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CHAPTER THREE

Musical motion and performance: theoretical and empirical perspectives

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THEORETICAL ISSUES

Traditional perspectives

Experiences of movement – of its character and expressiveness – are vitally important to composers, performers and listeners alike. This fact is borne out on several levels of discourse. As action plans, musical scores provide general instructions on how instrumentalists and singers may execute, control and coordinate their motor actions, the details of which are determined largely by the performers' musical sensibilities. Undergraduate harmony textbooks, theoretical treatises, analytical essays and historical studies all evoke images of movement presumably associated with the musical experience. 'Motion speak' may be as commonplace as the phrase 'C♯ moves to D', or as colourful as David Lewin's description (1982: 53) of a striking moment in Schubert's 'Auf dem Flusse', where the singer 'takes a sharp stone and scratches a G♯ on the icy surface of the [pianist's] right hand'. Do these expressions point to a genuine perceptual experience of movement or a propensity to speak in metaphor (or both)? If the former, then what is the nature of that experience?

In some form or another, these questions have occupied the minds of theorists and philosophers throughout the centuries, and more recently the minds of psychologists. Collectively, they have given us two basic categories with which to frame our understanding of musical motion: namely, *rhythmic motion* and *tonal motion* (the latter often being subdivided into melodic motion and harmonic motion). In the light of these categories, studies of musical motion tend to concentrate on one of four topics: (1) the source of motion; (2) the organisation of motion; (3) the character, or quality, of motion; and (4) the listener's perception and response to motion. In this part of our chapter, we focus on the first topic.

Identifying the source of movement has been of the utmost concern to music theorists. Phrases like 'arises from', 'basis of', 'result of' and 'product of' crop up in numerous discussions. Not all theorists, however, agree about the object of these phrases. Some see it as linked to the temporal patterning of sounds – to the rhythmic structure of music – and to the feeling of pulse and pulse-tempo. For many, rhythm in this more traditional (more restricted) sense is patterned movement. Esther Gatewood (1927) observed that listeners sense movement most strongly when a lively and distinct rhythmic pattern, rather than melodic contour or harmonic structure, predominates in the music. But some listeners, mostly analysts, have reported sensing movement across larger structural levels, as when successive rhythmic groups progressively increase or decrease in length, in effect producing large-scale deceleration or acceleration. The opening eight bars of Beethoven's Piano Sonata in F minor Op. 2 No. 1 are commonly cited to illustrate the latter effect.

Somewhat related to all of this is the more general idea that 'succession' itself is evidence of motion. This is the portrait Maury Yeston (1976) paints in his historical survey of musical rhythm (Chapter 1) and in his Schenker-influenced theory of rhythm. To be sure, the relationship between succession and motion has long been noted. As Jean de Muris ([1319] 1965: 172) put it, 'sound is generated by motion, since it belongs to the class of successive things . . . Succession does not exist without motion.'

More recently, Christopher Hasty (1981) has given careful attention to this relationship, particularly in terms of the continuity of succession in the face of discontinuous change. Bringing together the insights of the philosopher Errol Harris with the psychological notion of the 'perceived present' (a present in which events no longer sounding are nonetheless part of one's immediate consciousness), he concludes that 'motion arises . . . from the unification of events' (: 192). This unification is mainly temporal in origin, for it depends on the duration between successive events, although other structural factors may help to unify the events. Not surprisingly, de Muris also spoke on this subject: 'Time inseparably unites motion' ([1319] 1965: 172).

Looking beyond the succession of events, other theorists have pointed to the time-honoured qualities of tension and relaxation as sources of motion. These qualities manifest themselves melodically, harmonically and rhythmically.

Melodically, motion occurs when 'unstable tones' resolve to 'stable tones'. Victor Zuckerkandl ([1956] 1973) referred to these relative stabilities as the 'dynamic qualities' of tones. He averred that the experience of musical motion (specifically, tonal motion) is not based on the differences in pitch within a melody, or even on the melody's rhythmic structure, since, in his mind, rhythm is not a uniquely 'musical' phenomenon and, therefore, could not be the source of 'musical' motion (: 76). For motion to be musical it must be based on the qualitative differences in scale-degree position. He proposed that the diatonic scale, construed as a 'dynamic field', abstractly represents these differences as varying 'degrees of stability and instability' (: 98), the tonic being the most stable, the leading note the most unstable.[1] For Zuckerkandl, the

1 Zuckerkandl was not the first to observe these 'qualities'. Over a century earlier, Fétis ([1844] 1879) spoke of them as *affinités*. Kurth (1917), too, spoke of them, though in a seemingly impenetrable language. Beginning with the phrase 'Melodik ist Bewegung' (: 1), he set out to explain musical motion in terms of an 'absolute melody', an invisible stream of ebbing and flowing 'psychic forces'. Kurth believed that such 'forces' generated the transitions between discrete tones, which function 'only as markers along the path of a *Bewegungszug*' (Rothfarb 1988: 14). The main 'force' driving this motion is scale-degree $\hat{7}$ (: 9). It should be noted that Zuckerkandl ([1956] 1973) also applied the concept of 'dynamic quality' to the metrical order of pulses. Therefore, rhythm becomes motion only when it is in the dynamic field of metre (: 174).

dynamic field is imbued with a 'tonal force' with or against which the tones work. The natural state of this force is motion 'towards' a stable tone ($\hat{7}$ to $\hat{8}$, or $\hat{2}$ to $\hat{1}$), which acts as a centre of tonal gravity. Motion 'away from' this centre implies a succession of tones working against the natural state. In essence, dynamic qualities are directional qualities.

Harmonically, the sense of motion corresponds to the tension of dissonant intervals or chords resolving to consonant intervals and chords. As understood by some earlier writers, the primary aesthetic role of dissonance was to make the subsequent consonance 'sound more agreeable', providing 'great pleasure and delight' in its resolution (Zarlino [1558] 1983: 53). However, later writers such as Norman Cazden (1945: 5) came to view intervallic and harmonic dissonance as causing 'a restless expectation of resolution, of movement [to consonance]'. Walter Piston (1978: 7) is even more straightforward in this regard: 'The essential quality of dissonance is its sense of movement.'

Rhythmically, tension results from various forms of temporal 'conflict': local syncopation, complex polyrhythms ('rhythmic dissonance', according to Yeston (1976: 89–102)), rhythmic groupings 'out of phase' with metric groupings (another example of 'rhythmic dissonance'), metrically weak cadential endings and the like. But these conflicts, as well as the other tensional qualities of musical structure, are not so much sources of motion as they are sources of 'directionality'. In the words of David Epstein (1990: 198), 'Tension means energy unresolved and unresolved energy ultimately means forward motion.' Put differently, the tensional qualities of musical structure induce the expectation of resolution, in effect casting the listener forward in time. Nevertheless, Mari Riess Jones (1981: 37) characterises this future-orientated experience as 'psychological motion', which she attributes not merely to tension, but more generally to 'objective regularities in musical patterns' to which listeners of a given culture have become attuned and which they have learned to expect. The melodic and harmonic 'expectancies', as she calls them, induce motion-like percepts, i.e. subjective analogues of motion.

Looking more broadly at musical rhythm, some theorists have proposed that the changing properties of musical structure – pitch, duration, grouping, dynamics, timbre and texture – convey 'an analogical impression of motion' (Berry 1967: 8). Jan LaRue (1970) describes these parametric changes as 'sources of movement'; Bernard Vecchione (1987) calls them 'factors of mobility' (*facteurs de mobilité*); and a century earlier Eduard Hanslick ([1854] 1957) captured them in the well-known phrase 'tönend-bewegte Formen'.

One problem with this broad view of musical motion is that it can lead to the unfortunate conclusion that every kind of change on every level of musical structure is a potential source of motion. Indeed, Wallace Berry reaches precisely that conclusion (1967: 8): 'in music, change is motion'. But clearly this is an over-generalisation. We no more perceive a change in musical texture as an instance of *motion* than we do a change in physical texture, such as the surface of a car after a heavy hail storm. Both are significant events, to be sure, but not motion events, at least from the perspective of what James Gibson (1979) called the 'ecological level' of perception (the level situated between the microphysical and macrophysical extremes of reality). Although the perception of motion, musical or otherwise, is clearly linked to the perception of change (we shall reaffirm this point below), without proper constraint the idea that change in music induces an experience of motion has little explanatory power.

Countless others have spoken to these and similar ideas. Among the philosophers, Henri Bergson (1946) and Susanne Langer (1953) are perhaps the most influential. Psychologists other than Jones have also had their fair say, specifically, about melodic motion. For example, Roger Shepard (1981, 1984) suggests that melodic motion is the auditory equivalent of apparent motion, the experience of which 'seems to fall somewhere between perception and imagery' (1984: 423). This is different from the auditory illusions of locomotion observed by Harold Burtt (1917) or electronically simulated by John Chowning (1971) for compositional purposes. Rather, it is a mental image of a sonic object, a single tone, rising and falling in pitch space, in effect traversing an imagined path. Shepard has reason to believe that this 'auditory image' (to borrow from McAdams 1984) is evidence that 'the spatial apparatus of the brain, acquired through protracted interaction with concrete physical space [,] . . . has come – by extension or by preemption – to represent relations and transformations in spaces that are more abstract or metaphorical' (1981: 318). This explanation of melodic motion has much to commend it, especially since it sidesteps the problems inherent in the tension/relaxation theories noted above – problems such as mistaking the sources of 'directionality' for the sources of 'motion'. However, it accounts for only one part of the complex experience of musical motion. In the following section, we shall consider another part of the experience, though one rarely acknowledged by scholars.

Different levels of musical awareness

Introspection, the heart of all phenomenological enquiry, has a way of obscuring one's vision of the obvious. Ludwig Wittgenstein (1953: 50) perhaps said it best: 'The aspects of things that are most important for us are hidden because of their simplicity and familiarity. (One is unable to notice something – because it is always before one's eyes.)' Traditionally, to explain the source of musical motion, theorists, philosophers and psychologists alike have turned to musical structure, which by most accounts is abstract. This has led some to believe that the motion heard is virtual, illusory or abstract. In the words of Roger Sessions (1950: 20), 'The gestures which music embodies are, after all, invisible gestures; one may almost define them as consisting of movement in the abstract, movement which exists in time but not in space, movement, in fact, which gives time its meaning and its significance for us.' Hidden from this view is perhaps the most obvious source of musical movement: the human performer. Why have so many theorists failed to acknowledge that musical movement is, among other things, *human* movement?[2]

[2] Pierce (1978: 24) is among the few who have acknowledged the crucial link between performance movement and musical movement: 'I recognized that a performer necessarily renders musical movement with

Despite the differences in focus, the explanations discussed in the previous section share an unnecessarily restrictive view of music's ontological status: that while performers must move to produce music, such movements exist 'outside the music proper' (Epstein 1981: 197 n. 5). But what is 'the music proper'?[3] A perusal of the analytical literature on Western music will reveal that 'the music proper' (or 'music as music') is invariably conceived in terms of such things as melodic contour, harmonic progression, phrase relations, structural function, affective content and the like. In short, 'the music proper' is inextricably linked to the structure of music.

Defined as such, however, music stands apart (presumably in cognition) from those who perform it. This is a peculiarly Western conception of music, emerging perhaps only within the last two or three centuries. It is our belief, however, that the idea of musical autonomy (as some call it) *reflects but one mode of musical awareness among several.* In this regard, we agree with John Baily (1985: 258) when he writes: 'Music may be as much a motor event as a sonic event, as well as, of course, a social fact.'

The idea of multiple modes, or levels, of musical awareness, which is implicit in Baily's statement, has found resonances in the work of several other researchers. For instance, Stephen Handel (1989: 181) identifies three 'levels' of event awareness, each representing a different, 'after-the-fact attempt to specify the characteristics of [the] event'. At one level, a listener may hear the physical characteristics of sound, its intensity, duration, pitch and so on. At another level, the listener may perceive other (perhaps subjective) qualities such as 'warmth', 'roughness' and 'hollowness'. (Although Handel does not say whether these are the qualities of sound itself or of the environmental objects involved in the event – the hollowness of a perfect fifth versus the hollowness of a tubular bell – what is important here is that the listener can attend to the qualities apart from their source.) At yet another level, what we call the 'ecological level', the listener may directly perceive the environmental objects, surfaces or substances involved in the event. In other words, the listener does not merely hear the *sound* of a galloping horse or bowing violinist: rather, the listener hears a *horse galloping* and a *violinist bowing*.

As regards the perception of music, Eric Clarke (1985) has proposed that a listener is apt to hear three different types of events based on the information in musical sound. The first type corresponds to Handel's third level: the musician playing an instrument or singing. We call this a *performance event*. The second type is abstract and is often described as a *structural event*. Hearing structural events means hearing the articulation of

the physical movements of playing: blowing, tonguing, breathing, fingering, foot pedaling and the manifold gestures which in playing encircle these elementary movements.'

3 On this matter, Clifton (1983: 2) argues that while a sound source, such as a piano, 'must be there if we are to experience music at all . . . it is precisely the knowledge that such and such an instrument is indeed the sound source which is not necessarily included in the experience itself'. There is nothing particularly problematic about this statement, given its context. However, what he says shortly thereafter is specious at best: 'I am constantly making an association between these sounds and the objects [pots and pans] which produce them. They are signs of something occurring in the factual world, and music, whatever else it is, is not factually in the world the way trees and mountains are' (: 3). But music *is* 'factually' in the world, inasmuch as the objects (the musicians-cum-instruments) that produce musical sounds are in the world. That one must transcend the physical aspect of the musical event in order to experience it 'as music' is a condition imposed by Western culture. It is not a universal condition of musical experience (see Baily 1985).

motives, phrases, durational patterns, cadential progressions and so on. The third type of event is also abstract but corresponds to what Alf Gabrielsson (1973a, 1973b) calls the 'emotion character' of music, patterns of movement whose general characteristics are similar to bodily movement symptomatic of human emotions, moods or feelings. We call this an *expressive event*. Although there may be several more ways of experiencing musical events, we shall limit our discussion to these three.

The common thread passing through each of these perspectives is the perception of movement. On the ecological level, the source of this movement is the human performer. In this regard, musical movement is human movement. To the listener attending to music as a performance event, this fact is unmistakably clear, although the advent of electronic and computer-generated music may confound the perceptual experience. In those instances where the performer is indeed human, the listener may hear any number of 'articulators' (lips, fingers, hands) or 'articulatory systems' (finger–hand–arm units) moving rhythmically relative to the surface of an instrument (including the mouth of a singer). Note that seeing these movements is not a prerequisite to hearing them. By 'hearing' we do not mean that the listener must or can identify the mechanical details of the 'articulatory movement' or even the continuity of movement between each discrete articulation.[4] Such an ability may come with repeated aural experience, perhaps coupled with watching the performance, or it may draw on one's personal experience as a performer. At some point in one's experience, this ability will be no more necessary for the aural perception of performance movement than it is for the perception of someone walking in the dark. No one needs to see how high the feet are being raised to hear someone walking or to sense the continuity of the leg movements between the discrete footsteps. The series of footsteps is a natural, lawful consequence of the continuous movements of the legs (indeed, of the whole body). In this respect, their timing and amplitude 'specify' the continuity of movement. The same, we submit, is true of performance movement: the timing and amplitude of the sound-producing attacks lawfully specify the movement spanning a group of attacks, which one can hear as a unit of motion – as a gesture. Some may object to this claim on the (false) assumption that all one hears are the attacks, for they alone produce the sound. However, attacks are nested events, constrained by, affected by and thus lawfully specific to the performer's actions. To hear the attacks is to hear the performer move. That a listener fails to identify precisely where a pianist's hand is at a given moment reflects his or her lack of experience, not necessarily an inherent limitation of the auditory system.

It is instructive to note here that articulatory movements correspond more or less to the so-called 'surface rhythm' of music. Put differently, the rhythmic motions of the performer and of the 'musical object' are essentially one and the same. Of course, there are many instances in Western and non-Western music where the movements of the performer and the resultant auditory patterns do not correspond in a simple one-to-

4 Other types of performance movement include those that sustain sounds; those that modify sounds, either sustained or in a series; and those that are perhaps more visually than aurally interesting, but nonetheless affect the sound of the performance (for better or worse).

one fashion, if at all; the compound (or polyphonic) melodies of J. S. Bach's works for solo violin or solo cello are familiar examples.[5]

We readily acknowledge that the perception of musical movement is not limited to hearing the articulatory movements of a performer. In fact, from the other two perspectives, the performer quickly fades from view by most accounts. When attending to a sequence of sounds as a *structural* event, the listener is likely to attribute the motion heard to a 'musical object' – a melody, for example. By attending to the same sequence as an *expressive* event, the listener could hear it as an emotionally charged gesture, the source of which might remain indeterminate (Maus 1988). In either case, the experience of movement is undeniable.

Despite the obvious differences between these experiences of movement, we believe they have a common origin: the performer is the ultimate source of the movement perceived. True, the abstract image of a sonic object rising and falling in pitch space bears little, if any, resemblance to a pianist's fingers and hands moving across the surface of the keyboard. And if one takes into account the physical and mechanical differences between instruments, the resemblance becomes even more remote. Yet, without the performer's rhythmic movements (real, imagined or computer-simulated), the perception of melodic motion (for that matter, any motion) would be impossible. Simply put, patterned articulatory movements create patterned sequences of tones. In other words, articulatory movements are sound-structuring movements. The motion one attributes to a succession of tones – including its pacing, its character, even its directionality – belongs first and foremost to the performer. That a listener reports hearing a sonic object in motion, rather than a performer, reflects the listener's perceptual attitude towards the musical event.

Gibson's theory of perception and information

To understand how the same acoustic signal can support at least three different perceptual experiences of motion, we turn to the theoretical insights of the American psychologist James Gibson (1966, 1979).[6] Despite the controversy surrounding Gibson's 'ecological approach' to perception (a controversy based largely on his out-of-hand rejection of many essential concepts underpinning the information-processing

5 Kubik made a similar observation about his encounter with African xylophone music: 'Our playing sounded much more complicated than it actually was, and I heard a number of rhythm patterns which I was sure that none of us had played, while on the other hand the rhythms which we had actually played were inaudible on the tape' (1962: 34). Although the primary function of the auditory system is to identify the location, source and nature of events, the human brain seems to have developed a 'mechanism' for detecting abstract pitch–time relations, independently of how well or poorly they match the spatio-temporal structure of the performer's articulatory actions. Bregman (1990) refers to this mechanism as 'auditory scene analysis', the principal effect of which he calls 'auditory stream segregation'. In most cases, however, the correspondence between what the performer does and what the listener hears on the musical surface is direct. Ecologically speaking, to hear a melody is to hear, among other things, a musician move relative to the surface of an instrument (and that includes the vocal apparatus).

6 Within recent years, several musicians and music psychologists have made significant contributions to what is called 'ecological acoustics' (complementing Gibson's work in 'ecological optics'). Most notable among them are Balzano (1986, 1987), Clarke (1987), Jones (1976, 1981, 1986, 1990a, 1990b), Jones and Hahn (1986), and Risset (1988).

approach, concepts like 'mental representation'), most psychologists acknowledge Gibson's contribution to the present understanding of perception. In particular, they cite his emphasis not only on the study of natural, or 'ecologically valid', encounters with one's environment, but also on the idea that the environment is rich in information about its structure and dynamics. Under favourable conditions, this information is sufficiently available to the perceptual systems, thus enabling the perceiver to tailor his or her actions to the environment.

During the mid to late 1950s, Gibson began to think that perception is based not upon discrete sensations, as commonly believed, but upon the 'pickup' of 'stimulus information', or simply 'information'. He had long since recognised, like many before him, that the environment both changes and persists. A child smiles, thus transforming the contours of his or her face, yet one continues to see the same face. Gibson proposed that the flowing pattern of light (the 'optic array', as he called it) must contain information 'specific' to both the changing and the persisting features of the face.

Interestingly, the information in light, sound, touch and so forth is not concrete like the objects and events it specifies. Rather, it is abstract and formless, consisting of relational invariants defined over a transformation – in other words, invariants of a higher, mathematical order. As Gibson understood it, the perception of a relatively permanent, yet ever-transforming environment may be as simple as extracting 'the invariants of structure from the flux of stimulation while still noticing the flux' (1979: 247), however complex the process of extraction may be.[7]

It is reasonable to assume that different aspects of the stimulus information correspond to different features of the event. For example, in listening to Kiri Te Kanawa sing 'O mio Babbino caro', one may identify at least three basic properties of the event: its *location* (on the concert stage), its *source* (Kiri Te Kanawa) and its *nature* (singing). Yet, which aspects of the acoustic information specify 'Kiri Te Kanawa' and which 'singing'? Do we assign only the invariant features of the sound pattern to the persistent sound source and the changing features to the transient nature of the event?

According to Robert Shaw and John Pittenger (1978), a working solution to this problem begins with the understanding that events are 'invariant patterns of change':

> For to the extent that change proceeds according to some style, then to that extent change can be specified by invariant perceptual information. A motor can run invariantly, a couple can waltz invariantly, or a flower can grow according to a natural rhythm – an invariant policy of growth. None of these are static phenomena, rather they are distinct *events* precisely because they do exhibit different patterns of change. (: 188)

[7] Determining what remains invariant under transformation is by no means a simple task. Whereas change is usually easy to measure, isolating invariants is a perennial source of consternation. Handel (1989: 224) even goes so far as to suggest that 'it requires an act of faith to believe that a higher-order variable can be discovered'. Assuming, though, that Gibson's hypothesis is correct, the problem here may have more to do with the analytical method devised by the investigators than with the existence or nonexistence of such a variable. Balzano's (1987: 178–9) solution to this problem is to assume that perception itself is a 'species of measurement' and that what it measures need not 'show up' on a conventional measuring device. This is not a convenient sidestepping of the issue but rather an important acknowledgment that not all objective properties of our environment must be objectively measured to demonstrate their objective existence. Invariants, which one can model with the powerful tools of mathematical group theory, may have just such an existence, though forever eluding physical measure, save by the human observer.

With this novel understanding of change, it became necessary for Shaw and Pittenger to postulate two types of invariants: 'transformational' and 'structural'.

Transformational invariants are those relational aspects of the information that specify the identity of a particular pattern of change. Whenever Kiri Te Kanawa sings, she regulates the movements of her vocal tract in a manner distinguishable from most other forms of human activity, even speech. Consequently, her finely controlled vocal movements structure the surrounding air, distributing the initial energy of her actions through a sound field. The sound spectrum and temporal course of the resulting acoustic wave map onto the degree and rate at which she physically changes pitch and modulates the force of air through her vocal tract. Thus, one hears her *singing*.

Structural invariants, on the other hand, are relational properties specific to the structure of the source object undergoing a particular style of change. For the event 'Kiri Te Kanawa singing', these properties will correspond to the invariant structural features of her vocal tract and any other part of her body which may affect her production of sound. Her unique physical characteristics lawfully constrain the manner in which she sings and, consequently, the sound she produces, thereby allowing us to distinguish her from other singers. Presumably, the perception of a pianist's 'touch' also depends on the pick-up of structural invariants.

Though conceptually distinct, structural and transformational invariants are functionally interdependent. One perceives 'Kiri Te Kanawa' only as one encounters her singing, talking, laughing, walking and so on. Her identity is intertwined with what she does as a physical, dynamic being. And yet what she does – how she sings – is lawfully determined by the structure of her body.

The foregoing discussion exemplifies Sverker Runeson and Gunilla Frykholm's (1986: 262) claim that 'movements specify their causes', a claim theoretically supported by the Kinematic Specification of Dynamics (KSD) principle. Stated simply, the kinematic properties of an ambient array – the velocity profile of a sound sequence, for example – specify the dynamic factors of the source that generated the movement pattern, factors such as mass ratio and the effective damping characteristics of the source. We believe that the KSD principle, initially applied to visual perception, applies equally well to the auditory perception of events. Indeed, many analyses of musical sound are, in effect, analyses of the kinematic properties specific to the dynamics of a human performer. The difference here is that we are ascribing ecological values to traditional psychoacoustic variables.

Still, the problem remains: if acoustic information is lawfully specific to its environmental source, then why is the performer transparent to some listeners? In part, we have already answered this question. But as Clarke (1985) correctly notes, a perceiver can use perceptual information in various ways, especially when the experience entails looking at a painting or listening to music. The relational invariants in musical sound not only specify the structure and transformation of a performer, but also may constitute the structure and transformation of an imagined 'musical object', evident by such comments as 'the sound of a perfect fifth' and 'the transposition of the second theme into the tonic key'. Furthermore, it may be that both representational and nonrepresentational (absolute) forms of music embody relational invariants specific to natural classes of movement, including those symptomatic of human emotional states.[8] Mari Riess Jones and June Hahn (1986) refer to these as 'prototypical invariants'. Having extracted these invariants, a listener may spontaneously structure his or her awareness of the musical event in terms of familiar motion patterns, such as galloping and breathing, or emotional behaviour, such as that associated with rage or joy. This level of awareness, we presume, relies heavily on the listener's imagination.

In analysing performance movement, one may refer to several interrelated factors: the mode of production (bowing, tonguing), the style of articulation (staccato, legato), the physical 'shaping' of a sustained sound (vibrato, lip trill), the rate of movement (tempo and timing, or agogics), the pattern of movement (rhythm, in the narrow sense), the force of movement (dynamics) and even the changes in pitch (musical space). All of these, some to a greater degree than others, are represented kinematically in the acoustic array and, upon their particular extraction, will shape the listener's perception of musical movement. We have suggested, relying on Gibson's theory, how the listener picks up and uses this information. In the second part of this chapter we present a selective review of empirical studies which specify in more detail the nature of motion information in the musical signal, and which demonstrate that listeners can indeed recover this information and convert it into overt body movement.

EMPIRICAL APPROACHES

Music is made by moving hands, fingers or extensions thereof over an instrument, and the dynamic time course of these movements is reflected to some extent in the resulting stream of sounds. Conversely, people listening to music frequently perform coordinated movements ranging from foot tapping to elaborate dance. Although these movements on the listener's side are not the same as those of the performer, they are certainly not unrelated. At the very least, they share a rhythmic framework which is transmitted from player to listener via the sound structure.

In many cultures this close connection of music and body movement is so obvious as hardly to deserve comment. In Europe, however, the remarkable development of musical notation and of complex compositional techniques over the last few centuries has encouraged a focus on the structural rather than the kinematic properties of music, at least of so-called serious music. At the same time, as this music has been performed mainly in church, court or concert hall, a social proscription against overt movement by listeners has long been in effect. As a result of these practices, the close connection between music and motion has receded from people's consciousness, and twentieth-century aesthetic and technological developments have occasionally even severed that connection, with only few taking notice. There is a need today therefore to reassess the concept of musical motion and its role in performance and musical understanding.

[8] Many writers have questioned the degree to which an emotion can be expressed in music, if at all (e.g. Hanslick [1854] 1957; Cone 1974; Newcomb 1984; Kivy 1989).

In this more empirical part of our chapter we briefly review the pioneering work of three largely forgotten individuals who were active in Germany during the early decades of this century. We then sample the work of two contemporary researchers who – knowingly in one case, unwittingly in the other – have elaborated upon the German pioneers' ideas and made them sufficiently precise that they can now be subjected to rigorous tests. We conclude with a very brief foray into the motor control literature, again focusing on a single researcher whose work seems to be particularly pertinent to the kinds of motion that music engenders. Space constraints do not allow us to do justice to the related work of others, but we hope to convey at least the flavour of past and current research on musical motion.

Three German pioneers: Sievers, Becking and Truslit

Although no one doubts that there is visual information for motion, the concept of auditory motion information is less widely accepted among psychologists, especially since it involves an essentially stationary sound source – the musical instrument being played by a performer.[9] One reason for this scepticism may be that visual (spatial) motion information is generally continuous in time, whereas auditory (rhythmic) motion information, especially that in music, is often carried by discrete events (i.e. tone onsets) which only *sample* the time course of the underlying movement. The principal methodology for demonstrating that music does convey movement information is the reconstitution of an analogous spatial movement by a human listener. The listener's body thus acts as a *transducer*, a kind of filter for the often impulse-like coding of musical movement.

The first modern attempt to use such a technique in a systematic fashion must be credited to the German philologist Eduard Sievers, who applied it not to music but to literary works. Sievers called his method *Schallanalyse* ('sound analysis'), though it was concerned not with sound as such but rather with body posture and movement as a way of reconstructing and analysing the expressive sound shape of printed language, mostly poetry. Although he never published a complete account of his very complex methods, Sievers (1924) provides an overview, and Ungeheuer (1964) offers a more recent critical evaluation.

Sievers's initial impetus came from observations of a singing teacher, Joseph Rutz, published by his son Otmar Rutz (1911, 1922), about connections between body posture and voice quality. Certain body postures were said to inhibit vocal production, whereas others facilitated it and gave it a free, unconstrained quality. Sievers initially focused on these facilitating postures which he symbolised by means of 'optic signals' in the form of geometric shapes meant to cue different body postures in a speaker reciting a text. Subsequently, he elaborated this method into a system of dynamic

9 The pick-up of auditory information about the locomotion of a sound source is uncontroversial. Although such sound effects are occasionally used in music, both literally (by musicians walking across the stage, or by electronic simulation of sounds changing location – see Chowning 1971) and symbolically (e.g. by the extended crescendo–diminuendo pattern suggesting a passing procession in Albéniz's 'El Corpus en Sevilla' (*Suite Iberia*, I, 1906)), this is not the kind of motion with which we are concerned.

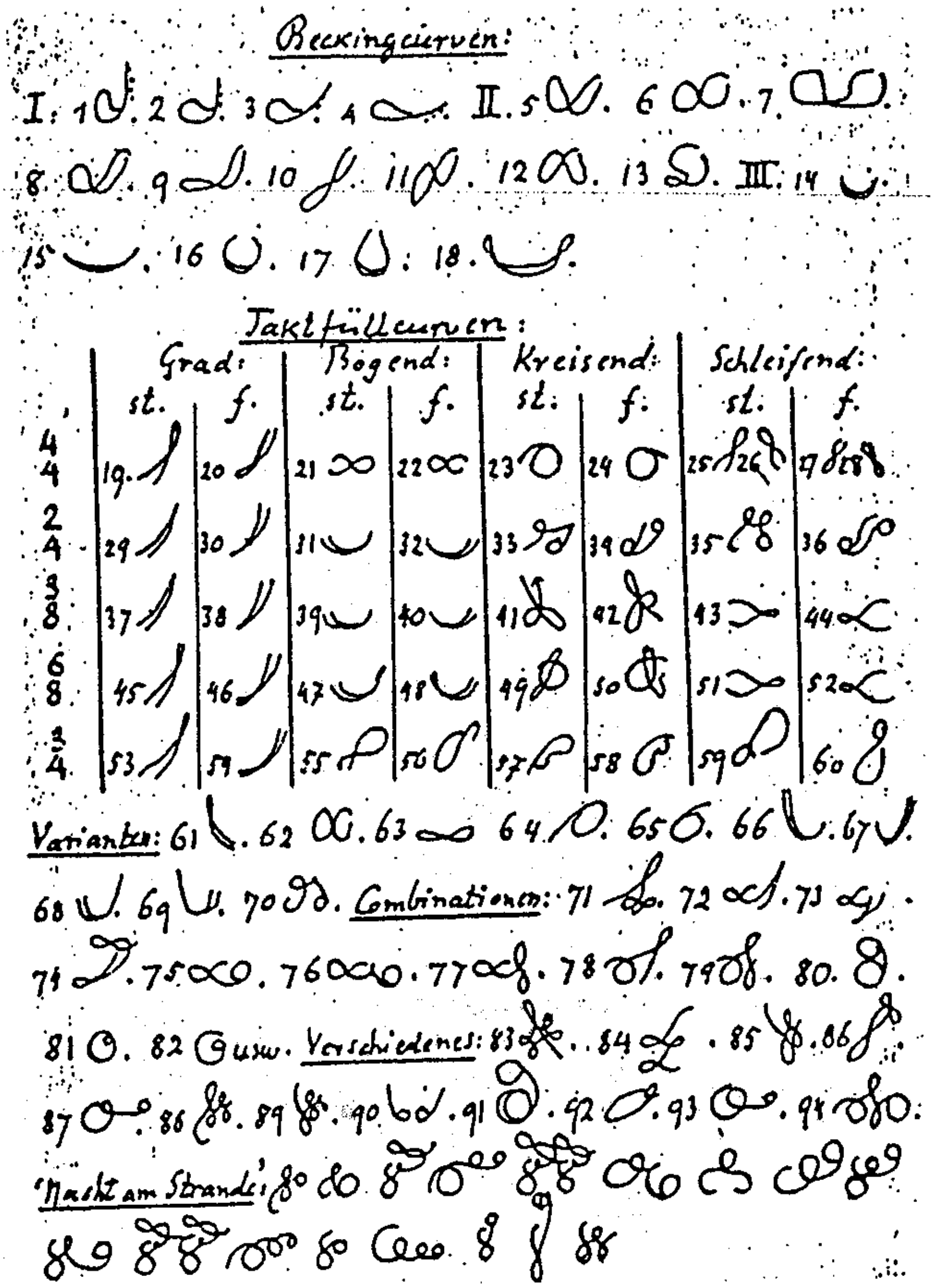

Figure 3.1 Examples of movement curves used by Eduard Sievers. Top: general curves. Centre: special curves (straight, curved, circular, looping). Bottom: variations, combinations, miscellaneous, and a kinematic interpretation of a text, 'Nacht am Strande'. (Reproduced from Sievers 1924: 73.)

movements to be carried out with a baton, with the index finger or even with both arms while speaking. The crucial criterion was the achievement of 'free and uninhibited articulation', and the goal of the analytical method was to find the accompanying movements that least interfered with (or most facilitated) the recitation of the text. The metric, prosodic and semantic characteristics of the text naturally varied with authors and their individual works, as did the accompanying movements considered optimal by Sievers. The movements were rhythmically coordinated with the speech and in general had a cyclic or looping character although a large number of their features were variable, such as the relative smoothness of turns, the tilt of the main axis, rising versus falling direction, etc.

Sievers distinguished two classes of curves, which are illustrated in Figure 3.1: general curves or so-called 'Becking curves' (to be discussed later), and specific or filler curves (*Taktfüllcurven*). The former, suggested to him by Gustav Becking, come in three types which in fact exhaust the possibilities for a cyclic movement with two turning points: pointed–round, round–round and pointed–pointed. Any individual speaker/writer was said to be characterised by one and only one of these types, if not as an obligatory then at least as a preferred mode of dynamic expression, and hence by a corresponding 'voice type'. However, many variations are possible within each type. The 'special curves', of which there is a bewildering variety, reflect the particular metric and sonic properties of a spoken text (or of music, as the case may be). It was to these special curves and their many variations that Sievers devoted most of his efforts.

Sievers was the only recognised master of the technique he had developed. He claimed to be in possession of an extraordinary 'motoric sensibility' which, combined with many years of self-training and observation, enabled him to find the accompanying movements for the most subtle variations in the sound shape of spoken texts. Although his dedication and expertise were never in doubt, the extreme subjectivity of his method obviously diminished its respectability as a scientific procedure. Nevertheless, its basic, underlying idea continues to be of value: rhythmic sound patterns have a dynamic time course which can be translated into accompanying body movements. Only the rules governing this translation remain somewhat obscure.

Sievers benefited from his interaction with Gustav Becking, a young musicologist who developed his own ideas in a monograph entitled *Der musikalische Rhythmus als Erkenntnisquelle* (Musical Rhythm as a Source of Insight) which appeared in 1928. Becking's pivotal assumption was that a *dynamic rhythmic flow* exists below the musical surface. This flow, a continuous up–down motion, connects points of metric gravity which vary in relative weight. Becking's important and original claim was that the distribution of these weights varies from composer to composer. The analytical technique for determining these weights was Sievers's method of accompanying movements, carried out with a light baton.[10] A downbeat always accompanies the

10 Even though Becking relied on and contributed to Sievers's system, he was in fact quite critical of the older scholar's methods. In particular, he criticised Sievers's movements as essentially passive, lacking pressure and dynamics, and hence devoid of musical content. According to Becking ([1923–4] 1975), the accompanying movements require an active attitude: one should not merely be moved by the music but should move as if one were the composer.

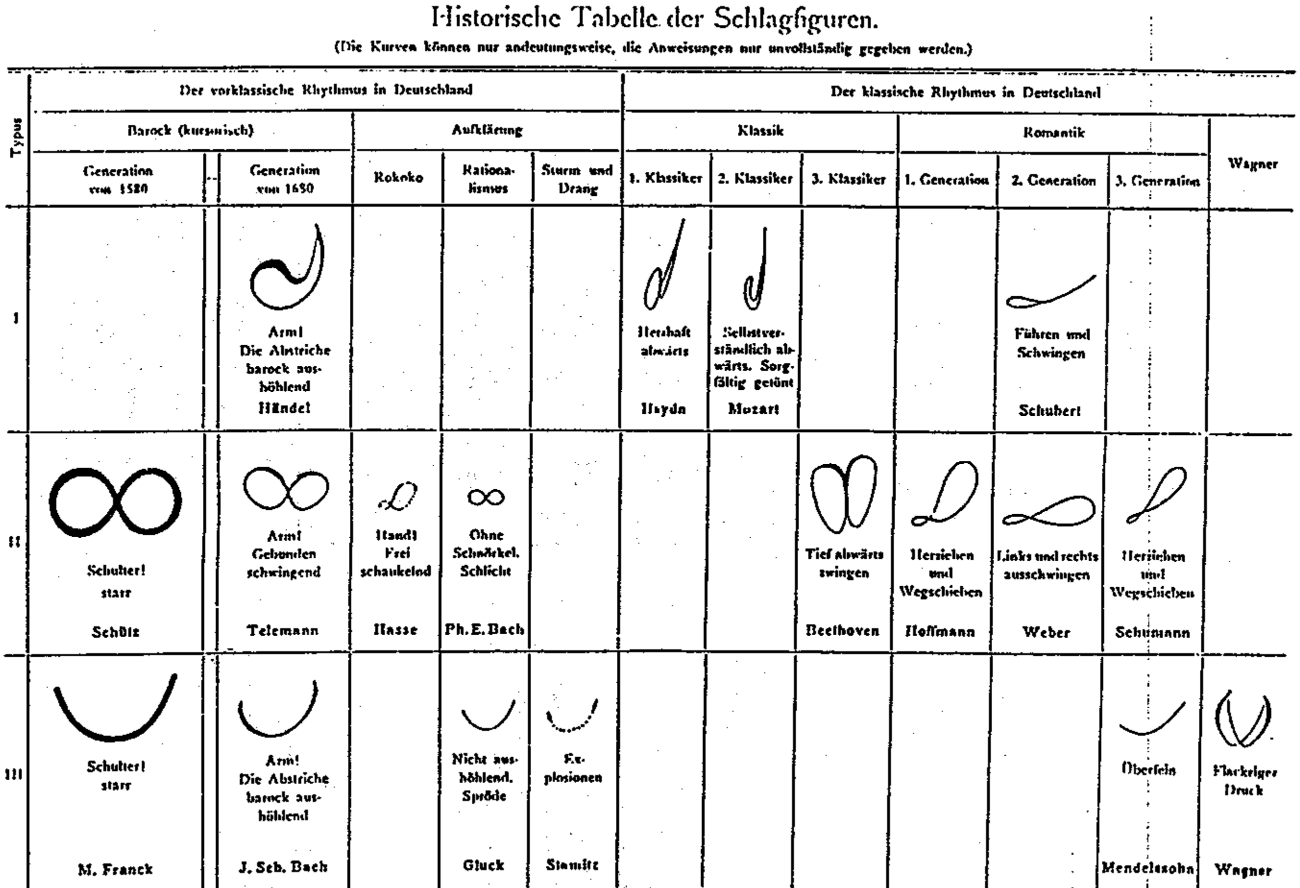

Figure 3.2 Becking's historical table of conducting curves for selected German composers. (Reproduced from the endplate in Becking 1928.)

heaviest metric accent; then an upward movement follows which leads into the next downbeat. The *dynamic shape* of this movement cycle is of interest. For example, the strongest pressure in the downbeat is never at the beginning but at varying delays; the movement may be deep and vertical or shallow and more nearly horizontal; and the connection of downward and upward movements may be smooth or abrupt.

Becking's primary interest was not in the differentiation and proliferation of movement curves for individual works of art but in the personal constants of individual composers – in other words, *invariance* rather than variability. He said that the personal curves reflect a composer's individual 'management of gravity'. Gravity being a physical given, different composers' solutions reflect different philosophical attitudes towards physical reality – as something to be overcome, to adapt to or to be denied, as the case may be. Becking's ultimate goal was thus a typology of personal constants linked to a typology of *Weltanschauungen* (world views) – a philosophical undertaking in which he was preceded by Nohl (1920), among others.

As already mentioned in connection with Sievers's 'Becking curves', Becking distinguished three types of 'personal curves', examples of which are illustrated in Figure 3.2. *Type I* has a sharp, pointed onset of the downbeat, which is straight and usually vertical but nevertheless actively guided rather than passively falling. At the bottom, there is a narrow but round loop ending in a small downward movement (a secondary accent between downbeats) before leading vertically upward, resulting in a figure somewhat like a golf club. This pattern, with its strong differentiation of rhythmic accents but nevertheless individual dynamic shape, is attributed to the 'Mozart family', which also includes Handel, Haydn, Schubert, Bruckner and most Italian composers. These composers are said to be monists (in that they largely obey the physical force of gravity) as well as idealists, because they actively impose a personal dynamic shape on the movement. *Type II* has a round, curving, inward-going (towards the body) onset of the downbeat and a similarly round, outward-going turn upwards, leading to a figure resembling a horizontal or tilted figure 8. Differences in accentuation among metric subdivisions tend to be reduced here. Composers characterised by this personal curve form the 'Beethoven family', including Weber, Schumann, Brahms, Richard Strauss and many other German masters. According to Becking, these composers aim to overcome gravity and force it into a winding path. Thus they are dualists (in that they oppose the material force with their own spiritual force or will) as well as idealists (in that they impose a personal dynamic shape on the raw pulse of the music). Finally, *Type III* is characterised by a pointed downbeat as well as a pointed return, resulting in a semicircular, pendulum-like curving motion from right to left and back. Consequently, the main accents on the downbeats and the secondary accents in between tend to be equally strong and to form a rigid rhythmic framework. This pattern Becking ascribes to the 'Bach family', among them Mendelssohn, Chopin, Wagner, Mahler and most French composers. These masters are said to be naturalists because they follow the force of gravity without opposing it or necessarily imposing a personal pulse on it. Yet there are numerous personal variants of the trajectory between the two rigid endpoints, resulting in more or less idealistic curves

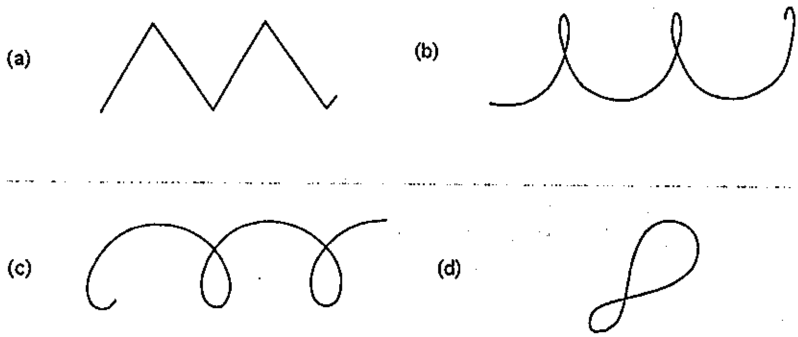

Figure 3.3 Truslit's movement types: a. straight (mechanical); b. open; c. closed; d. winding. (After Plate 2 in Truslit 1938; reproduced from Repp 1993: 54, with permission of the publisher.)

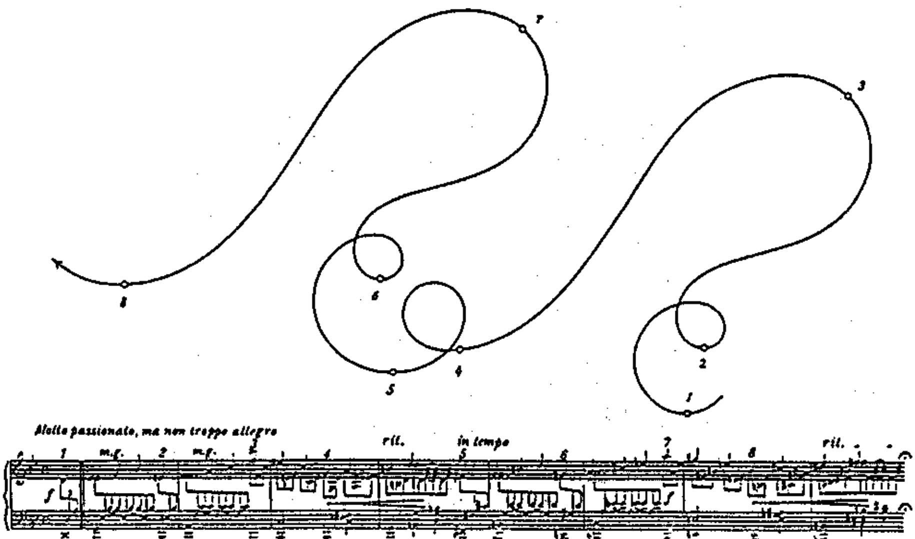

Figure 3.4 Truslit's kinematic interpretation of the beginning of Brahms's Rhapsody in G minor Op. 79 No. 2. Numbers along the movement curve correspond to numbered points in the score. (Reproduced from Truslit 1938: 144, with permission of the publisher.)

(as in the case of Wagner). Nevertheless, all these composers accept the objective, even pulse and hence are only minor idealists, with Bach being the least idealistic and most objective of all.

Becking's method of determining the personal curve of a composer was highly subjective. It required a thorough acquaintance with a composer's works as well as, presumably, performances by great interpreters and biographical details helping to elucidate the artist's personality. The personal curve is *not* derivable from the score, nor is its subjectively judged fit to a particular piece of music necessarily perfect, especially if that music is an early or otherwise atypical creation. Rather, knowledge of the personal curve, verified by the composer's most characteristic works, enables the scholar or performer to imbue even the less characteristic works with the composer's identity. Clearly, this method is somewhat circular and by no means scientifically rigorous; however, Becking's extraordinary perspicacity, well-chosen musical examples and eloquent verbal characterisations make his book a unique and fascinating document.

The third important person among the German pioneers is the least known today – Alexander Truslit, whose book *Gestaltung und Bewegung in der Musik* (Shaping and Motion in Music) appeared in 1938. Truslit's orientation is much closer to the natural sciences than that of his predecessors and in some ways presages Gibson's (1979) writings on ecological perception and action. Unlike Becking, who believed that composers' personal dynamics exist largely beneath the musical surface (i.e. in the listener's musical imagination), Truslit focused on the information in the sound pattern. He contended that the musical dynamics and agogics (timing variations) convey movement information directly to the sensitive listener, who can then instantiate these movements by acting them out, if necessary. For Truslit, the goal of music performance is to arrange the musical surface in accord with the appropriate underlying movement.

Like Becking, Truslit distinguished three basic types of movement curves: 'open', 'closed' and 'winding' (*gewunden*) – i.e. b–d in Figure 3.3, where they are contrasted with an unnatural linear motion path (a). Superficially, they resemble Becking's three types; in particular, the winding curve seems like Becking's Type II, and the open curve like his Type III. However, these similarities are more apparent than real. Truslit's curves are not conducting movements: they are to be carried out slowly and with outstretched parallel arms, so that the whole upper body is involved. Their height in space tends to follow the pitch contour of the melody; thus they often start at the bottom and move upwards rather than beginning with a 'downbeat'. They are a means of portraying the melodic dynamics in space, with the speed of movement and the consequent relative tension being governed mainly by the curvature of the motion path. That is, a slowing-down and commensurate increase in tension in the music is portrayed by a tight loop, whereas faster, more relaxed stretches correspond to relatively straight movements. The varied melodic structure of a composition elicits complex paths of various combinations of clockwise and anticlockwise turns, interpolated loops, etc. Even the type of movement may change within a composition. Figure 3.4 illustrates the combination of closed and winding movements that Truslit found most appropriate for the initial section of Brahms's Rhapsody in G minor Op. 79 No. 2.

Truslit's curves are not at all 'personal' and composer-specific; rather, they are work-specific. In that respect, he was somewhat closer to Sievers than to Becking. He explicitly assigned a secondary and subordinate role to rhythmic patterns: they should not be too pronounced, in order not to disrupt the smooth flow of the melody. Rhythmic patterns affect the limbs, he said (which is consistent with Becking's use of the hand to conduct), whereas the more global melodic patterns affect the large muscles of the back and hence the whole body. Thus Truslit's curves often extend over a number of bars, with the more detailed rhythmic structure marked by small local loops, if at all. Not surprisingly, Truslit seems most interested in music which exhibits a pronounced gestural character: many of his musical examples come from Wagner, while there are no Mozart or Bach examples in his book. His most intriguing speculation is that the perception and translation of musical movement at the scale he was interested in may be mediated by the vestibular organ (i.e. the labyrinth of the inner ear), which controls body orientation and equilibrium. In support of this claim he cited scientific evidence from early physiological experiments. Furthermore, to illustrate the concrete instantiation of different movement types in music performance, Truslit adduced recorded sound examples varying from scales and arpeggios to excerpts from commercial recordings of standard repertoire, as well as some measurements of the acoustic microstructure of the scales and arpeggios. Although his empirical contribution remains fairly negligible, the modernity of his theoretical ideas and the clarity and force with which they are presented must be greatly admired.[11]

Two modern successors: Clynes and Todd

Despite the many interesting observations that these German authors, especially Becking and Truslit, have to offer the modern reader, their work has largely been forgotten. Although some of their ideas may be outmoded, others are clearly relevant to more recent research on musical expression and performance. Among the small group of researchers active in this area, two seem particularly close in spirit to the German pioneers: Manfred Clynes and Neil Todd. Clynes was acquainted with Becking's work as he began in the 1970s to develop further the concept of composers' 'personal curves', making ingenious use of computer technology. Todd independently formulated ideas resembling those of Truslit, without actually being aware of his work.

Over a number of years, Clynes (1977) developed the notion of *essentic forms*, dynamic time forms which characterise basic emotions. To measure them, he devised a simple apparatus called the sentograph, which consists of a button sensitive to finger pressure in vertical and horizontal directions and a computer registering the pressure over time and averaging successive pressure cycles. Subjects who imagine certain basic emotions (love, anger, grief, etc.) while pressing rhythmically on the sentograph produce very different pressure curves for different emotions.

Clynes argues that meaning in music derives from essentic forms, which are conveyed by the musical macrostructure (melody, rhythm) and microstructure (dynamics, agogics). The more closely an essentic form is approximated, the more beautiful and meaningful the music is perceived to be. This emotional 'story', however, unfolds against the background of a fixed, repetitive, dynamic rhythmic pattern which represents the composer's individuality and 'point of view'. This is the composer's 'inner pulse' – a concept clearly derived from Becking's theory of 'personal curves'. In

11 See Repp 1993 for a synopsis of Truslit's book.

recent writing, Clynes (1992) has referred to this as his 'double stream theory' of musical expression.

The sentograph offered itself as a suitable instrument for measuring the essentic shapes of a musical work, as well as the composer's inner pulse. To assess the former, the (musically experienced) subject presses the button in synchrony with larger musical gestures or phrases while listening to or imagining a piece of music. To assess the latter, the subject presses more rapidly (about once per second) in synchrony with successive downbeats. These repeated pressure curves can then be averaged, yielding a stable average pulse shape. Such averaging cannot easily be achieved with the longer essentic shapes, which may be one reason why Clynes has not explored this aspect in any detail.[12]

To determine the shape of famous composers' inner pulses, Clynes used several outstanding musicians (including Pablo Casals and Rudolf Serkin) as subjects, as well as himself. They were asked to press rhythmically on the sentograph while imagining various works of Beethoven, Mozart, Schubert and others. It was not a counter-balanced experiment: not every subject produced every composer's pulse, while some produced several pulse shapes for different pieces by the same composer. In any case, as can be seen in Figure 3.5, the average vertical pressure curves (see Clynes 1977) show striking differences between these composers (i.e. Beethoven, Mozart and Schubert) and considerable agreement within composers across different subjects and different pieces. Clynes thus went one step beyond Becking by registering the 'conducting' movements that Becking represented only schematically by means of graphs. Even though the finger movements on the sentograph differ from the baton-aided hand movements Becking had in mind, they seem to capture some of the composer-specific characteristics that he talked about. The main analogy between Becking's and Clynes's curves seems to lie in the onset time, relative speed and depth of the downward movement.

Some years after his demonstration of composers' inner pulses on the sentograph, Clynes (1983) advanced towards an objectivisation of the pulse concept. Although Becking had provided some hints of the manner in which individual composers' pulses might be manifested on the musical surface of a performance, he basically thought of them as mental or 'inner' phenomena. Clynes pursued the idea that composers' personal pulses must somehow be manifested in the expressive microstructure of an expert performance. Rather than analysing the performances of great interpreters, he developed a computer program which enabled him to play back music with different agogic and dynamic patterns, repeated cyclically from bar to bar. Using himself as a listener and judge, he manipulated and refined these objective pulse patterns for various works of different composers, primarily Beethoven, Mozart and Schubert. He eventually arrived at settings which he considered optimally appropriate for each

12 Some interesting examples are presented in the appendix of his 1977 book, apparently representing his own responses to several musical excerpts. However, since the variety of dynamic shapes encountered in music is much greater than the small inventory of essentic forms, it is not clear what counts as an essentic shape and how the emotional meaning of a given dynamic shape is determined.

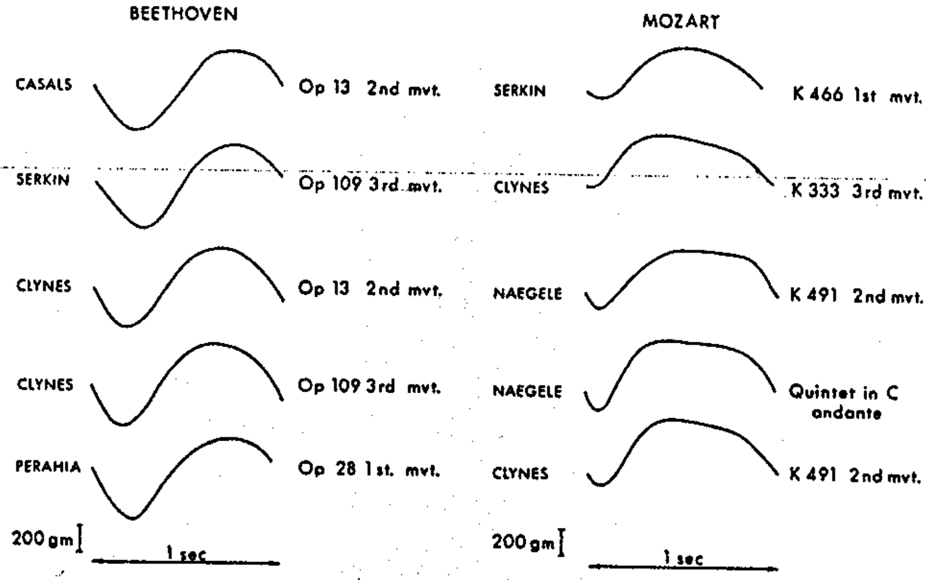

Figure 3.5 Average sentograph responses (vertical pressure curves) of several distinguished musicians during mental rehearsal of compositions by Beethoven and Mozart. (Reproduced from Clynes 1969: 200, with permission of the publisher.)

composer; these patterns were quite different between composers but seemed to fit various works by the same composer. They could be specified numerically in terms of the relative amplitudes and durations of the tones within a metric cycle. Subsequently, Clynes (1986) expanded his scheme to encompass one or two higher levels within which the basic pulse cycles are nested, and which in turn exhibit the temporal and dynamic relationships of the composer's inner pulse, so that the rhythmic surface pattern is a multiplicative combination of higher- and lower-level pulse parameters.

These pulse patterns, then, represent Clynes's subjective judgement, which identifies his enterprise as being partially in the intellectual tradition of Sievers and Becking. What distinguishes it from its historical precedents, however, is that the pulses are *quantified* and hence open to empirical testing. Several attempts have been made to test the effectiveness of Clynes's specifications in conveying the composer's individuality to unbiased listeners. The method was to generate computer performances of several composers' pieces with each composer's pulse, in a factorial design, and to see whether listeners prefer the performances with the 'appropriate' pulse over the others. Several experiments (Thompson 1989; Repp 1989, 1990a) have yielded mixed results, but the most recent study, conducted by Clynes himself (in press), provided unambiguous evidence that highly trained musicians prefer the appropriate composers' pulses over inappropriate pulses in computer-generated performances. Questions remain, however, about how a composer's inner pulse is manifested in human performances, where many factors besides the composer's individuality may affect the expressive microstructure (see Repp 1990b, 1992a).

In these studies, the emphasis was on the quantification and perceptual evaluation of cyclic pulse patterns, not so much on their relation to physical movement. Clynes and Walker (1982) addressed this latter point by investigating the biological 'transfer function' between rhythmic sound patterns and the rhythmic movement of a human listener. The subject pressed on a sentograph while listening to cyclic repetitions of two tones having variable onset times, durations and amplitudes. The resulting averaged pressure curves varied systematically with the sound patterns presented. For example, the downward movement of the finger, which usually accompanied the louder of the two tones, depended on the temporal separation of the softer tone from the louder tone. The timing of the upward movement depended on tone duration: patterns of long tones resulted in smooth, 'rounded' movements, whereas patterns of short tones (with long gaps in between) induced sharp, angular movements.

To relate these results, obtained with arbitrary rhythmic patterns, to the hypothesised pulse patterns of actual music, Clynes and Walker matched two-tone patterns to synchronously played music. They adjusted the physical parameters of the two tones until they perceived a congruence with the musical rhythm. Subsequently, they had subjects press the sentograph when listening to either the music or the matched two-tone 'sound pulse'. Figure 3.6 shows that there was a significant similarity between these motoric responses, indicating that the simple two-tone pulse patterns captured the rhythmic pulse of the acoustically much more complex music.

Clynes's theories and research (of which we have provided only a brief glimpse here) represent a highly original and important contribution to music psychology and to the understanding of music performance. However, his observations are in need of extension and replication in other laboratories, as they are often based on very limited data.

While Clynes was inspired by the ideas of Becking, Todd is in some ways the intellectual heir of Truslit. The most obvious coincidence is both authors' hypothesis that the perception of musical motion may be mediated somehow by the vestibular system (Todd 1992a, 1992b, 1992c, 1993). Although there is little evidence that vestibular stimulation actually occurs in ordinary music-listening conditions, we suspect that this is not really necessary: the sound patterns that characterise body movement could be recognised at an abstract auditory or cognitive level. They may be the very same as those that, under certain extreme conditions (e.g. in very loud music), can evoke vestibular sensations.

Like Truslit, Todd is concerned primarily with motion at the level of the whole body, rather than of the limbs or fingers. He appeals, as did Truslit before him, to physiological evidence concerning two distinct motor systems, the ventromedial and lateral systems (Todd 1992b). The former controls body posture and motion, and is closely linked with the vestibular system. Since larger masses are to be moved, the movements are slower than those possible with feet, hands and fingers, which are controlled by the lateral system. Typically their cycles extend over several seconds, whereas the pulse microstructure studied by Clynes (and executed by finger pressure on the sentograph) is contained within cycles roughly one second in duration which

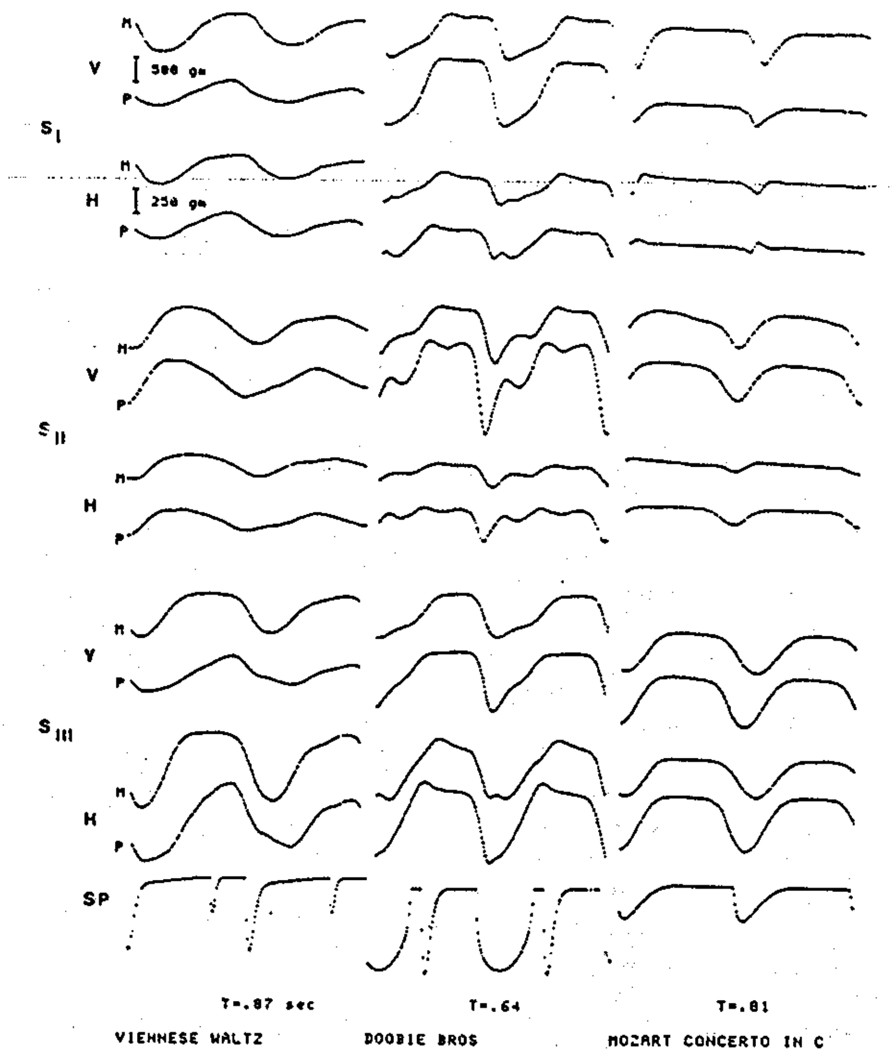

Figure 3.6 Vertical (V) and horizontal (H) sentograph pressure curves for three subjects (S_I, S_{II}, S_{III}) listening to music (M) or to a simple sound pulse (P) matched to the music. Each column represents a different piece of music. The amplitude envelope of the sound pulse (SP) is shown at the bottom. (Reproduced from Clynes and Walker 1982: 211, with permission of the publisher.)

may be nested within the larger cycles described by Truslit and Todd. Recently, Todd (1992b; Todd, Clarke and Davidson 1993) has undertaken to study the motoric instantiation of these larger cycles in the 'expressive body sway' of performers. His preliminary data indicate that pianists' head movements are synchronised with expressive tempo fluctuations in the music, such that tempo minima coincide with turning points in the head movement. Observations such as these have led Todd to propose that expressive variation in tempo and in the correlated dynamics may be a representation of self-motion. Clearly, such a representation has the potential of inducing actual or imaginary motion of a similar kind in a listener/observer.

Concerning the tempo variations in performances, Todd (1992a, 1995) has presented evidence that they are a linear function of real time. In other words, expressive timing consists of alternating phases of constant acceleration and deceleration, one cycle typically corresponding to a musical group or gesture. Listeners also seem to prefer performances whose timing follows this rule, although more extensive perceptual tests remain to be done. Constant acceleration or deceleration seems to characterise various forms of physical and biological motion, so that music having this property would seem an optimal stimulus for the perception and induction of motion. Todd (1992a) has also begun to investigate the way in which changes in musical dynamics accompany changes in timing and has devised a system for the automatic extraction of hierarchical rhythmic structure from the energy flux of the acoustic signal, be it music or speech (Todd 1994). His exciting work is at the cutting edge of research on music performance.

Other contemporary authors who have concerned themselves with problems of motion in music include: Gabrielsson (1973a, 1973b; Gabrielsson, Bengtsson and Gabrielsson 1983), who has done extensive work on the dimensions that underlie the subjective experience of different rhythms; Kronman and Sundberg (1987), who showed that the final ritardandos in performances of baroque music (Sundberg and Verrillo 1980) follow a function resembling the deceleration of physical motion, as in walking; Repp (1992a), who demonstrated that listeners prefer a particular, 'natural' timing pattern in a phrase; and Feldman, Epstein and Richards (1992), who examined examples of very slow tempo changes and concluded that they could be interpreted in terms of underlying force dynamics. These studies suggest that expert performers (and listeners) have a mental model of principles of natural movement which they apply to tempo changes in music. For a tempo change to 'sound natural', it must apparently conform to these principles.

Research on biological motion

As Feldman et al. (1992) point out, a performer who produces tempo changes is not under any physical constraint to follow a particular function; the constraint is a purely mental, aesthetic one. However, the finding that these mental constraints mimic aspects of human movement leads one to wonder whether additional, perhaps more intricate principles of physical motion have found their way into musical aesthetics. There have been few points of contact in the past between the study of kinematics and the study of music performance, and these have been restricted to the 'hard' physical constraints of playing an instrument.

Evidence for constraints on natural motion comes from research on human motor control. There is one body of research which seems particularly relevant, that of Paolo Viviani and his collaborators (for overviews, see Viviani 1990, and Viviani and Laissard 1991). Over the last decade, they have investigated the constraints that link the geometry and the kinematics of guided hand movements. The movements in question involved the drawing or tracking of ellipses or of more complex curvilinear paths. The consistent finding has been that, within a single coherent movement, velocity varies as a power function of trajectory curvature (Viviani and Terzuolo 1982; Viviani and Cenzato 1985; Viviani and Schneider 1991). In other words, the greater the local curvature, the slower the movement.[13] Viviani, Campadelli and Mounoud (1987) have demonstrated that subjects are unable accurately to track a light point moving at a constant velocity around an elliptical path, whereas the task is easy when the target velocity changes with curvature according to the power function. It has also been shown that dynamic visual stimuli of the latter kind are judged by observers to represent constant velocity, whereas elliptical stimuli exhibiting constant velocity seem to vary in speed (Viviani and Stucchi 1992; see also Derwort 1938 and Runeson 1974).

The *spatio-temporal coupling* described in this research on biological movement enhances considerably the scientific respectability of the technique of 'accompanying movements' developed by Sievers, Becking and (particularly) Truslit. If spatial trajectory determines the velocity profile, then a given velocity profile also implies a spatial trajectory of a particular kind. What Truslit evidently did was to convert the velocity information available in the temporal and dynamic microstructure of music into arm movements with a matching spatial trajectory whose direction also took the melodic pitch contour into account. In his book he describes how, with practice, a close subjective match between the spatial trajectory and the auditory information can be achieved. What at first seems like a highly idiosyncratic method may in fact have a solid foundation in the constraints of biological motion.

Conclusions

We conclude from this very limited survey of empirical studies that performed music, by virtue of its temporal and dynamic microstructure, has the potential to represent forms of natural motion and to elicit corresponding movements in a human listener. While a rigid rhythm may inspire only foot tapping or finger snapping, an expressively modulated structure can specify movements with complex spatial trajectories which, for the purpose of demonstration and analysis, can be realised as guided movements of the limbs or the whole body. However, execution of such movements is not necessary to appreciate the motion information: experienced listeners, at least, can judge by ear whether the musical motion is natural or awkward, and they can move along with the music inwardly, as it were. An aesthetically satisfying performance is presumably one whose expressive microstructure satisfies basic constraints of biological motion while also being responsive to the structural and stylistic requirements of the composition.

[13] In particular, the angular velocity is equal to the 2/3 power of the curvature times a constant. The exponent of this function increases with age; that is, children slow down more as a function of curvature than adults do (Viviani and Schneider 1991). The constant is different for different movement segments (Viviani and Cenzato 1985) and represents a velocity gain factor which depends on the linear extent of the movement: the larger the extent, the faster the movement.

Much music composed in this century encourages only primitive forms of motion or inhibits natural motion altogether. Many twentieth-century composers focus on sound qualities or on abstract tonal patterns, and performers of their compositions often neglect whatever kinematic potential the music may have. The absence of natural motion information may be a significant factor limiting the appreciation of such music by audiences. While compositional techniques and sound materials are subject to continuous change and exploration, though not without perceptual and cognitive constraints of their own (Lerdahl 1988; McAdams 1989), the laws of biological motion can only be accepted, negated or violated. If more new music and its performers took these laws into account, the size of audiences might increase correspondingly.

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