Chapter 10
Space, Time and Expression in Orchestral Conducting

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Abstract The art of conducting involves a formal set of gestures, designed to convey musical meaning through movement. Interestingly, this relatively simple collection of gestures enables the conductor to communicate highly complex musical messages to the ensemble, indicating a non-trivial interaction between movement kinematics and sound. The following book chapter discusses this phenomenon. We first introduce movement-to-sound cross-modal mapping, surveying behavioral and neurophysiological research suggesting how spatio-kinetic features may be "translated" into aspects of musical rhythm, loudness and pitch. This is followed by a detailed discussion of the kinematics of right-hand gestures in conducting and their musical meanings. The kinematic correlates of expressive conducting are discussed by introducing some of the basic principles governing human movement generation. These principles include the wish to maximize motion smoothness, captured by the "minimum jerk" model, and the isochrony principle governing motor timing. Notwithstanding the considerable work that has already been invested in analyzing music conducting, many of the secrets underlying musical conducting still remain to be unraveled. This can only be achieved through a multidisciplinary approach, involving a variety of research disciplines, such as social psychology, computational motor control, musicology, mechanics, acoustics, as well as cross-modal sound-to-movement mapping.

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T. Flash and A. Berthoz (eds.), *Space-Time Geometries for Motion and Perception in the Brain and the Arts*, Lecture Notes in Morphogenesis,
https://doi.org/10.1007/978-3-030-57227-3_10

10.1 Why Conducting?

Conducting is an enigmatic profession. On the one hand, conducting gestures are relatively easy to learn. Anyone with intact motor control and bimanual coordination can master them in a rather short period of learning. Consequently, it is considered by many to be an easily acquired skill (Schuller 1999, p. 3). However, simple as it may seem, very few conductors have established major international careers, strongly suggesting that there is more to conducting than learning a set of movements. Conducting gestures are considered by experienced conductors to be basic tools, beyond which lies an entire world of unwritten secrets. These secrets are considered by some well-known conductors to be a heavenly gift, which cannot be formally taught. The late Pierre Boulez, for example, summarized his views of teaching conducting with the words: "*You can only teach how to start and stop*". Similarly, New York Philharmonic conductor, Anton Seidl (1850–1898) stated that: "*The ability to conduct is a gift of God with which few have been endowed in full measure. Those who possess it in abundance do not wish to write about it; for them the talent seems so natural a thing that they cannot see the need to discuss it. This is the kernel of the whole matter. If you have the divine gift within you, you can conduct; if you have not, you will never be able to acquire it. Those who have been endowed with the gift are conductors; the others are time-beaters*" (Seidl 1899, p. 215). Following this line of thought, textbooks of conducting only teach basic gestures (discussed later in this chapter), using more or less the same diagrams to illustrate them. Beyond that, one can find a great variability of approaches to the pedagogy of conducting, highlighting the controversial characteristics of the conducting profession, which has never been completely formalized (Scherchen 1989, p. 3–5). Conducting is a multifaceted activity, requiring high-level musicianship, alongside excellent interpersonal communication skills, strong leadership abilities, verbal skills, motor coordination, emotional intelligence, and many more interdisciplinary qualities. This versatile combination of qualities is difficult, if not impossible to evaluate and quantify. It is as difficult to teach, since many of the required qualities of a good conductor involve personality characteristics, which are molded through life experience, rather than through formal training. Furthermore, conductors differ substantially in their implementation of the formal rules of the conducting gestures. Some use minimal movements, and in some cases, refrain completely from conducting. The famous video of Bernstein Conducting a Haydn Symphony using his eyebrows only, is a clear example of the difficulty in trying to formalize the art of conducting, considering the great variability in conducting methods, between and even within conductors. Growing trust between conductor and ensemble enables the conductor to be more and more minimal in the amount of information conveyed by formal conducting gestures, while dedicating more to the communication of general inspiration to the ensemble. Verbal instructions may also substitute for gestural information, not to mention the important role of facial expressions in communicating emotion to the ensemble. Hence, an evaluation of real-life conducting may require a weighted sum of multiple factors, some of them difficult, if not impossible to evaluate. This poses a theoretically unfeasible enterprise, which may lead to the conclusion that conducting is indeed impossible to evaluate in quantitative measures. This may explain the dearth of publications offering a quantitative evaluation of conducting gestures. However vague and enigmatic as it may seem, the art of conducting is taught at most university-level music institutes in the world, producing the next generation of professional conductors. The formal training of a conductor ubiquitously involves formal baton technique (i.e., right-hand gestures), as well as rehearsal planning, orchestral score reading, ear training, and other measurable musical skills. This set of tangible skills enables orchestras to perform with dozens of conductors every concert season, sometimes having no preparatory rehearsals before the performance. Hence, notwithstanding the extensive array of characteristics defining a good conductor, there seems to be a set of common traits characterizing a prototypic professional conductor. Otherwise, there would be no possible way for an orchestra to quickly adjust to the considerable turnover in conductors taking the podium in rehearsals and concerts. The most quantifiable attribute of conducting is the kinematics of hand movements. Right-hand movements in conducting are intended to convey rhythmic properties of the music being played, alongside articulation, loudness ("dynamics" in musical terms-we will use the term "loudness" to avoid confusion with the term dynamics used in the motor control literature), as well as emotional expression. Left-hand movements are dedicated mainly for communicating emotional expression, cues for specific sections or players, alongside additional information on loudness and articulation (McElheran 2004, pp. 37–38). Together, bimanual movements in conducting communicate a comprehensive musical statement to the musicians in the ensemble, portraying the highly complex emotional and esthetic information conveyed in music. Consequently, conducting offers an excellent field of study for anyone interested in the subtlety of motor movements, and their ability to convey a complex and personal message. Up-to-date studies of conducting gestures usually employ motion capture devices, alongside corresponding kinematic analysis algorithms, providing useful information on the kinematics of conducting movements. These have led to a greater understanding of the linkage between conducting gestures and the musical outcome. However, there is still a great amount of research work to be carried out, in order to achieve a greater understanding of the expressive component of conducting movements, and how they may lead to an inspiring performance. The current book chapter describes in detail the formal language of conducting, from kinematic and perceptual perspectives, employing a systematic review of musical parameters and their corresponding conducting gestures. The musical elements which will be addressed will include: beat, meter, loudness and articulation. All these parameters and their gestural representations in conducting have been the subject of various studies focusing on the language of conducting. More abstract phenomena, such as the effect of the conductor on emotional expression portrayed by the ensemble are considerably more difficult to study, and have scarcely been addressed by empiric studies. We chose, in the current book chapter, to focus exclusively on right hand conducting gestures, which are much more prototypically defined than left-hand movements, in order to enable a methodological evaluation of conducting gestures and their effect on the musical outcome. Conducting gestures introduce a transformation of sound to movement (on the conductor's side), and vice versa (at the ensemble's end of the information flow). Therefore, a detailed discussion on sound-to-movement cross-modal transformations will proceed, followed by a systematic discussion of the kinematics of conducting gestures, and their effect on the musical outcome.

10.2 Conducting and Cross-Modal Relationships

At the basis of conducting as a communicative process lies cross-modal "translation" involving different sensory modalities: the conductor's bodily motion, perceived visually by performers, affects the sound patterns performers produce—patterns themselves generated through the performers' bodily action. This communicative process may have various semiotic grounds. A conducting movement pattern may serve as a conventional symbol, whose denotation is based on arbitrary convention or agreement, rather than on any inherent relationship between symbol (the conductor's movement) and its interpretant (the performed musical output). However, while such conventional stipulations could perhaps have shaped some elementary conducting gestures, they cannot account for the wealth of non-conceptualized movements which convey subtle shadings of expression to performers—slight changes in tempo, minute yet systematic deviations from the metronomic beat, shadings of dynamic change, or gradations of articulation and accent—movements whose precise enactment shapes musical expression and distinguishes one performance from another.

One source of cross-modal "translation" in conducting may be the multi-modal nature of the temporal features communicated by a conductor. Features such as beat, meter or patterns of articulation may be depicted by both auditory and non-auditory stimuli (e.g., points of light, changes in tactile pressure, bodily motion), and correspondingly perceived through non-auditory sense modalities—visual, tactile, or proprioceptive (Guttman et al. 2005; Huang et al. 2012; Ross et al. 2016). Indeed, recent studies suggest that the same brain network was activated in beat perception tasks regardless of the sensory modality applied—auditory, visual, or tactile (Araneda et al. 2017). The cross-modal translation involved in conducting may employ such supra-modal resources.

Temporal features such as beat and meter are particularly associated with motor action, either overtly (tapping, dancing, walking, etc.) or covertly, by way of mental preparation and simulation of action. The latter is revealed by the activation of brain areas associated with preparation and support of motion, such as the dorsal premotor cortex and the supplementary motor area (SMA), during passive beat perception (see Ross et al. 2016, for research review). Notably, the association of auditory beat and meter with bodily motion is reciprocal. Just as musical beat and meter may induce corresponding bodily motion, movement expressing metrical structure may engender the perception of beat and meter in sound. For instance, 7-month old infants who were bounced every two or every three beats while listening to an ambiguous rhythm, later preferred a version of that rhythm corresponding to the metrical pattern (double or triple) induced by their bouncing (Phillips-Silver and Trainor 2005, 2007). The precise association of a conductor's movements with performed tempo and meter may rely on this strong, possibly innate ability to induce beat and meter through bodily motion.

Unlike such multimodal temporal features, dimensions such as loudness or pitch are essentially auditory. This notwithstanding, such auditory dimensions may exhibit consistently perceived correspondences with non-auditory features. Louder sound, for instance, is associated with larger objects, and changes in loudness—with motion in both the vertical and depth axes: crescendo with spatial rise and approach, and diminuendo—with fall and withdrawal. Such *cross-modal correspondences* (CMC)—"systematic associations found across seemingly unrelated features from different sensory modalities" (Parise 2016)—may affect basic aspects of human perception and cognition, including cross-modal binding in time and space (Parise and Spence 2009), perceptual learning (Brunel et al. 2015), selective attention (Marks 2004), and the perception of spatial location and motion direction (Pratt 1930; Maeda et al. 2004). Such effects are often automatic, and do not necessarily rely on conscious reflection or conceptual thought (for research reviews see Eitan 2013, 2017; Marks 2004; Spence 2011).

In the context of this paper, CMC of loudness or loudness change are of particular interest. Conductors convey loudness primarily through movement amplitude: a wider movement signifies a louder sound (see section on controlling loudness in conducting for more detailed discussion). Necessarily, increasing amplitude while maintaining a steady beat implies increasing velocity; hence, louder sound is also associated with faster movement. This practice reflects two well-established CMC involving loudness. First, greater loudness (or "volume") is associated with larger size. Children as young as 3 years old, as well as adults varying in cultural background, associate louder sound with larger physical size (Lipscomb and Kim 2004; Smith and Sera 1992; Walker 1987). This association may be based on the experienced correlation between the object size and the loudness of sounds it produces. Indeed, loudness significantly partakes in the auditory discrimination of objects' size (Burro and Grassi 2001). Second, loudness is associated with speed, as well as speed change. Louder music was rated as "faster" than softer music with the same tempo (Katz 2011). Loudness changes were associated with speed changes, both in music-induced imagery tasks (Eitan and Granot 2006; Eitan and Tubul, 2010) and in actual motion tasks, in which children reacted to crescendi and diminuendi with accelerating and decelerating body movements, respectively (Kohn and Eitan 2016).

Two additional CMC involving loudness partake in conductors' movements (expressed by left-hand gestures). First, loudness change is experientially (as well as acoustically) associated with change in distance. In particular, loudness increase (crescendo) serves as a fundamental signal for approach, affecting even infants rapidly and pre-attentively (see Eitan 2013, for a research review). Second, loudness change has been strongly associated with the vertical direction of motion. In fact, listeners' association of diminuendi (gradual loudness decrease) with spatial descent is as strong as their association of pitch descent and spatial descent (Eitan 2013). Even when not intentionally expressed by the conductor, these CMC may still affect performers' reactions.

Notably, a conductor does not merely indicate any *crescendo* or *diminuendo*, but rather, a particular change in loudness, with its specific amplitude envelope, duration, and extent. Quantitatively modeling how aspects of the conductor's motion suggested by loudness-related CMC, including amplitude, velocity, jerk or curvature, map onto aspects of performed loudness levels and loudness changes would be an interesting and necessary challenge for empirical studies of conducting.

Unlike loudness or tempo, musical dimensions such as pitch height or timbre are not explicitly conveyed by a conductor's movements. Nevertheless, one may inquire whether such dimensions may still affect these movements through implicit application of CMC. Consider pitch height, associated with several aspects of physical space and motion. Lower pitch, for instance, is associated with low and left-hand location, slow speed, and large physical size (Spence 2011; Eitan 2013). While Pitch height is normally not conveyed intentionally by a conductor's movements, CMC of pitch and space may still affect these movements. Moreover, CMC of pitch (and of other musical features not explicitly expressed by a conductor) may unintentionally affect aspects of a conductor's posture, head and neck movements, or facial expressions. Though not codified into an established repertoire of conducting movements, such effects may still influence performers' reactions. Exploring the effects of implicit CMC on a conductor's actions (including not only hand movements, but all visible body movements, postures, and facial expressions), and correspondingly investigating whether and how they are reflected in performers' output, could present an exciting new frontier for an empirical investigation of the art of conducting.

10.3 Beat

Right hand conducting gestures are primarily designed to communicate two main rhythmic parameters: beat and meter. The beat is the inner pulse of the music. It is a subjective, perceptual phenomenon, perceived as a regular pace determined by the pace of musical changes in time. The frequency of beats (i.e., the mean inter-beat-intervals per-unit of time) determines the perceived tempo of the music. The range of tempi (Italian: plural for tempo) usually involved in human music is between 40 and 300 Beats Per Minute (BPM), corresponding to inter-beat-intervals of 200–1500 ms (Van Noorden and Moelants 1999). The timing of musical beats is indicated in conducting gestures by reaching points in space which are characterized by distinct kinematic properties. Theoretically, one may expect the location of the beginning of musical beats in conducting gestures to correspond to the points of change in the direction of the movement trajectory. Surprisingly, this seemingly trivial property of conducting is controversial. A study by Clayton (Clayton 1986) demonstrated that the ictus (the point in time of the beginning of the beat) is determined by the lowest part of the trajectory along the vertical axis, either as the baton rounds the corner, or bounces back up. Luck (2000) corroborated these findings, but also hypothesized that the perception of timing of the ictus is affected by multiple kinematic factors (G. Luck 2000). Later studies supported this supposition, showing that synchronicity in the orchestra's playing is strongly associated with the acceleration of the baton hand (Luck 2008; Luck and Sloboda 2009; Luck and Toiviainen 2006). Accordingly, the perceived location of a beat was believed to be based on the position landmark of the maxima in vertical acceleration. This finding was also validated by Wöllner et al. (2012), who investigated the reaction of musicians to morphed conducting gestures. Their findings indicated that musicians find it easier to synchronize with morphed gestures (the grand averaged conducting gestures of 12 different conductors) than with real-life, individual conducting gestures. A preference for morphed gestures may indicate that orchestra musicians form an internal model of average, prototypical set of conducting gestures, enabling them to respond quickly to the great variety of conductors they encounter as professional orchestral players, as long as their conducting gestures are in line with the "prototypical" conducting technique (Wöllner et al. 2012). Additional findings indicate that synchronization among musicians is enhanced when conducting gestures resemble a kind of motion, similar to that produced by gravity (Luck and Sloboda 2007). These findings are actually not in line with the ictus being at the point of maximum acceleration, since free fall movements involve constant acceleration. Since the direction of movement is changed at the end of the downbeat, it is actually the point of maximum deceleration which might be easier to detect. These findings are in line with the results obtained by Luck and Toiviainen (2006), who showed that maximal synchronicity within the ensemble was reached in points of maximal deceleration. They also pointed at vertical velocity as an important factor influencing ensemble synchronicity (Luck and Toiviainen 2006). Luck and Sloboda (2007) pointed out that gravity causes higher downward velocity, necessitating a more marked deceleration as the gesture rounds the corner (Luck and Sloboda 2007). These results indicate enhanced changes in velocity towards the 1st beat compared to all other beats, predicting more pronounced ensemble synchronization for the downbeat (see next section for a detailed discussion on synchronization with the meter). Another relevant finding shows a linkage between gesture curvature and synchronicity in the ensemble's response. Luck (2008) showed that synchronicity is negatively correlated with the amount of curvature contained within a gesture (Luck 2008). This adds curvature to the factors influencing conductor-ensemble synchronization and interpretation of the ictus.

The discrepancies between findings regarding the kinematic characterization of the ictus could derive from several factors (or their combination): a. Diversity of conducting techniques between conductors who participated in different studies. b. Differences in experimental methodologies and in analysis methods. c. Differences in synchronization to different beats in the meter, d. Differences in experience of following various conductors who took part in a large array of different studies. Supportive of the last factor are results showing that synchronicity within the orchestra is positively correlated with experience, introducing an additional factor into the equation. Another finding by Luck and Toiviainen (2006) showed that musicians respond with a significant delay between the perceived ictus and the actual onset of the ensemble (Luck and Toiviainen 2006). Interestingly, musicians tend to lag behind the beat more than non-musicians. These findings highlight the difficulty encountered in attempting to track down the moment of the ictus. A variable delay in response to the ictus requires a recalculation of the results, based on orchestral experience. Notwithstanding the methodological difficulties in characterizing the point of ictus, there seems to be an agreement on the importance of acceleration (and deceleration) as a major factor influencing ictus detection.

10.4 Meter

Meter is defined as the pattern in which a steady succession of rhythmic pulses are organized (Harvard Dictionary of Music: (The new Harvard dictionary of music 2003). The organization of the beats in a meter is hierarchically defined, with the first beat (the "downbeat") in the meter being the most accentuated. This principle is clearly reflected in dance music, where the meter reflects the patterns of dancing steps, and their periodic nature. For example, the dance pattern of a waltz includes a periodic pattern of three steps, which is also conveyed by the music. Sub-hierarchies also exist within a meter containing more than 3 inner beats. For example, in a meter of four, the first beat is the most accentuated, the third beat contains a lighter accent than the first beat, while the second and fourth beats are perceived as lighter. This hierarchical structure divides the meter of four into three sub-hierarchies. Similarly, a meter of 5 can be hierarchically divided into two successive groups of 2 + 3 or 3 + 2, a meter of 6 into two groups of 3 + 3, etc. Conducting gestures are specifically designed to communicate these hierarchies, through division in the space of these hierarchical groups. The "heaviest" beat in a meter would always be the first one (the "downbeat") which is conducted with a downward movement, possibly signifying the heaviness of the force of gravity. The last beat of a meter (the "upbeat"), accumulates musical energy towards the first, heavy beat, and is conducted with an upward movement, possibly symbolizing an increase in potential energy and tension. The rest of the beats in any meter, are indicated by a movement to the right or the left (see Fig. 10.1 for a detailed description of right-hand conducting

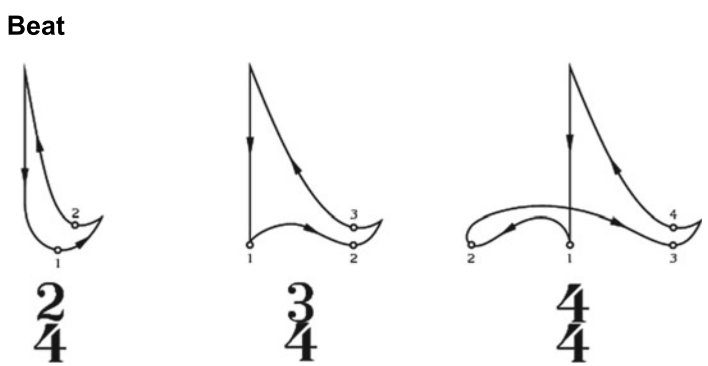

Fig. 10.1 Conducting gestures for 2, 3, and 4 beat meters

gestures), parallel to the ground. There is no formal explanation for the choice of direction of the beats. However, one could speculate that there might be a kinematic-musical explanation for choosing specific directions for specific beats in a meter. For example, in a meter of 4, the third beat, which is partially accentuated, is conducted in an outward movement, which allows a greater movement-amplitude, signaling louder sound production. As discussed in the previous section, conductor-ensemble synchronization tends to be at its highest level on the downbeat of the meter (Luck and Sloboda 2007). There may be several explanations for this phenomenon. The most obvious is the change in movement direction characterizing both the upbeat and downbeat in conducting gestures. An additional explanation derives from multiple studies demonstrating periodic allocation of attention, affected by metric hierarchies. Attention level appears to be at peak towards the downbeat (Fitzroy and Sanders 2015). Taken together, it is possible that the greater synchronicity of ensembles on the downbeat of the meter derives both kinematic factors and periodic allocation of attention. This conjecture requires further examination in empiric studies, evaluating the effect of meter on visual perception of movement.

10.5 Loudness

Loudness is one of the most important cues indicating character in music (Juslin 2000; Juslin and Laukka 2004). Classical music compositions include detailed instructions regarding the degree of loudness (e.g. forte and piano-Italian terms for loud and soft). Loudness is conveyed in conducting through the amplitude of the movement, both in theory and in practice. The larger the movement, the louder the musical outcome (Wöllner et al. 2012). Very often in music, a steady beat is maintained, while loudness changes. In this case, spatial inter-beat intervals of conducting gestures remain constant, while amplitude and velocity will change to convey the change in loudness. This alteration of movement kinematics is carried out effortless by novices in conducting. A simple exercise recommended for the reader, demonstrates the easiness with which such alteration of movement dynamics is carried out. Tapping at a steady beat, with increasing amplitude of tapping movement (which will result in louder taps) should prove to be of no difficulty for anyone in the general population with no musical background. The “principle of isochrony” could prove a credible explanation for this phenomenon. This principle indicates that the duration of movements remains nearly constant, while changing amplitude, speed and acceleration. In other words, movement duration is nearly independent of its amplitude. Two aspects of isochrony were reported: ‘global isochrony’ (Viviani and Schneider 1991) refers to the near constancy of the entire movement duration, while ‘local isochrony’, refers to the observation that within more complicated movements the durations of the internal segments are also roughly equal independently of the segments’ lengths, as long as the entire movement is planned as a whole (Flash and Hogan 1985). Going back to conducting, the principle of isochrony enables conductors to easily convey expression through change in amplitude, muscle tension, curvature of movement etc.

while maintaining a steady beat. The same would probably apply to the ensemble, having no difficulty in keeping the pulse, while extracting relevant additional information on loudness, sound quality, articulation etc. conveyed by various kinematic properties of conducting gestures, which are independent of movement duration.

10.6 Articulation

Articulation can be defined as "The characteristics of attack and decay of single tones or groups of tones, and the means by which these characteristics are produced" (The new Harvard dictionary of music 2003). Another definition by the Grove Dictionary reads: "The manner in which successive notes are joined to one another by a performer" (Grove Dictionary of Music and Musicians 1995). A unified definition for articulation would encompass both duration and attack. Articulation has a substantial effect on the emotional impact of musical performance (Juslin 2000). For example, while sadness is associated with legato (tied) articulation, happiness is associated with staccato (separated and short) articulation. Hence, communicating a complete emotional characterization of the music requires clear instruction regarding articulation to be included in conducting gestures. The acoustic manifestation of sound attack and decay can be observed in 4 main stages of loudness progression of sound in time: attack, decay, sustain and release (Hähnel and Berndt 2010). An accentuated attack would be reflected in an abrupt decay at the attack stage of the sound, while a softer attack would be reflected in a slower decay. Conducting gestures can portray these acoustic changes through jerk (the rate of change of acceleration). The more jerky a movement is, the more accentuated (i.e.-played with an accent) the sound (Nakra et al. 2009).

The duration of sound is rather simple to control through conducting gestures. Stopping the movement of the right-hand stops sound. This straightforward technique is described in the following quotation from McElheran's method of conducting: "*Simply hold the hand still when you come to the fermata, letting the note continue as long as you wish*" (McElheran 2004). Short tones ("staccato") are represented in conducting technique by a quick wrist movement, signifying the quick bounce of the bow, in string players, or the tongue in wind players (Rudolf 1980, p. 16).

10.7 Motion, Emotion and Sound: Expressive Conducting, Unraveling the Enigma

One of the most enigmatic features of conducting is the ability of conductors to inspire the ensemble, at times leading to an enrapturing performance. This intriguing feature of conducting is difficult, if not impossible to quantify. Conducting gestures alone cannot possibly account for the great differences in musical character obtained by different conductors. There is, no doubt, a central role for personal charisma, facial expression, professional authority, quality of verbal instruction, as well as many other personal and professional traits underlying the ability to successfully transmit an emotional message to an ensemble. However, it is possible that one could isolate some of the kinematic characteristics involved in communicating emotional messages in conducting. Prior studies investigating the expressive content of human motion may provide important information regarding conductor-ensemble emotional communication. Pollick et al. (2001) investigated point-light displays of human arm movements and their ability to convey an emotional message to spectators (Pollick et al. 2001).They employed the circumplex model of emotion to evaluate the emotional impact of movements (Russell 1980). This model (as well as other multidimensional models of emotion) suggests that emotions can be described by a two-dimensional circular space: activation, represented by the vertical axis, and valence, represented by the horizontal axis. Their results indicated that the amount of activation characterizing the emotional content of arm movements is positively correlated with velocity, acceleration and jerk of the movement.

As mentioned before in this chapter, movement's jerk is also an efficient method of conveying articulation (Nakra et al. 2009). Interestingly, the motor system does not show an inclination towards larger jerk. Rather the contrary: mathematical models based on optimization theory (Flash and Hogan 1985; Harris and Wolpert 1998; Todorov and Jordan 1998, 2002; Uno et al. 1989) suggest that the motor system optimizes certain costs, those being based on either kinematic or dynamic variables or variables related to neural activations. According to the minimum-jerk model (Flash and Hogan 1985), a primary objective of motor coordination is to achieve the smoothest possible hand trajectory under the circumstances. This objective was equated with the minimization of hand jerk (the rate of change of hand acceleration), and the specific trajectories yielding the optimal performance were mathematically determined and compared to measured movements. Hence, jerky conducting movements are less consistent with the optimal characteristics of movement. Furthermore, one would expect experienced conductors to reconcile between the principle of jerk minimization (i.e., reducing movement jerk to a minimum), and the necessity to convey articulation and emotional activation, reaching a result which would seem more natural to the musicians and audience alike. This conjecture calls for further investigation, focusing on jerkiness and gesture effectiveness in novice and experienced conductors.

Timing and amplitude were also found to correlate with activation (Amaya et al. 1996). While arm movement kinematics seems to portray activation reliably, valence does not seem to be portrayed as clearly. It is now assumed that valence is conveyed through a multimodal combination of body postures, facial expression and movement kinematics. Darwin, In "The Expression of Emotion in Man and Animals", (1872) emphasized the importance of body postures in conveying emotions both in animals and in humans. These views have been supported by a multitude of studies, demonstrating the emotional impact of body posture on human spectators. It is beyond the scope of the current book chapter to discuss static body postures, and their combination with movement kinematics in conducting. However, it seems imperative for future studies, investigating the emotional impact of conducting on the ensemble and audiences, to include both static and dynamic features in their analysis of conducting.

10.8 Conclusion

Despite the growing number of studies on conducting gestures and their effect on musical performance, conducting remains an enigmatic phenomenon. We strongly believe that the fascinating interaction between conductor and ensemble is a holistic phenomenon, which can only be understood by combining multidisciplinary research methods, including social psychology, computational motor control (in action and perception, alike), musicological analysis tools, physics and acoustics of musical instruments, biomechanics of conducting and music-instrument playing, as well as cross-modal sound-to-movement mapping.

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