dance. It is useful to parse the causes of injury into intrinsic and extrinsic risk factors (Emery 2003; Liederbach 2010; Ojofeitimi and Bronner 2011).

Intrinsic factors of injuries can be subdivided into modifiable and nonmodifiable factors. Examples of nonmodifiable factors include sex, age, genetic, epigenetics training history, and previous injury. Modifiable factors include fitness level, flexibility, strength, stability, proprioception, nutrition, total workload, and psychosocial factors.

Extrinsic risk factors can also be subdivided into nonmodifiable and modifiable factors. Some of these nonmodifiable factors would include type of dance, dance level, and unpredictable accidents. Modifiable factors include the disregard of sound training principles, predictable accidents, temperature, surface, and choreography. The modifiable character of this last factor depends naturally on the goodwill of the choreographer. Indeed, in more than a few instances, one would be excused in believing that the definition of a choreographer is “someone who creates new ways of getting injured.”

12.7.1 Injuries and Their Impact on Motor Control of an Artist

Let us take, for example, the case of an artist with an ankle sprain (Gehring et al. 2013a, b; Hubbard-Turner et al. 2013; van der Wees et al. 2006). When a person sprains his ankle, common clinical findings include the following: (1) inflammation and swelling, (2) hypermobility of the ligaments, (3) loss of mobility of the ankle joint, (4) pain, (5) loss of muscle strength, and (6) loss of proprioception. In fact, most of the injuries of the various joints of the body will generate the same clinical findings. These findings can be used as outcome variables to help therapists determine when the injury has resolved. In the case of an ankle sprain, the sprain will be healed when there is no more inflammation; the ligaments have healed with a length and stiffness that is as close as possible as the pre-injury state; the range of motion of the ankle has been restored; the pain is gone; the strength, speed, and endurance of the muscles are back to normal; and proprioception has been restored.

Let us consider the effect of these six variables on normal motor control.

1. Inflammation will cause abnormal neural messages to be sent to the nervous system through two main types of stimuli: chemical stimuli, caused by specialized molecule, and physical stimuli, caused by abnormal increases of volume and pressure on the nerve endings (Pongratz and Straub 2013). This array of abnormal stimuli caused by inflammation will serve as a negative feedback loop to inhibit muscle activity.

2. Hypermobility between two bones will have an inhibiting effect on muscle action through a different pathway than the previous one. Recall that the relative length of muscles is regulated through muscle spindles and their relative strength through the Golgi tendon organ (Kistemaker et al. 2013). The laws of mechanics tell us that the array of mechanoreceptors measure not only the "action" (force) of the muscles involved but also the "reaction" (including the inertial properties (heaviness) of the bones and other tissues) on which the muscles act. Recent research suggests that perceived heaviness is related to mass, volume, and symmetry of the perceived object (Turvey et al. 1999).

   When excessive (abnormal) mobility is perceived between two bones, the nervous system will send instructions to the muscles to protect the body from this excessive mobility. Thus, muscles will not be allowed to stretch to their maximal length. The same muscles will also not be allowed to exert their maximal force. Based on his clinical experience, one of the authors has found that trained artists (circus, dance, music) are able to sense these effects in great detail and can give very useful feedback to the health professionals that treat them.

   These changes may be triggered because the body perceives that the combined inertial properties of the bones and other attached structures have changed. Naturally, at the cellular level, the array of Golgi tendon organs involved probably does not measure "force," but rather sends out signals in proportion to the deformation of their physical and chemical structure, signals that are interpreted qualitatively ("heavier than," "lighter than," etc.).

   How simultaneous loss of strength and loss of maximal muscle length are mediated can be predicted and explained by the equilibrium point theory of motor control (Feldman 2008). The equilibrium point theory (or threshold control theory) seems to be the only theory that is presently capable of explaining why the same muscle can be measured as being weak at one end of the range and spastic at the opposite end of the range, in stroke patients (Levin et al. 2000).
3. Hypomobility is often also accompanied by a loss of strength and a loss of maximal muscle length. If the muscle is directly damaged, the cause of both the loss of mobility and of strength is readily apparent. However, there are common injuries that are accompanied by a misalignment between the bones in the joint space. Surprisingly, this can coexist with the fact that the joint is not necessarily painful, yet the muscles seem to be "switched off" or "toned down." In these cases, restoration of anatomical congruence by the means of manual treatments is accompanied by an instantaneous return of maximal muscle length and strength (Cibulka et al 1986; Suter et al. 1999). Research is ongoing as to the local and regional effects of these treatments (Dunning and Rushton 2009). Again, the equilibrium point theory brings a neurophysiological explanation to this common response, which is observed by health professionals on a daily basis in the clinical setting. Because of their heightened proprioceptive awareness, artists are able to guide the therapist in a step-by-step manner during the treatment session to restore proper mobility of each joint as required for optimal performance.
4. Pain in the tendon or in the muscle (due to a muscle tear, for instance), despite the pain component being a "subjective" sensation created by either increased focal

pressure or tissue damage (Moayedi and Davis 2013), will directly generate a loss of strength and resistance to lengthening through "nociceptive" stimuli (antalgic paresis).

5. Loss of strength and endurance can be caused either directly through damage of the muscles or tendons or indirectly through damage of the nerves, or through inhibition caused by inflammation, hypermobility, or hypomobility.
6. Loss of proprioception can be caused either directly through damage of the nerve endings (mechanoreceptors) or indirectly, because of inflammation, hypermobility, or hypomobility.

   All the joints of the body generate the same reactions to tissue damage. These phenomena are scale invariant, whether the damage involves a joint of a finger, the knee joint, or the intervertebral segments. In the case of a microscopic tear of the intervertebral disc, even without any bulging or change of shape of the disc, inflammation and disruption of the nerve endings within the annulus fibrosis will affect muscle function. Certain muscles will lose their maximal strength and maximal length, and this will disrupt the overall synergies of the trunk muscles.

12.7.2 The Special Properties of the Spine

If the joints of the locomotor system are all the same, as they are indeed histologically, being composed of bone, cartilage, synovial fluid, joint capsules, ligaments, enthesis (Benjamin et al. 2004), tendons, muscle, nerves, and skin, why is the spine perceived to be somehow different?

Yet, the trunk is indeed different, for three main reasons. These reasons are physical, anatomical, and neurological.

1. Neurologically, the spine and trunk muscles are the oldest part of the locomotor system, from a phylogenetic point of view. Human consciousness does not have a clear image of the mobility of the vertebrae, compared to the consciousness that we have of our upper or lower limbs. With our eyes closed, it is easy for us to visualize the motion between the phalanxes of the finger, or the motion between the thigh and the leg. If we try to visualize the rotation of the vertebra L4 versus L5, we are incapable of doing so. When we turn the trunk to the right, we will only have a general idea of the motion that takes place between the vertebrae. Obviously, part of us knows which muscles to activate and how, but our consciousness does not have access to that information. When we injure a knee, for instance, it is possible for us to adopt a strategy to reduce nociception, such as deciding to walk with the knee extended to avoid painful flexion. When we injure the joint space between L4 and L5, however, there is no way we can have conscious access to muscle strategies that permit us to dissociate the movement of L4–L5 from that of the rest of the trunk.
2. From an anatomical point of view, all the trunk movements are multi-muscle movements that are united through synergies between agonists and antagonists

(Robert et al. 2008; Vora 2010). We would be tempted to say that the trunk muscles are enslaved to one another, in a similar way and for the same reasons as the muscles of the fingers (Zatsiorsky et al. 2000). When there is an injury between L4 and L5, all of the 20 or so muscles that attach to these vertebrae on each side of the body are affected by whatever is taking place at the joint space. Thus, all the muscle synergies of the trunk will be affected by this very localized injury at only one level. Some muscles will receive instructions telling them to activate less strongly and to not lengthen to the maximal length, but other muscles will receive the usual instructions they would get to accomplish the given task. This conflict between normal functioning muscles and abnormal ones will create, for instance, the so-called spasm that takes place because a muscle is extended beyond its minimized range, trying to follow its companions. The spasm caused by palpation is due to the same mechanism: The palpating finger lengthens the muscle beyond its permitted range, generating a painful reaction.

3. Physically, the trunk is where the center of gravity of the body is situated when the human being is standing. The gravity line passes through the trunk and the center of mass projects between the feet. As the body moves around in space, so does its center of mass (Roussouly and Pinheiro-Franco 2011). Each displacement in space will require activation of the trunk muscles and mobility of the intervertebral spaces, possibly triggering an increase of inflammation, increase of hypermobility, etc. It is not possible to physically isolate these vertebral joints in the same way that one can isolate an injured knee or ankle during locomotion. Every movement of the whole body requires necessarily a movement involving all of the vertebrae of the body.

So, for these neurological, anatomical, and physical reasons, spinal dysfunctions are much more debilitating than injuries of the upper and lower limbs. These are probably the main reasons why spinal injuries are intuitively perceived by patients and health professionals to be different from limb injuries, even if the basic histological structures and physiopathological mechanisms are similar.

Circus artists and dancers develop an exquisite sense of body awareness of their spinal movements. This enhanced spinal proprioception makes them ideal subjects to study the normal and abnormal function of the trunk, as they are able to pinpoint exactly the intervertebral segments that are not functioning correctly. In the situation where manual treatments are required, they are able to give immediate feedback as to the effectiveness of a given manipulation. Through the course of a half-hour- or an hour-long treatment, all the intervertebral segments that are hypomobile can have their proper motion restored. This is accompanied by a gradual and significant increase in mobility of the gross movements of the trunk (flexion, extension, rotation, etc.) throughout the treatment session. Naturally, if there is an underlying segmental hypermobility associated with deep muscle weakness, this will need to be treated by an appropriate series of exercises.

In addition, undiagnosed inflammation is a common finding that may lead to failure of treatment if not addressed correctly. The role of the nervous system at the level of the joint has been identified as a significant factor in the modulation of the inflammatory response (Schaible and Straub 2014). In particular, the intravertebral disc has attracted a lot of attention, and many recent publications demonstrate the ongoing interest in this area (Adams and Dolan 2012; Rajan et al. 2013; Ulrich et al. 2007).

The experience of one of the authors is that practically all dancers and circus artists affected by common spinal dysfunctions ("low back pain") are able to return to performance with no functional limitations whatsoever, even after being off work and in treatment for 1 or 2 years. Even taking into account the "well-worker effect," understanding the reasons for this may lead to a better understanding of how to treat spinal dysfunctions in the general population.

12.8 The Healthy and Injured Artist as an Object of Study

As was discussed initially, arts and science are related to each other like both sides of a piece of paper. In the same way, understanding injury and disease is another way of understanding health and performance. Both go hand in hand. Developing research projects to understand how high-level artists achieve the mastery of their art form and how injury or disease interferes with artistic performance has the potential to lead to better insights about how the human body works in general.

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