Cognitive Dance Improvisation: How Study of the Motor System Can Inspire Dance (and Vice Versa)

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ABSTRACT

This paper describes several dance improvisation techniques inspired by the study of the motor system. One technique takes experiments on interlimb coordination from the laboratory to the dance studio. Another technique, termed fixed-point technique, makes use of the fact that one can change which part of the body is fixed in space. A third technique is based on the idea that one can maintain the action, as it were, by "reversing the acting limb." All techniques target a specific capacity of the motor system and as such may inspire new psychophysical experiments. The present approach to generating movements, which merges dance improvisation with insights from cognitive neuroscience and biokinesiology, may also be fruitfully extended to robotics.

As a choreographer, I take an active interest in all issues concerning motor control and motion perception. Inspired by my readings on the neural mechanisms of human movement and the work of the American choreographer William Forsythe, I have developed a new approach to dance improvisation and choreography. The essence of this approach is the formulation of high-level techniques for generating movements of one or several bodies while taking into account the workings of the motor system and the principles of aesthetic experience as implied by the properties of the visual system [1,2]. Rather than prescribing every single movement, these techniques can be regarded as tools for solving the problem of "which move to make next." As such they require the exercise of both cognitive and motor faculties. Because the generative process is the same across successive performances, they give way to a rich palette of movements while maintaining an overall consistency.

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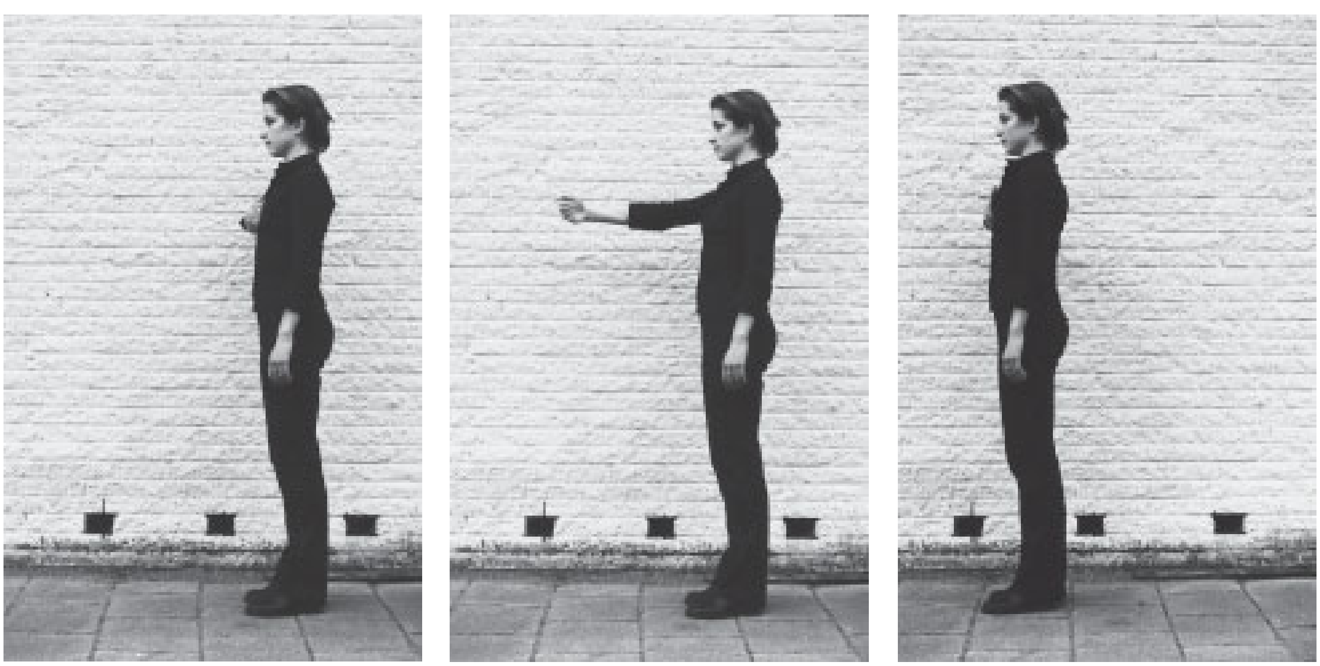
Of Landscapes, Guides and Getting Stuck

A dance performance can be seen as a journey through the state space of all possible movements. In a choreography the dancer, who acts as a guide to the audience on this journey, has to follow the path set out by a choreographer, who has mapped out an itinerary in advance. In dance improvisation, by contrast, the journey is created on the spot, which is what makes improvisation interesting to both dancer(s) and audience.

When planning an itinerary, dancers and choreographers face the same problem as writers, painters and composers before an empty sheet: which movements to make out of the in-

Fig. 1. Fixed-point technique. Stand up, holding the right hand to the chest (a). Extend the arm (b). To re-establish the point of departure, bring the hand to the body (return to [a]) or bring your body to your hand (c). (Photos © Ivar Hagendoorn. Dancer: Ester Nazijl.)

(a) **(b)** **(c)**



finite number of possible movements. Improvisation introduces an additional problem, as the dancers have to make their decisions on the fly. The moment they have made up their minds, they are confronted by the same problem all over again. Dancers thus face two conflicting challenges. On the one hand they have to structure their movements so as to create an interesting performance, while on the other hand they have to avoid "getting stuck" in the same patterns of movements.

Habits and How to Avoid Them

Habits are unconscious and can therefore get in the way of desired movements. As a matter of brain processing, habits are computationally efficient. An action can unfold without requiring every individual step to be worked out in advance. It is therefore not surprising that, when improvising, dancers also tend unconsciously to repeat certain movements. For instance, when sitting on the floor, a dancer may always get up in the same way or she may hold her arms in a particular position when they are not engaged. Of course some dancers' habits may constitute a personal style. The issue, however, is freedom: freedom from constraints and freedom to choose.

The French author Raymond Queneau once observed that "the classical author who writes his tragedy according to certain rules he knows is freer than the poet who writes whatever comes to his mind and who is a slave of rules he does not know" [3]. The unknown rules to which Queneau refers are the processes through which the brain comes up with a word, a sentence or a movement. It follows that if we could gain more insight into these processes, we might be better able to put them to use. This is what cognitive neuroscience can contribute to the arts.

If we read between the lines we may also learn how, according to Queneau, one can be as free as a classical artist without adhering to the "classical" rules of composition: invent your own rules. After all, the rules that explicitly or implicitly govern a sonnet, a detective novel or a fugue were also once designed. So why not design different guiding principles and constraints? A fascinating example of this approach is *La Disparition* by Georges Perec, a novel entirely without the letter *e,* which is also a detective story about a disappearance [4]. Another example is Queneau's own *Exercises in Style* [5], which consists of 99 variations on the same story and which itself was inspired by Bach's *Art of the Fugue.*

This method can also be applied to dance. One could for instance constrain the use of space by performing with one's back to the audience or improvise around a theme the way Queneau did upon a story. *Transit* (1962), by Steve Paxton, for instance, consisted of a series of movements from classical ballet that were repeated again and again at different speeds and with changing emphasis. For one of my group improvisation techniques, the dancers have to imagine they are in a labyrinth [6]. They can only make right-angle turns and, because the corridors are narrow, they can spread their arms sideways only if they make a 90° turn. One of the pioneers of such a game-based approach to dance was Simone Forti, who during the 1960s had her dancers interact and move through space according to various game-like rules [7].

Improvisation Techniques

Instead of applying constraints, one can also design rules or techniques for generating a particular type of movement. An improvisation technique should be *generic* in that it can apply to different body configurations and movements. It should also be *specific* in that it offers a cognitive shortcut to describing a particular class or subset of (the space of all possible) movements. Moving the arms while holding the hands together would therefore not quite qualify as a technique; generalizing this idea to keeping two limbs or parts of the body connected would constitute a technique, however.

The American choreographer William Forsythe has created a wide range of such techniques and metaphors for generating movements, most of which are now collected on the CD-ROM *Improvisation Technologies* [8]. For instance, one can "draw" lines, circles or any other shape with any endpoint effector in the body: hand, elbow, shoulder, hip, head, etc., or imagine a fence or other obstacle and then avoid it.

In my own work, I look for sources of movement strategies in the way that movements are processed by the brain. The idea is that, when made *explicit*, the *implicit* properties of the motor system can be put under conscious control. And because these properties are hardwired in the brain, they may be easily generalized and extended to other movements or body configurations. For instance, a default property of the motor system can be seen as a specific instance of a range of movements, while a solution to a particular behavioral problem can be generalized to other situations. Or, to give a more specific example, it has been shown that, during grasping, the hand preshapes well ahead of the actual contact with the object [9]. This kind of information can instantly be put to creative use. One could pre-shape the hand at the very end of the trajectory or at the very start. In general it is possible to observe any kind of action and then vary the different stages of its execution.

In the following sections I describe some of my neuroscience-inspired improvisation techniques. While illustrating my particular approach to dance improvisation, they also serve the more general goal of demonstrating how one might design an improvisation technique.

Fixed-Point Technique

A number of my improvisation techniques relate to the representation of space. The brain does not accommodate a single, uniform representation of space, but a multiplicity of sensory and motor spaces subserving perception and action [10]. To construct a representation of space, the brain builds on information delivered by the senses. For instance, without information about the orientation of the eyes, head and trunk, it would be impossible to tell that the object that is in front of you when you look straight ahead is to your right if you turn your head to the left.

In order for one to reach for an object, say, an apple, visual information about its location and information about the position and orientation of the body have to be combined with information about the position of the hand relative to the apple, its estimated size and weight and the use to which it will be put [11]. To bring the apple to the mouth, the brain must also "know" the position of the hand holding the apple relative to the mouth. In other words, to determine the location of an object, the brain constructs a world-referenced representation of space based on information delivered by the senses to guide a movement towards it. This information is then transformed into a frame of reference with the relevant part(s) of the body at the origin.

It has been shown that these two frames of reference have a neural correlate in the brain. It was found that some 40% of neurons in the ventral premotor cortex of a monkey respond to both tactile and visual stimuli, meaning that if a neuron fires when a particular part of the body is touched it also becomes active when an object appears near that part [12]. What is more, if the monkey looked in a different direction, these neurons still responded to the presentation of a visual stimulus around that part of the body. The receptive field of some neurons in this brain area therefore appears to be tied to a part of the body, not to the retina—a result, I would like to speculate, that can be extended to other parts of the body.

Now whatever goes on inside the brain (the "computations" and transformations) is only of indirect relevance to dance. However, when I first read about these findings, I realized that both external objects and parts of the body are, or can be, represented in terms of intrinsic and extrinsic frames of reference. And since this distinction is hardwired in the brain, drawing on it cognitively may be a matter of "rewiring." Thus, the position of every body part can be described with respect to any other part of the body and within a world-centered frame of reference (e.g. imagine having to tell someone over the phone where to hold his or her hand, undoubtedly a potentially hilarious task for a television game show).

This dual conception of space forms the basis of a technique that makes explicit use of the ability to switch between multiple frames of reference; my dancers have come to refer to this as "fixed-point technique." I have retained this name because it reminded me of how Brouwer's fixed point theorem, one of the great mathematical theories of the 20th century, was once explained to me [13].

The first thing to observe is that we can fix an intrinsic relationship between two or more parts of the body and maintain that relationship as we move across extrinsic space [14]. For instance, we can stretch an arm and walk around, squat, lie down on the floor, etc., while keeping the arm stretched—that is, while maintaining the intrinsic relationship between arm and chest.

By extending an arm to a point in extrinsic space, we change the intrinsic relation between the arm and the rest of the body. For example, stand up holding the right hand to the chest (Fig. 1a). Now extend the right arm forward as far as possible, while maintaining a parallel relationship between hand and chest, meaning that the wrist has to become progressively more flexed (Fig. 1b). To re-establish the original relation between body (chest) and hand, there are essentially *two* possibilities: either reverse the movement by bringing the hand back to the chest, or walk towards the hand while flexing the elbow and wrist joints (Fig. 1c). In the first instance the body is fixed in extrinsic space; in the second, the hand.

This way of alternating the parts of the body that are held fixed in intrinsic and extrinsic space creates a remarkable variety of movement. For instance, by extending your arm and then fixing the hand in space, you can walk around your hand as if you are holding onto an imaginary stick fixed at its base [15]. You can also keep your hand fixed and "turn towards your arm" by rotating around the shoulder, or put your hand on your shoulder and then squat, leaving the hand fixed in extrinsic space. Of course, one might object that there will always be another intrinsic relationship that is kept constant across different body configurations. This is precisely what dancers become aware of as they practice this technique and what they learn to take advantage of by varying the relationships that are changed or kept constant.

There are many ways to enhance this technique. The relation between hand and chest is only one of many, and, instead of reestablishing a *previous* relation, a dancer can also establish a *new* relation by moving another part of the body: extend the right arm and bring the left knee towards the right hand; then, while returning the left leg to its original position, "take the right hand with you,"

Fig. 2. Global/Local. By switching between "global" and "local" movements a dancer/choreographer can bring structure to a dance while simultaneously expanding or contracting the audience's attention. From left to right: "local" movement of the hands; from top to bottom: "global" movement of leg. (Photos © Ivar Hagendoorn. Dancer: Lia Poole.)

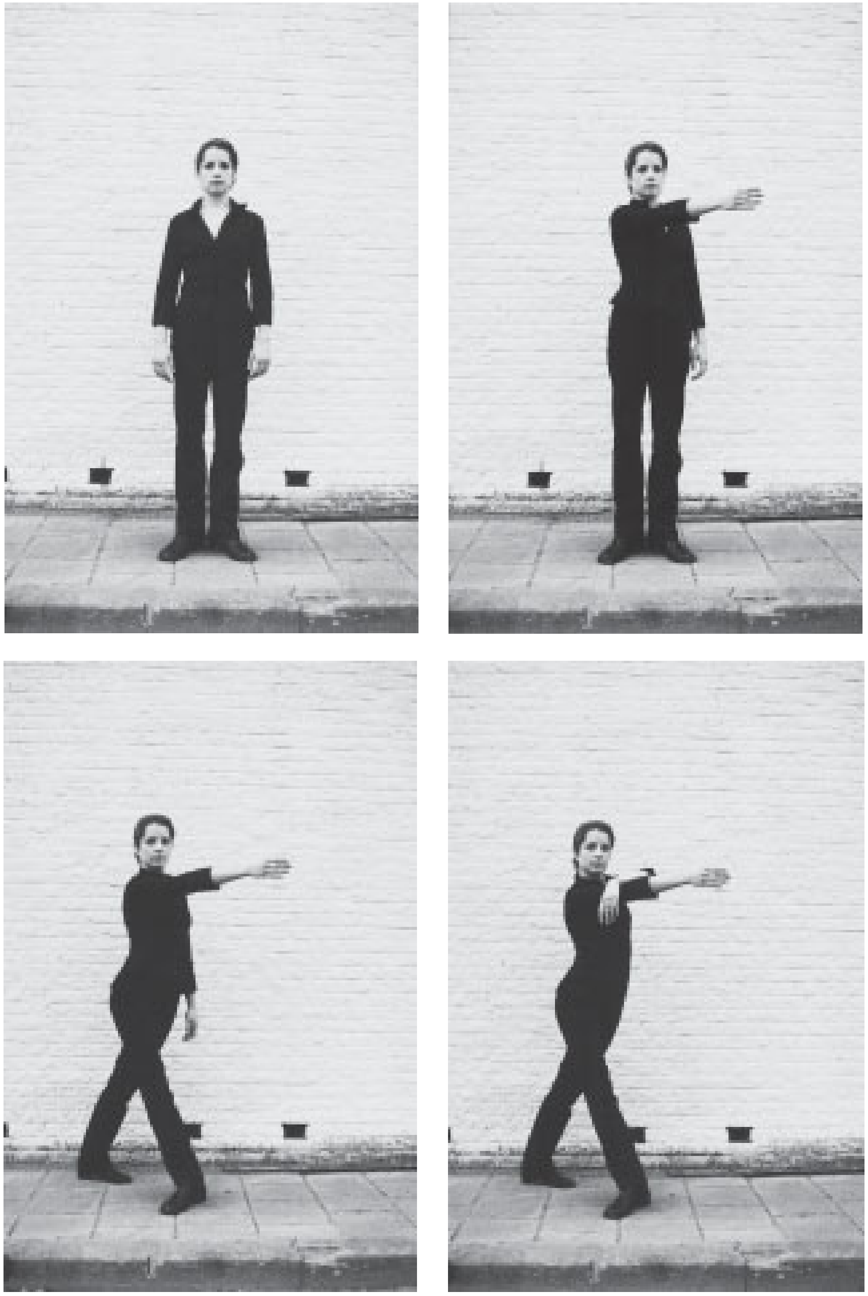


Fig. 3. Changing the leading movement. Move a different limb or part of the body in a different direction at every step. (Photos © Ivar Hagendoorn. Dancer: Ester Natzijl.)

maintaining the new (intrinsic) relationship between hand and knee.

Reversals

An interesting offshoot of fixed-point technique, and one that has become a technique in itself, is what I have called "reversing the acting limb," or "reversals" for short. Suppose you have been bitten by a mosquito on the back of your left hand. To relieve the itching, you scratch your hand with your right index finger. Now, instead of keeping your left hand still and moving your finger along the back of your hand, you could keep your right finger still and move your hand along your finger. This is what I mean by "reversing the acting limb." Even though the example just given may sound artificial, in our everyday lives we sometimes perform a reversal if the situation requires us to do so. For instance, if a glass is too full, we bend forward to sip at it before bringing it to the mouth. As a matter of fact, we rarely just bring the food to our mouth when eating; we also usually adjust our head and body.

The general idea can easily be extended to the whole arm and other parts of the body. If, for instance, you move your right hand along your left arm, you can "maintain the action" or its purpose by reversing the acting limb and moving your left arm along your right hand. In the first instance the hand brushes the arm, in the second the arm brushes the hand. Rigorously applying this task can entail more complicated auxiliary movements. If you *first* move your right hand all the way from your left shoulder along your arm to your left hand and *then* "reverse the acting limb," fixing the right hand in extrinsic space, you are forced either to squat or to bend forward.

This technique has an interesting scientific corollary. It relates to what in the motor-control literature is known as motor equivalence [16]. It has been found that if, during pinching with the thumb and index finger, movement of the thumb is restrained, for instance by a band-aid, its reduced mobility will be compensated for by the index finger. I would suggest that this form of compensation relies on proprioceptive feedback, whereas "my" reversals require (a) an understanding of how two parts of the body contribute to an action and, (b) in the absence—as in dance—of an object as the goal of a movement, an understanding of the spatial relationships within the body and of the body in relation to extrinsic space. The scientific question would then be whether there is a difference in the neural organization of movement between the motor equivalences referred to in the scientific literature and my "reversals," and, if so, where would this difference reside?

Conversions

A well-known observation in the motor-control literature, and an excellent textbook example of the characteristics of the human motor system, is that it is difficult to rub one's stomach while patting one's head [17]. To analyze this phenomenon, known as dual task interference, biokinesiologists distinguish between the temporal and spatial aspects of both movements. Within the spatial domain, a further distinction can be made between iso- and anti-directional movements and between two different trajectories, such as circles and lines [18]; between differences in size, such as of small and big circles [19]; and between differences in orientation, for instance when one arm is in front of the body and one to the side [20]. A final distinction is the use of identical or different end effectors (both hands versus hand and foot) [21].

(a) (b) (c)

Fig. 4. Leading and residual movement. Starting from (a), if the task "bend forward" is strictly applied to the back or spine, gravity will cause the arms to rotate in the shoulders, as in (b). To prevent the arms from "falling forward," an additional force has to be applied to keep the arms tight to the body (c). (Photos © Ivar Hagendoorn. Dancer: Lia Poole.)

These laboratory tasks constitute a technique one might call "concurrent repetitive bilateral movement": concurrent, because it involves simultaneous movements of more than one limb; repetitive, because the movements are cyclical and bilateral, involving two sides of the body. However, because I had already christened one technique "reversals"—a reference to my former career in finance—I opted for the more poetic "conversions" [22]. The dancers I have worked with in developing this technique, while playing with the general idea, independently came up with all of the above possibilities. Interestingly, they also added another possibility, the number of limbs involved: e.g. two hands and one foot; or arm, leg and head.

In motor control experiments, the emphasis is on measuring the interference during the repetitive performance of two trajectories. What is most interesting from the perspective of dance improvisation, however, is switching between two modes: e.g. changing from small clockwise circular movements with the right foot and both hands to a large counterclockwise circle with one arm and small lines with the other hand and foot.

Motor Schemas

A useful concept in the study of motor behavior is that of a motor schema [23]. A motor schema is an abstract representation of a prototypical movement sequence such as a tennis serve or an arabesque. It refers to the pattern or the structure of a movement sequence rather than giving a full description of its dynamics. An arabesque remains an arabesque whether it is performed slowly or quickly, with grace or with vigor. A motor schema can be either simple or complex, which is what makes it such an attractive concept. Schemas are recursive in that they can be decomposed into smaller schemas down to the level of their neural foundation or alternatively embedded in or combined with other schemas to form a new higher-order schema. It follows that new schemas evolve as instances of existing schemas or, in the words of neuroscientist and computer scientist Michael Arbib, "They start as composite, emerge as primitive schemas" [24].

While this has been proposed to underlie how we learn and exercise any movement, the concept provides a powerful approach to *generating* movements. One can either start with a composite sequence, decompose it into smaller schemas (segments) and then recombine them into new configurations or, alternatively, start with a set of small schemas and combine them into larger schemas, whereby the individual schemas can also be transformed.

This approach is one of the cornerstones of William Forsythe's *Self Meant to Govern* (1994) and *Eidos:Telos* (1995), of which *Self Meant to Govern* is now the first part. *Self Meant to Govern* is based on a collection of some 130 movements and a number of associative rules for combining them. First, every one of the 130 movements was given a name such as book, ball, beard, brick, bottle, oyster, pizza, chest, crack, wallet, lion, atlas, faint, zebra. The dancers could then jump from one word to another, in the sense that "honey" could give way to "pizza," because they are both food items, but also because they are both five-letter words. The dancers could also take the last letter of one word as a cue for a movement starting with that letter: "wash" could thus be connected with "honey." The stage design for *Self Meant to Govern* added another dimension. Distributed over the stage floor were several clocks with letters instead of digits, which the dancers could use to find a word/movement. Finally, any given movement or position could remind a dancer of another movement from the vocabulary. Thus, if for whatever reason a dancer would find himself in a position in which the hands are held together, this position could be connected with another movement from the vocabulary involving both hands.

I myself use a potentially infinite action vocabulary, comprising among other things everyday routines, choreographed phrases and interesting sequences from previous sessions. In addition, at any moment during a performance, a dancer can isolate a sequence and subsequently perform a series of variations on that movement. I have also developed a set of transformations that extend any given movement or position to a virtual "family" of related movements and positions, as the following project illustrates.

In 2002 I created an Internet project [25] in which a database of movement sequences (to date, stills only; future plans will incorporate movement sequences) inspired by the sign language used by option traders was coupled to financial data collected in real time from the Internet. The actual signals consist of movements of the hands and arms only. This being a dance project, we wanted to transcend reality while retaining the systematic nature of the original motions. Using a small number of elementary movements, positions and transformations, we were able to give an accurate description of each movement/position and create a "generative grammar" for their recombination. For instance, a movement could be performed while standing, kneeling or squatting; the spine could be bent or straight; the arms parallel or crossed; the direction of movement of an arm, leg or finger could be upward, downward or sideways. The movement could involve one or two hands or fingers, which could be held against the front, back (if applicable) or side of the chin, head, nose, knee, arm or back.

Global/Local

Several of my techniques address the sequencing and layering of movements. One of the most powerful techniques in this respect is what I have called "global/local" (Fig. 2). Local movements are defined as movements that span a small region in space—scratching one's thigh, patting one's foot or rolling one's eyes—and relate to what in Cunningham technique are referred to as isolations. Global movements are movements that extend into space and usually involve the whole body or outstretched arms or legs. However, what counts as global or local is in part defined by previous and subsequent movements, and that is what this technique addresses. By switching from global to local movements and vice versa, a dancer can bring structure into his or her improvisation.

Interestingly, this also works from the audience's point of view: attention is "expanded" or "contracted" in space. Knowing how the visual system responds in this respect, a dancer can freeze into a pose, slowly stretch an arm to the side, freeze for a few seconds and then abruptly open the hand. Since the arm was the last moving limb, this is where the audience's attention was fixed during the second freeze. The opening of the hand narrowed attention down to the hand. Moving a foot would have suddenly shifted attention to another location and part of the body.

Changing the Leading Movement

An essential feature of "fixed-point technique," "reversals," "conversions" and "global/local" is the ability to switch: e.g. from drawing clockwise circles to counterclockwise circles or from fixing an intrinsic relationship within the body to fixing a point in extrinsic space. One technique specifically addresses switching from one limb or direction to another. It was inspired by the observation that dancers tend to continue a movement in the direction of what one could call the leading limb or movement. If an arm is extended in a certain direction you can often tell that the rest of the body will move in the same direction.

What I have called "changing the leading movement" and what some of my dancers refer to as "going against the logic of the movement" entails moving one limb in one direction and then moving another limb in another direction (Fig. 3). The motion thus switches from right arm to left shoulder to left leg, etc. "Changing the leading movement" may of course become a logic in itself. A dancer should therefore change how she changes the leading movement and alternate it with "continuing the leading movement."

This technique builds on the conceptual distinction between leading and residual movement introduced by William Forsythe and the idea that, within a composite movement, one limb can be "prioritized." A movement can be seen as a task assigned to a particular part of the body. To perform the movement, that part has to be integrated with the present configuration of the body. Consider the task of reaching for an object on a table when sitting in a chair. If the object is near the current position of the hand, the movement can be relatively simple. However, the farther away the object, the more the body has to be stretched and the more auxiliary movements are required to bring the hand towards the object. These auxiliary or supportive movements are one example of "residual" movements. Residual movements can also follow from the movement of the leading limb without serving any function. Consider, for instance, the simple task of bending forward while standing up (Fig. 4). If the arms are left loose, gravity will cause them to remain in an approximately vertical relation to the ground, causing a rotation in the shoulder. Bending the spine therefore changes the position of the arms relative to the rest of the body. The idea is that when bending forward one can "develop" or "prioritize" some of these "residual" movements [26].

Merging Motor Control and Perception

The brain does not only control movement; it is also where visual stimuli, for instance dance performances, are processed and transformed into an aesthetic experience. When designing a technique the response of a viewer watching the resulting movements (i.e. the viewer's brain) can be taken into account. For instance, the visual system is assumed to extrapolate the trajectory of a moving object. I have speculated that congruity with and deviation from this internally generated, anticipated movement have an emotional correlate, which, within a proper framework, can be called aesthetic [27]. Congruity between the actual and the simulated movement can be associated with grace and beauty, whereas deviation may fit with the Kantian notion of the sublime. As a result of playing with this natural tendency of the brain, for instance by "changing the leading movement," the brain can be put on the wrong track, thus raising the awareness of the viewer, who will have to work harder to follow the movement.

The brain also enjoys patterns [28], and this is why decomposing and recombining a movement is such a successful technique. For instance, by performing a movement first in one orientation and then somewhere else onstage in another, a dancer causes the brain of the viewer to perceive both novelty—in the form of a different angle—and familiarity—in the form of a similar movement: in other words, a pattern in both space and time.

Conclusion

Learning and practicing the techniques described in this article requires a form of understanding. This is what distinguishes the process from pure motor learning, such as learning to swim or classical ballet training. Interestingly, with practice not only are motor skills improved, but the understanding of the concept behind a technique is also enhanced. The more a dancer practices fixed-point technique, the more aware she becomes of the duality of intrinsic and extrinsic space. These techniques therefore merge cognitive and motor faculties and raise intriguing questions about their intertwining in the brain.

Even though my focus here has been on dance improvisation, the techniques may serve the more general purpose of movement composition (choreography); at the same time practicing the techniques enhances dancers' coordination and versatility. In addition to their artistic merits, some techniques betray their source of inspiration in that they not only apply the insights gained through scientific research but also can themselves be regarded as experiments. However, in their present form they inspire hypotheses rather than addressing them and as such are like answers waiting for a question [29].

Epilogue: Algorithmic Dance Improvisation

Because of its modularity, this approach to generating movements has great appeal for roboticists. I have discussed with computer scientists working in robotics the possibilities of implementing some of my techniques on a humanoid robot.

A computer program can systematically go through all possible movements and body configurations, not all of which will appeal to a human observer. Comparing the performance of a robot and a human dancer may thus not only reveal movements overlooked by a dancer but may also tell us more about the implicit (aesthetic) choices made by a dancer when improvising and by viewers who later watch the movements.

Unfortunately, most of the techniques described here are too complicated to be implemented using a robot or avatar. As a thought experiment, I reversed the problem and started with the simplest possible movement, one that can be performed by a robot: a one-degree-of-freedom movement in the shoulder—in other words, moving the arm back and forth. Exploring what can be done within such tight constraints is also an artistic challenge [30].

One of the new techniques that came out of this thought experiment involves "coupling" two limbs; that is, if both arms are extended in front of the body, both are raised above the head (if the action was "raise"). If only one arm is extended in front of the body and the other arm is in another position, this technique quickly becomes a challenge for human dancers. On a robot, however, one could virtually (i.e. algorithmically) connect any two limbs and have one limb "follow" the other. Another technique that might be successfully implemented on a robot, and which I have already used in my work with "real" dancers, uses the bilateral symmetry of the human body. If the right arm is in a certain position, the left arm is brought to the same position, whatever its original position. Above I observed that a dancer could recall some previous movements and recombine them in a new sequence. Since a robot can store any number of movements or motor commands and "replay" them, having robots perform this technique could offer a new range of aesthetic possibilities that exceeds human capacities.

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13. If you stir a cup of coffee—assuming no coffee is spilled—odd as it may sound, at least one bit will remain at its original location. For a popular introduction to Brouwer's fixed point theorem and its applications, see J.L. Casti, *Five Golden Rules: Great Theories of 20th-Century Mathematics and Why They Matter* (New York: Wiley, 1996).

14. For ease of reference I refer to the various body-part-centered frames of reference as intrinsic space and to the world-centered frame of reference as extrinsic space.

15. Moving around an imaginary point, e.g. keeping a hand on the floor and then walking around the hand, is sometimes referred to as "space-hold technique." It is one particular instance of fixed-point technique. I would like to thank an anonymous reviewer for drawing my attention to it.

16. For a review see J.H. Abbs and K.J. Cole, "Neural Mechanisms of Motor Equivalence and Goal Achievement," in S.P. Wise, ed., *Higher Brain Functions: Recent Explorations of the Brain's Emergent Properties* (New York: Wiley, 1987). I would like to thank the anonymous reviewer for drawing my attention to this work.

17. M.S. Gazzaniga et al., *Cognitive Neuroscience: The Biology of the Mind* (New York: Norton, 1998) p. 408.

18. E.A. Franz et al., "Spatial Logical Constraints in a Bimanual Task," *Acta Psychologica* **77** (1991) pp. 137–151.

19. E.A. Franz, "Spatial Coupling in the Coordination of Complex Actions," *The Quarterly Journal of Experimental Psychology* **50A** (1997) pp. 684–704.

20. D.J. Serrien et al., "The Identification of Coordination Constraints across Planes of Motion," *Experimental Brain Research* **128** (1999) pp. 250–255.

21. H.H. Ehrsson et al., "Simultaneous Movements of Upper and Lower Limbs Are Coordinated by Motor Representations That Are Shared by Both Limbs: A PET Study," *European Journal of Neuroscience* **12** (2000) pp. 3385–3398.

22. In finance, reversals and conversions are option trading strategies.

23. For an overview of schema theory see M.A. Arbib et al., *Neural Organization. Structure, Function and Dynamics* (Cambridge, MA: MIT Press, 1998).

24. See Arbib [23].

25. See <http://www.thefisheraccount.com>.

26. This is my interpretation of a demonstration William Forsythe once gave to the dancers at the Frankfurt Ballet.

27. See Hagendoorn [1].

28. See Hagendoorn [1] and Ramachandran and Hirstein [2].

29. Videos of the techniques described here as well as a number of other techniques can be viewed at <http://www.ivarhagendoorn.com>.

30. I subsequently created a solo dance, not surprisingly called *One Degree of Freedom,* exploring this idea.

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