MICROANALYSIS OF NONVERBAL COMMUNICATION

DEVELOPMENT OF A NONVERBAL RESEARCH METHOD USING HIGH-PERFORMANCE 3D CHARACTER ANIMATION

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Haug Leuschner

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Primary Supervisor: Prof. Dr. Gary Bente

University of Cologne
Department of Psychology
Gronewaldstraße 2
50931 Cologne, Germany

Secondary Supervisor: Prof. Dr. Dr. Kai Vogeley

University Hospital Cologne
Department of Psychiatry and Psychotherapy
Kerpener Straße 62
50924 Cologne, Germany

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Abstract

The purpose of this work is to provide a research tool for the field of nonverbal communication, with the primary goal being to transform motion capture data or manually coded 3D animation data into nonverbal metric data that allow for the application of standard statistical methods such as analysis of variance, factor analysis, and multiple regression analysis.

For this purpose, three nonverbal coding systems describing (1) static body postures, (2) dynamic body movements, and (3) proper body part motions such as head nods have been developed. A geometrical model describing postures and movements as flexion angles of body parts on three clearly understandable and nonverbal relevant dimensions—the sagittal, the rotational, and the lateral—provide the basis for math formulas which allow the transformation of Euler rotation angles of motion capture data or 3D animation data into metric measures describing body postures, movements, and proper motions.

Furthermore, math formulas were developed to compute about 30 nonverbal cues described in the literature that can be understood as geometrical features of body parts: e.g. postural openness, symmetry, and expansiveness, head positions and head nods, gaze direction and body orientation, pointing behavior and relational gestures, interactional synchrony, proxemics and touch, including statistics such as rates, velocity, and acceleration of movements.

To transform motion capture and 3D animation data into nonverbal metric measures, the software APEx (Automatic Parameter Extraction of Nonverbal Parameters) has been developed with a number of convenient features converting motion capture data into more than 150 metric nonverbal parameters. In addition, statistical parameters are supplied for each nonverbal parameter such as mean, standard deviation, minimum, and maximum.

Keywords: nonverbal communication, nonverbal behavior, nonverbal coding system, nonverbal cues, pattern recognition, kinesics, body language, body postures, body movements, motion capture, 3D character animation, data extraction, software, program, APEx.

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Chapter 1: Introduction

Nonverbal communication is a vital and important part of everyday human interaction, its roots grounded in the early days of humankind before language unfolded (Argyle, 1975; Birdwhistell, 1970; Burgoon, 1994; Darwin, 1872). The interest of philosophers and scientists in understanding the latent principles of unspoken dialogue is enormous (Burgoon & Hoobler, 2002). In order to provide deeper insight into the nature of nonverbal communication, thousands of scientific studies have been conducted since the 1950s in all sorts of different areas such as psychology, anthropology, sociology, education, linguistics, and medicine (Harrigan, Rosenthal, & Scherer, 2005). In more recent times, studies have also been conducted in neurorobotics science and engineering in interdisciplinary areas in conjunction with social cognitive neuroscience in order to construct human-like robots for everyday assistance (Bicho, Louro, & Erlhagen, 2010; Schaal, 2007; Vogeley & Bente, 2010).

Numerous studies have demonstrated the enormous impact of nonverbal behavior such as facial expressions, gaze behavior, touch, gestures, postures, and movements on person perception, impression formation, and interaction control (Andersen, 2008; Burgoon, Guerrero, & Floyd, 2010; Guerrero, Andersen, & Afifi, 2010; Knapp, Hall, & Horgan, 2013; Manusov, 2005; Manusov & Patterson, 2006; Remland, 2009; Riggio & Feldman, 2005), and these have helped to reveal the unconscious nature of the processes involved in the encoding and decoding of nonverbal messages (Castelli, Carraro, Pavan, Murelli, & Carraro, 2012; Choi, Gray, & Ambady, 2005; Dimberg, Thunberg, & Elmehed, 2000; Hofmann, Gschwendner, & Schmitt, 2009; Mehrabian, 1972). Nonverbal communication science postulates the automaticity and unconscious character of nonverbal communication, the high degree of automation, and a direct connection between the encoding and decoding processes (Lakin, 2006). Nonverbal communication "can thus be seen as unaware, efficient, uncontrollable and unintentional" (Vogeley & Bente, 2010, p. 1079).

The effect of nonverbal behavior arises not only from nonverbal cues with certain semantic meanings such as the facial expressions of basic emotions but also from "dynamic qualities that are implicit to the ongoing behavior and can hardly identified with the naked eye" (Vogeley & Bente, 2010, p. 1079). Research has found that dynamic qualities of movements such as speed, periodicity, or complexity of body movements convey socially relevant information which cannot be consciously identified but which may have a stronger impact on social perception than the static aspects of nonverbal cues (Grammer, Filova, & Fieder, 1997; Grammer, Honda, Juette, & Schmitt, 1999; Riggio & Friedman, 1986).

Johansson's (1973, 1976) point light displays are an impressive demonstration of how dynamic qualities of nonverbal behavior convey socially relevant information. Point light displays visualize body motions, usually the human gait, with white spots moving on a black background and representing the major body joints of a body[*]. This method allows us to study body motions on an experimental basis, and several studies using this technique have shown that people can recognize sex (Barclay, Cutting, & Kozlowski, 1978; Cutting, Proffitt, & Kozlowski, 1978; Kozlowski & Cutting, 1977; Mather & Murdoch, 1994; Troje, 2002), age (Montepare & Zebrowitz-McArthur, 1988; Montepare & Zebrowitz, 1993), identity (Cutting & Kozlowski, 1977; Jacobs, Pinto, & Shiffrar, 2004; Loula, Prasad, Harber, & Shiffrar, 2005; Stevenage, Nixon, & Vince, 1999; Troje, Westhoff, & Lavrov, 2005; Westhoff & Troje, 2007), emotions (Atkinson, Dittrich, Gemmell, & Young, 2004; Barliya, Omlor, Giese, Berthoz, & Flash, 2013; Brownlow, Dixon, Egbert, & Radcliffe, 1997; Chouchourelou, Matsuka, Harber, & Shiffrar, 2006; Gross, Crane, & Fredrickson, 2012), or personality traits (Thoresen, Vuong, & Atkinson, 2012), merely by observing white spots moving on a black background. Displaying static pictures of point light displays allowed recognition only on a chance level, showing evidence that the relevant social information is coded only in the body motions (Atkinson et al., 2004; Kozlowski & Cutting, 1977; Loula et al., 2005).

[*] Various animations of point light displays can be viewed at www.biomotionlab.ca.

In order to find the spatiotemporal characteristics explaining the participant's judgments, some mathematical methods have been suggested which provide geometrical data. Johansson (1973, 1976) described a two-dimensional vector analysis model for calculating the velocity and acceleration of each point light according to its moves on the monitor surface of the point light display, but other studies preferred simpler measures such as walking speed in paces per minute (Kozlowski & Cutting, 1977), ratings by participants to classify gait characteristics (Montepare & Zebrowitz-McArthur, 1988), or measures of static body characteristics such as walkers' shoulder and hip width (Barclay et al., 1978) or the torso torques of male and female walkers (Cutting et al., 1978).

Troje (2002, 2008) developed a framework to obtain parameterizations of human motion characteristics from motion capture data. His approach transforms the spatiotemporal three-dimensional trajectories of discrete data points captured on a person's body into a representation that allows for the application of standard methods of linear statistics and pattern recognition. These trajectories are the time series of 3D Cartesian coordinates of 15 data points representing the main joints of the human body. For periodic motions such as human gait, Troje uses Fourier decompositions to achieve low-dimensional linear components that represent biologically and psychologically relevant attributes. After the motion capture data are linearized for each data point, PCA is applied to the Fourier-transformed time series of all of the participating walkers in order to reduce the dimensionality of the data points. The resulting data are used in a subsequent discriminant analysis to explain group differences with the spatiotemporal characteristics of the spots. For this purpose, a discriminant function can be computed, resulting in a discriminant vector that can be decomposed into different terms describing the structural and kinematic differences between the groups, and this can be used to generate point light displays visualizing the spatiotemporal characteristics of each group. Several studies used Troje's approach of a Fourier decomposition of motion capture data (Barliya et al., 2013; Troje et al., 2005; Westhoff & Troje, 2007).

The point light display research paradigm was groundbreaking for the investigation of biological motion, but the method is highly adapted to the situation of human walkers. For analysis of human gait, it may be appropriate to neglect the postures and positions of body parts, in particular the head, the hands, and the feet, by replacing them with dots and considering only the Cartesian coordinates of the dots for data analysis and Fourier decomposition.

Nevertheless, for other situations in which nonverbal communication occurs the postures of body parts are highly relevant and should be considered. In particular, body movements are transitions between sequentially arranged and always visible and meaningful body postures which convey important nonverbal messages such as attitudes, emotions, motives, status, and interpersonal relationships (Mehrabian, 1972, 1981). According to Burgoon (2010, p. 273), most of the research on postures is dated and may no longer be valid, so an update of the research on body postures is needed along with research on body movements which is desirable for new insights beyond the findings of the point light display research paradigm.

The effort of coding body postures and body movements is enormous—the body can show a number of different positions and movements for each part every second. Harrigan (2005, p. 138) recommended coding only the body parts of interest, but manual coding is still enormously time-consuming and error-prone. Since motion capture systems are efficient and accurate, it seems reasonable to use motion capture data to analyze body postures and movements. The problem with motion capture data is that they describe the orientation of body parts in space with so-called Euler rotation angles. In small ranges between 0° and 15°, they appear to reflect the flexion angles of body parts, but this is not actually the case. Euler angles instead denote the angles to be used by successive rotation of a body part about the *x*-, *y*-, and *z*-axes of its center, which is hard to imagine. In addition, there are many sequences which apply different rotation angles in order to reach the same orientation in space. For these reasons, Euler rotation angles are not meaningfully interpretable, and are not included in nonverbal data analysis.

Since the Euler rotation angles of motion capture data are useless for the analyses of body postures and proper body part motions, i.e. rotations of a body part around its center such as head nodding, it is essential to develop a method for transforming motion capture data into useful nonverbal parameters qualified for standard analytical methods and allowing a novel kind of nonverbal research method. This approach results in a nonverbal coding system which provides values accurately describing body postures and body movements on a metric scale, which has never been done before. Nonverbal position and movement data with the full spectrum of metric information on clearly understandable and nonverbal relevant dimensions are a novelty, and allow the application of standard statistical methods such as analysis of variance, factor analysis, and multiple regression analysis.

Furthermore, the nonverbal literature was reviewed in the search for nonverbal cues that can be calculated from motion capture data, and the following groups of nonverbal cues were taken into account: the five immediacy cues (Mehrabian, 1969b, 1972), the nonverbal involvement behavior (Patterson, 1982), the relaxation cues originally discovered by Goffman (1961) and described by Mehrabian (1969b, 1972), the expansiveness behavior observed by Scheflen (1972), pointing gestures and touching behavior as described by Henley (1977), interactional synchrony in the sense of posture mirroring and motor mimicry (Bavelas, Black, Chovil, & Lemery, 1988; Bavelas, Black, Lemery, & Mullett, 1986, 1987), and sagittal head nods, rotational head shakes, and lateral head tilts as described by Bente (1989).

This set of around 30 nonverbal cues describes the most investigated characteristics of postures, movements, and dyadic relations and allows the updating of existing research findings and discovery of new research findings on nonverbal communication.

Purpose of the Work

The purpose of this work is to provide a research tool for the field of nonverbal communication, with the primary goal being to transform motion capture data or manually coded 3D animation data into nonverbal metric data that allow for the application of standard statistical methods such as analysis of variance, factor analysis, and multiple regression analysis.

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Furthermore, math formulas were developed to compute about 30 nonverbal cues described in the literature that can be understood as geometrical features of body parts: e.g. postural openness, symmetry, and expansiveness, head postures and head nods, gaze direction and body orientation, pointing behavior and relational gestures, interactional synchrony, proxemics and touch, including statistics such as rates, velocity, and acceleration of movements.

To transform motion capture and 3D animation data into nonverbal metric measures, the software APEx (Automatic Parameter Extraction of Nonverbal Parameters) has been developed with a number of convenient features converting motion capture data into more than 150 metric nonverbal parameters. In addition, statistical parameters are supplied for each nonverbal parameter such as mean, standard deviation, minimum, and maximum.

Importance of the Work

This work provides the first systematic and comprehensive method for transforming motion capture data *including Euler rotation angles* into metric data in three nonverbal meaningful dimensions, thereby allowing the researcher to apply standard statistical methods such as analysis of variance, factor analysis, and multiple regression analysis. In addition, a comprehensive set of around 30 nonverbal cues including statistical parameters is supplied.

Various researchers used motion capture systems to calculate measures from the three-dimensional Cartesian coordinates of point light spots, e.g., body part flexion angles as projection in the two-dimensional sagittal plane (e.g., Barliya et al., 2013; Crane & Gross, 2007; Das, Lazarewicz, Wilson, & Finkel, 2009; Gross, Crane, & Fredrickson, 2010) or duration, velocity, and acceleration of point light spot movements (Ada, Suda, & Ishii, 2003; Gross et al., 2012; Naugle, Hass, Joyner, Coombes, & Janelle, 2011; Pollick, Paterson, Bruderlin, & Sanford, 2001). Other researchers supply motion capture libraries with various avatars and corresponding motion capture data (Busso et al., 2008; Ma, Paterson, & Pollick, 2006).

Obviously, the nonverbal research community requires accurate spatiotemporal measures and could benefit from an all-round research tool based on nonverbal research findings which provides transformation functions for motion capture and animation data.

Limitations and Assumptions

The research tool APEx can be used with Windows XP and higher. APEx supports the reading of *global translation* and *rotation data* (i.e., Cartesian coordinates and Euler angles which are globally related to the center of the 3D world) stored in text files using the *comma separated values* (CSV) format (see Chapter 7, p. 91). A script is provided (see Appendix B, p. 110) that allows the export of the required *global data* from the 3D animation software MotionBuilder into csv files. For other software, a corresponding script is to be written.

Organization of the Work

Chapter 1: Introduction highlights the great significance of nonverbal communication for interpersonal communication and social interaction and reports the current state of nonverbal communication research regarding unconscious nonverbal messages conveyed by dynamic qualities of body movements. After a review of the methods and findings of the point light display paradigm marking a milestone in this research field, the basic drawbacks of this research paradigm and the use of motion capture data are discussed, the solution provided by this work is described, and perspectives for future applications are presented.

Chapter 2: Nonverbal Communication reviews common definitions of nonverbal communication. Because of the complexity of the research subject, many different views have been expressed since the 1970s, and they are still hotly debated.

Chapter 3: Review of the Literature on Nonverbal Coding Systems reviews the literature on the history, advantages, and disadvantages of the most commonly used nonverbal coding systems. After postulating four requirements with which a nonverbal coding system should comply, the existing coding systems are evaluated in terms of their suitability. The Bernese coding system does not meet the criteria of supplying metric measures and describing body movements but has been proven to be the most suitable coding system and therefore provides the basis for the development of the SRL coding system, as described in Chapter 4.

Chapter 4: Measuring Body Positions and Body Movements describes the SRL coding system supplying 135 flexion angles for 15 body parts. The basic idea and the geometrical model are presented, and successive images illustrate how flexion angles describe positions and movements as deviations from base positions. Math formulas are derived which allow the transformation of uninterpretable Euler rotation angles into meaningful SRL flexion angles. The scope and limits of the math formulas are described, characteristics of the SRL flexion angles discussed, and recommendations for choosing the best base position offered. In addition, 26 statistical parameters are described and recommendations for their use are given.

Chapter 5: Review of the Literature on Nonverbal Cues reviews the main findings of kinesic research in order to find the best set of nonverbal cues computable from motion capture and animation data. After a brief overview of nonverbal codes found by researchers since the 1950s, the historical development of nonverbal research regarding gestures, facial expressions, postures, movements, gaze, touch, and proxemics is described. The research findings lead to the discovery that those nonverbal cues relate to three fundamental dimensions of human socio-emotional perception and behavior (Mehrabian, 1972; Osgood, 1966; Schlosberg, 1952; Vogeley & Bente, 2010; Wundt, 1896), thereby providing a theoretical framework for the parameters computed by APEx: (1) *evaluation/pleasure/pleasantness*, (2) *potency/status/dominance/power/control*, and (3) *responsiveness/arousal/activation/activity*.

Chapter 6: Measuring Nonverbal Cues describes the nonverbal parameters developed according to the nonverbal cues found as an expression of the three nonverbal dimensions outlined in Chapter 5. Their operationalization is presented along with geometrical models, math terms, and details of their implementation in APEx.

Chapter 7: The Program APEx describes input data files, output data files, program handling, and functions of the software. For the purpose of exporting motion capture data or 3D animation data from the 3D animation software *MotionBuilder*, an installation guide and step-by-step instructions for the script *ExportGlobalData* are supplied. The user interface of APEx allows the user to load multiple input data files, to define data fields, and to set various program options controlling APEx. Moreover, the user can manipulate APEx's transformation process by modifying the nonverbal parameter list defining how APEx transforms the input data or by creating new definitions of nonverbal parameters.

Chapter 8: Limitations and Future Directions shows the limitations of this approach and outlines the direction of future developments: collision detection, pattern recognition, facial recognition, and eye tracking could be key components of an all-round nonverbal research tool for the future.

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Chapter 2: Nonverbal Communication

Theories and findings from nonverbal communication research form the basis of the conceptual framework used for this work. They are required for the understanding of the developed research instruments. The latest textbooks, e.g., those written by Andersen (2008), Burgoon et al. (2010), Knapp et al. (2013), Manusov and Patterson (2006), More, Hickson, and Stacks (2009), Remland (2009), and Richmond, McCroskey, and Hickson (2007), describe the *interpersonal perspective* of nonverbal communication, exploring the communication process between individuals. In the last decade, this perspective was extended to include the *intrapersonal perspective* of social cognitive neuroscience in order to explore the cognitive processes and neural mechanisms responsible for the production and perception of nonverbal behavior. Those processes have become a key topic in social cognitive neuroscience, which has recently evolved into an autonomous scientific discipline (Vogeley & Bente, 2010).

Approaches in Nonverbal Research

The research on nonverbal behavior and nonverbal communication began with Darwin's work *The expression of the emotions in man and animals* (1872), which concluded that "the young and the old of widely different races, both with man and animals, express the same state of mind by the same movements" (p. 352). Scientific research on nonverbal behavior and communication using scientific methods and resulting in the fundamental works which lay the foundation of contemporary nonverbal theories started in the early 1950s (Knapp, 2006). As depicted in *Figure 1*, the online database PsycINFO lists 10,899 publications regarding the keywords *nonverbal communication* or *nonverbal behavior*. Annual publications numbered seven in the 1950s, increased to 55 in the 1960s, 196 in the 1970s, 223 in the 1980s, and 236 in the 1990s, and reached 320 after the millennium.

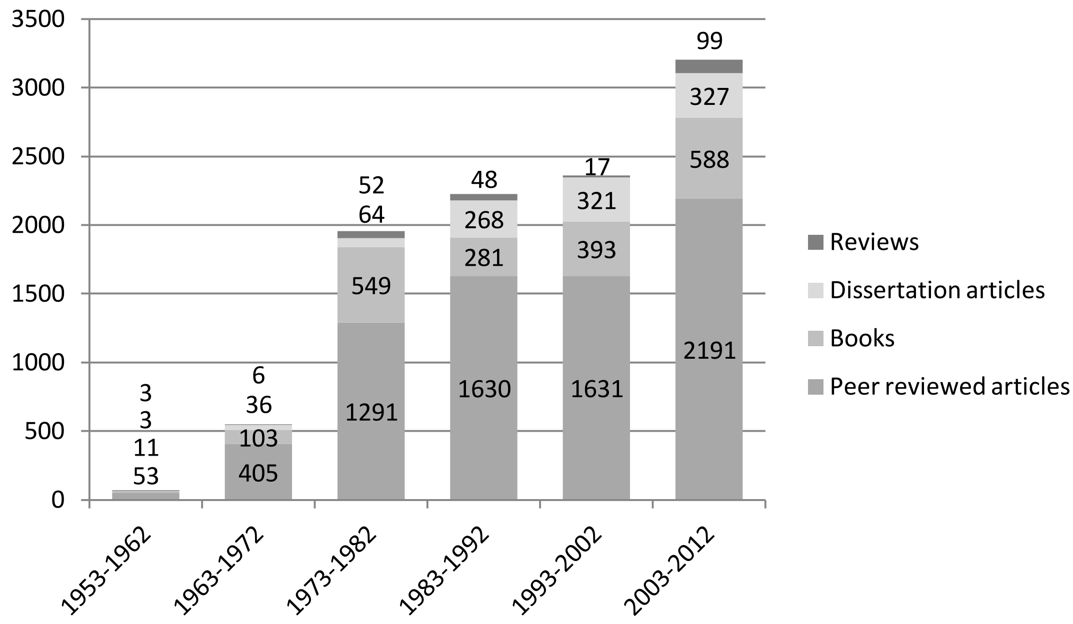


Figure 1. Number of publications about NVC or NVB listed in PsycINFO.

These publications originate from many areas such as communication, psychology, anthropology, ethnology, sociology, linguistics, psychotherapy, and education (Harrigan et al., 2005), and as a result they are based on different approaches. Traditionally, anthropologists and sociologists such as Margaret Mead, Gregory Bateson, Edward Hall, Ray Birdwhistell, and Erving Goffman favored the *nurture approach* (Moore et al., 2009). They believed that nonverbal communication is learned, similarly to verbal communication, and did not accept that some nonverbal cues such as basic emotional facial expressions are universal across cultures. In contrast to this approach, the *nature approach* of Darwin presumes that nonverbal behavior relies on a biological, genetically determined signaling system of human beings and other animals, and this theory is still used by researchers such as the psychologist Ekman (2003b), the zoologist Morris (1980), and the communication scientists Andersen (2008) and Remland (2009). Most contemporary psychologists and communication researchers such as Burgoon et al. (2010), Knapp et al. (2013), Manusov and Patterson (2006), Moore et al. (2009), Remland (2009), and Vogeley and Bente (2010) emphasize the *functional approach*, which focuses on the functions of nonverbal communication.

Definition of Nonverbal Communication

There is no generally accepted definition of nonverbal communication. In the 1970s, different points of view emerged (for an overview see Burgoon, 1980), which are still hotly debated. The definitions can be classified as those relying on *specifying nonverbal behavior*, *separating nonverbal from verbal communication*, the *standard communication model*, and a *biological signaling system*.

Specifying nonverbal behavior. A frequently used approach lists various behaviors indicating nonverbal communication (similar to Table 8, see p. 61) without mentioning any criterion which may or may not belong to the list (e.g., Barker & Collins, Benson & Frandsen, Leathers, as cited in Andersen, 2008). This approach offers no criteria about which behavior type belongs to the list, and as a result contemporary scholars give a more precise definition.

Separating nonverbal from verbal communication. In the attempt to find criteria to identify nonverbal communication, human communication is seen as separated into two antithetical parts, the verbal and the nonverbal part. The most common definition of this kind is supplied by Mehrabian (1972): "In its narrow and more accurate sense, 'nonverbal behavior' refers to actions as distinct from speech. It thus includes facial expressions, hand and arm gestures, postures, positions, and various movements of the body or the legs and feet" (p. 1). Andersen (2008, p. 18) gives the most elaborate list of 19 distinct categories which distinguish nonverbal from verbal communication, and refers to the first three categories as the three fundamental differences for defining *nonverbal communication*: "Nonverbal messages include all communication that is analogic, nonlinguistic, and typically governed by the right brain hemisphere" (p. 5). The three fundamental differences between nonverbal and verbal communication rely on the results of decades of nonverbal research and come to surprising conclusions, but the approach is criticized by other scholars for not fully meeting the complexity of human communication as described in the following subsections.

Analogic vs. digital messages. According to Andersen (2008),

> analogic messages have a direct, nonarbitrary, intrinsic relationship to the thing they represent (Andersen, 1986; Watzlawick et al., 1967; Wilden, 1972). Such messages look or sound like what they refer to or represent. . . . Digital communication, by contrast, indirectly communicates information via arbitrary codes such as language. (p. 5)

This point of view has a surprising consequence for gestures. Andersen (2008) considers the sign languages of deaf-and-dumb people and symbolic hand gestures, called emblems, to be digital, and as a result part of verbal rather than nonverbal communication. Other scholars do not accept Andersen's conclusion, and they maintain their view that symbolic hand gestures belong to nonverbal communication. Burgoon et al. (2010, p. 204) argue that regarding nonverbal codes as analogic creates a "false dichotomy" because although emblems must indeed be regarded as digital they are nevertheless nonverbal.

Linguistic vs. nonlinguistic messages. According to Andersen (2008), language is an indirect communication system that conveys information using linguistic symbols, which are arbitrary representations for other things. In contrast, nonverbal communication is a direct communication system that conveys information using nonlinguistic signs, which "naturally represent the things they stand for" (p. 8).

Left vs. right brain hemisphere. Andersen, Garrison, and Andersen (1979) reviewed the neurophysiological literature relating to nonverbal communication, and they concluded that neural correlates of nonverbal functions are located in the right brain hemisphere, whereas the left brain hemisphere is responsible for verbal functions. They suggested treating nonverbal behavior that is assumed to be a linguistic and left-hemispheric code as verbal.

According to Purves et al. (2008, p. 550), nearly all neuroscience researchers exploring the neural basis of language agree that in the majority of humans almost all cortical regions that are part of language comprehension and expression reside in the left hemisphere, whereas the corresponding cortical regions in the right hemisphere are responsible for the emotional coloring of speech prosody and other nonverbal aspects of language. Purves et al.

noted that there is evidence that the cortical representation of language is independent of the perceived or expressed symbols that can be verbal indications as well as gestures of a sign language.

Burgoon et al. (2010) argued that this only applies to where stimuli are initially perceived and that contemporary researchers have suggested “a far more complex, synchronized relationship between the two brain hemispheres in the perception, comprehension, retrieval, and encoding of social information (Borod, 1993; Ross, 2000)” (p. 213).

Research results of social cognitive neuroscience support the objection that the hemispheric lateralization refers only to the perception and expression of stimuli. Vogeley and Bente (2010) described nonverbal communication with regard to psychological processes and neural mechanisms. *Social cognitive processes* such as *mindreading*, *mentalizing*, and *theory of mind* attribute mental states to others by interpreting nonverbal information. Vogeley and Bente noted that neuroimaging studies in this field have consistently shown that brain areas of the social neural network (SNN) are involved. As depicted in *Figure 2*, the SNN includes the medial prefrontal cortex (MPFC), the superior temporal sulcus (STS), the amygdala (A), and the anterior temporal poles (TP) (p. 1082). In particular, the posterior STS (pSTS) is involved in the perception and interpretation of socially relevant nonverbal cues and inferring the other person’s mental states (p. 1083); this applies also to the temporo-parietal junction (TPJ) (Vogeley & Roepstorff, 2009). MPFC, STS, TP, pSTS, and TPJ exist in both hemispheres.

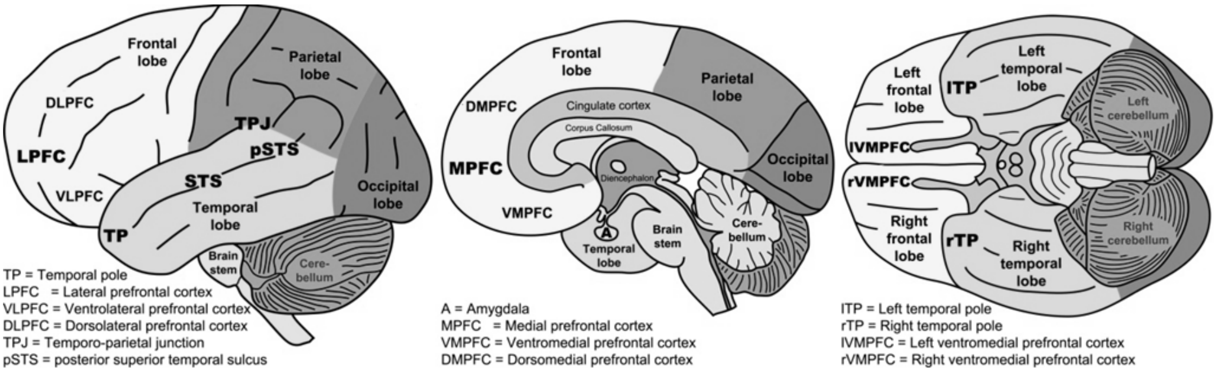


Figure 2. Locations of brain areas involved in the social neural network
Drawings adapted from “view of a human brain” by NEUROtiker, 2007.
Retrieved from Wikimedia Commons.

Standard communication model. The definitions of this category rely on the *mathematical communication model* of Shannon and Weaver (1949), also known as the *standard view of communication*, and later revised as the *Sender-Message-Channel-Receiver Model of Communication* (SMCR Model of Communication) by Berlo (1960). The basic statement is that a sender encodes a message and transmits it over a channel to a receiver who decodes the message. The central element is the message and the terms *encoding* and *decoding* stress that the sender translates the message into signals according to the chosen communication channel (e.g., text, speech, facial expressions, hand gestures, body movements) and the receiver translates the received signals back by reconstructing the original message. Therefore, definitions regarding nonverbal communication can be classified into definitions with *sender orientation*, *receiver orientation*, and *message orientation*. The key difference between these three categories is which viewpoint (*sender*, *receiver*, or *message viewpoint*) decides which behavior constitutes nonverbal communication. This question has been heavily contested since the 1970s.

Sender orientation. A definition with sender orientation advocates that only intentional behavior can be considered to be part of nonverbal communication (Motley, as cited in Andersen, 2008 and in Burgoon et al., 2010). The problem is that unconscious messages are not taken into account, but most nonverbal behavior is either well-learned, automated, and unaware (Burgoon et al., 2010; Lakin, 2006) or it is based on a biological signaling system which operates mostly outside our consciousness (Darwin, 1872; Ekman, 1973, 2003a; Ekman & Friesen, 1971; Ekman et al., 1987; Ekman, Sorenson, & Friesen, 1969).

Receiver orientation. This category relies on the axiom “one cannot not communicate” of Watzlawick, Beavin, and Jackson (1967/2008, p. 75). The receiver orientation postulates that any behavior a receiver interprets as a message is communication: “If a receiver obtains meaning from another's action, then communication has occurred” (Andersen, 2008, p. 16). The drawback of this approach is that every behavior is interpreted as communication, including those which might be informative but not communicative (Burgoon et al., 2010).

Message orientation. The message orientation was introduced by Burgoon (1980, 1985), and her definition is widely known. She periodically revised her definition and the latest one reads: "Communication refers to the *process of creating meanings between senders and receivers through the exchange of signs and symbols*" (Burgoon et al., 2010, p. 12). She assumed four criteria deciding which nonverbal behavior constitutes nonverbal communication and stressing that nonverbal behavior need not be regarded as intentional:

> Communication is viewed as only including those behaviors that form a socially shared coding system. This includes behaviors that (1) *are typically sent with intent*, (2) *are used with regularity among members of a given social community, society, or culture*, (3) *are typically interpreted as intentional*, and (4) *have consensually recognized meanings*. (p. 16)

Burgoon's definition of nonverbal communication includes: (1) the sender encoding intended messages and unconsciousness messages, (2) the receiver decoding the message, (3) the message, which creates the meanings between the sender and receiver, and (4) a socially shared coding system ensuring consensually recognized meanings of messages, according to the *social meaning model of nonverbal behavior* of Burgoon and Newton (1991).

The receiver orientation has the advantage that the researcher can investigate research questions outside the research topic of nonverbal communication. Burgoon et al. (2010) suggested distinguishing between *nonverbal information*, *nonverbal behavior*, and *nonverbal communication*. Information includes any perceived stimuli, behavior includes any action, and communication includes any intentional message targeted at a receiver. Whereas the receiver orientation denotes all nonverbal behavior as nonverbal communication which is perceived and interpreted, the distinction between nonverbal behavior and nonverbal communication allows us to differentiate between nonverbal communication that creates shared meanings between two individuals and nonverbal behavior that is unilaterally perceived and interpreted by a receiver without any communication intention on the part of the sender.

Biological signaling system. *The expression of the emotions in man and animals* is Darwin's (1872) contribution to the understanding of a biologically based and genetically determined signaling system for both animals and humans. He was the first scientist to send a questionnaire with rating scales and photos showing emotional expressions to different ethnic groups asking them which emotions were depicted. His method has become the most popular research method in the field of facial expression (Ekman, 2003a). From the worldwide responses, he drew the conclusion that facial expressions of emotion are innate, inherited, and therefore universal to humanity. Ekman and Friesen (1969) tried to disprove Darwin's view, but instead have identified two primary types of communication codes: *intrinsic codes* and *arbitrary codes* (Remland, 2009). "An *intrinsic communication code* is a biologically shared, innate signaling system in which a particular species uses symptoms for its communication with other members of the species" (p. 6). In contrast, an *arbitrary communication code* is a socially constructed signaling system that uses symbols (arbitrary codes) or signs (iconic codes) to convey messages (p. 8). Whereas signs show directly what they mean, the association between a symbol and what the symbol represents must be learned. Spoken or written words are symbols. The two communication codes complement each other: "Communication takes place whenever two or more individuals, using a socially shared or biologically shared signaling system, send and receive a message" (Remland, 2009, p. 5).

Chapter 3: Review of the Literature on Nonverbal Coding Systems

Requirements of a New Nonverbal Coding System

A new nonverbal coding system should meet the following four requirements.

Separation of description and evaluation. According to Frey and Pool (1976), a nonverbal coding system should describe nonverbal behavior without any interpretation or evaluation of the observed behavior. Any data collection based on inferences about nonverbal behavior contains implicit presumptions or explicit theories about the meaning or effect of nonverbal cues, and therefore prevents new results and discoveries in nonverbal research.

Experimental control of nonverbal behavior. The second requirement is the use of a research method within the experimental paradigm of the social sciences community enabling the examination of causal relationships between nonverbal behavior and its hypothesized effects on social cognitive processes such as person perception or impression formation.

Metric scale of nonverbal data. Acquired nonverbal data should operate on a metric scale to enable the use of sophisticated statistical approaches developed in the last few decades to detect and examine causal relationships in complex systems. Advanced statistical techniques such as analysis of variance, multiple regression analysis, exploratory and confirmatory factor analysis, path analysis, structural equation modeling, and time series analysis can only be applied if the nonverbal data operate on a metric scale.

Description of both body positions and body movements. Two different aspects of nonverbal behavior belong together: body positions and body movements. Nonverbal behavior is normally a sequence of alternating body positions and body movements. Each body movement starts with a body position and ends with a body position. Body positions and body movements have a great influence on the nonverbal communication process. Therefore, as the fourth and last requirement, a nonverbal coding system should describe body positions as well as body movements.

Separation of Descriptive and Evaluative Research Methods

Traditional nonverbal communication research does not meet the criterion of separation of description and evaluation which is necessary for exploring nonverbal communication. Frey and Pool (1976)) point out that traditional nonverbal research has primarily used three methods of data collection, which—because of implicit assumptions or explicit hypotheses—reduce behavioral observations to incomplete data where valuable and detailed information is lost or biased by subjective ratings: *generic*, *restrictive*, and *evaluative coding*. As visualized in *Figure 3* (see p. 24), all three methods have in common that the nonverbal behavior cannot be reconstructed from the collected data. Although these coding methods could theoretically provide explanations for different phenomena such as emotional impressions or person perception, important information about subtle cues or the dynamics of behavior is not available.

Generic coding. The observed behavior may be exhaustively captured, but is pooled into only a few categories so important details are lost. For example, nodding and shaking of the head could be combined in a category of head movements so that subsequent distinctions are no longer possible.

Restrictive coding. Specific behaviors may be recorded, avoiding the risk of regarding distinct nonverbal cues as identical, but only a few closely defined cues are collected. Donaghy (1989) has pointed out that this kind of coding causes the problem of "neglecting the interrelationship that all nonverbal behaviors have to one another" (p. 299).

Evaluative coding. The description of nonverbal behavior is ignored entirely. The observed behavior is directly interpreted, subjectively evaluated, and rated on defined psychological scales. Therefore, these rating scales may give information about the subjective impressions of particular observers induced by a specific nonverbal behavior, but information about which specific nonverbal behavior induced these impressions is lost.

Only complete and detailed coding is capable of reconstructing observed behavior, and therefore the description and evaluation of nonverbal behavior should be separate.

Descriptive Coding Systems for Nonverbal Behavior

Early coding systems. Several coding systems have been developed that are purely based on the physical description of body movements without confounding evaluation and description. Harrigan (2005) gives a brief overview of coding systems that have gained greater attention in the research of nonverbal behavior; however, they all use qualitative symbols or lack the accuracy to measure body positions and body movements, which require data on a metric scale. Birdwhistell (1952, 1970), an anthropologist and pioneer in the study of body movement, is known for having popularized the descriptive approach to nonverbal behavior research. He created a complex coding system for recording body movements using verbal and numerical symbols. Scheflen (1964, 1972), a psychiatrist greatly influenced by Birdwhistell, analyzed recordings of therapist-client interactions and coded the nonverbal behavior with a similar system of qualitative symbols. *Labanotation* (Hutchinson, 1961; Laban, 1956) is another exhaustive coding system using graphical symbols which was specifically designed for dance movements. The *Benesh Movement Notation* (Benesh & Benesh, 1983) is a dance notation system that can document any form of human movement, but it is also based on graphical representation of the human body. The *Eshkol-Wachmann Movement Notion* (Eshkol & Wachmann, 1958; Golani, Zeidel, & Eshkol, 1969) uses a spherical coordinate system to determine the orientation in space for each limb of the human body. Although this coding system uses a numerical system, it has a resolution of only 45° between two positions and therefore lacks the accuracy required to describe body positions. The *Bernese System for Time Series Notation of Movement Behavior* (BTSN) (Frey & Pool, 1976) uses the three Cartesian axes to assign numerical values to the position of each body part. As we will see in the next section, this coding system only meets the first requirement for a nonverbal research instrument, but it is the most accurate coding system developed in the twentieth century.

The Bernese system for time series notation of movement behavior. The *Bernese coding system* is a spatial-temporal coding system that uses the Cartesian coordinate system to describe the direction and position of each body part of a sitting individual by assigning numerical values to the various deviations of the body parts from a base position. The nonverbal behavior is coded from video tapes into a data matrix twice or five times each second and for each body part, thereby covering all possible positions and directions of the head, chest, hips, arms, hands, legs, and feet (Frey, Hirsbrunner, Florin, Daw, & Crawford, 1983). The result of the *Bernese coding system* is a detailed data protocol enabling high degrees of reliability and objectivity, and this classifies the Bernese coding system as a transcription method with complete and detailed records, as depicted in *Figure 3* (see p. 24).

Descriptive accuracy has been demonstrated in a static reconstruction task comparing original data protocols coded from video tapes with real people with second-order data protocols coded from pictures with human models whose body parts were placed in the same positions as those recorded in the original data protocols. Ninety-eight percent of the second-order codes were identical to the original ones (Frey & Pool, 1976). It should be noted, however, that this reconstruction task only examined the reliability of the data protocols and not their accuracy, because the data protocols were only compared in rough instead of exact positions. It is likely that the body positions of the models did not exactly match the original ones.

Nonverbal data from the *Bernese coding system* operate statistically on the ordinal scale level (Frey et al., 1983), because rough, easily localizable positions are used to take into account that human coders are unable to measure precise angular degrees and spatial distances simply through appearance. Furthermore, only body positions are measured, not movements. Other disadvantages are that only the nonverbal behavior of sitting individuals can be coded, and that the coding procedure is very time-consuming and expensive. Depending on the degree of activity, the notation can be up to 200 times the length of the video being coded (Bente, Senokozlieva, Pennig, Al-Issa, & Fischer, 2008).

Experimental Control of Nonverbal Behavior

Nonverbal research found that social perception depends primarily on nonverbal cues. Many other sources, however, such as the physical appearance of the sender, the situational context, or the cultural background of the receiver might influence the impression formation. One primary research task is to investigate thoroughly the causal relationship between nonverbal behavior and impression formation. As pointed out by Cook, Shadish and Campbell (2002), no other scientific method is as appropriate for studying causal relationships as the experiment in which (1) the presumed cause is manipulated to observe the outcome afterward, (2) the controlled variation of the cause is related to the observed variation in the outcome, and (3) various methods are used to exclude other possible explanations of the effect, i.e., variation in the outcome. To allow inferences about causal relationships in behavioral rating studies which determine the effects of specific body movements on the impression formation with rating scales, nonverbal behavior has to be manipulated systematically in order for the researcher to observe its effects while controlling the effects of other influential variables.

Early attempts at experimental control. As shown in Figure 3 (see p. 24), several attempts have been made to fulfill the requirements of an experimental approach, but they have failed in large part for various reasons: Lewis, Derlega, Shankar, Cochard, and Finkel (1997) instructed actors to vary singular nonverbal cues and found that they were unable to keep other aspects of their nonverbal behavior consistent. This approach also failed to meet the requirement for controlling the influence of the physical appearance of the actors. Other studies considered this aspect by using hand drawings (Schouwstra & Hoogstraten, 1995), retouched photos (Frey et al., 1983) or pictures of wooden figures (Trautner, 1991). These static techniques do not, however, allow investigation of the effect of body movements on impression formation and person perception. First attempts to separate body movements from human physical appearance were animated, graphically reduced object representations like geometrical shapes (Heider & Simmel, 1944), point light displays (Johansson, 1973), or pixelated video sequences (Berry, Kean, Misovich, & Baron, 1991). The first attempts to vary body movements systematically while controlling physical appearance were computer-simulated point light displays (Cutting & Proffitt, 1981).

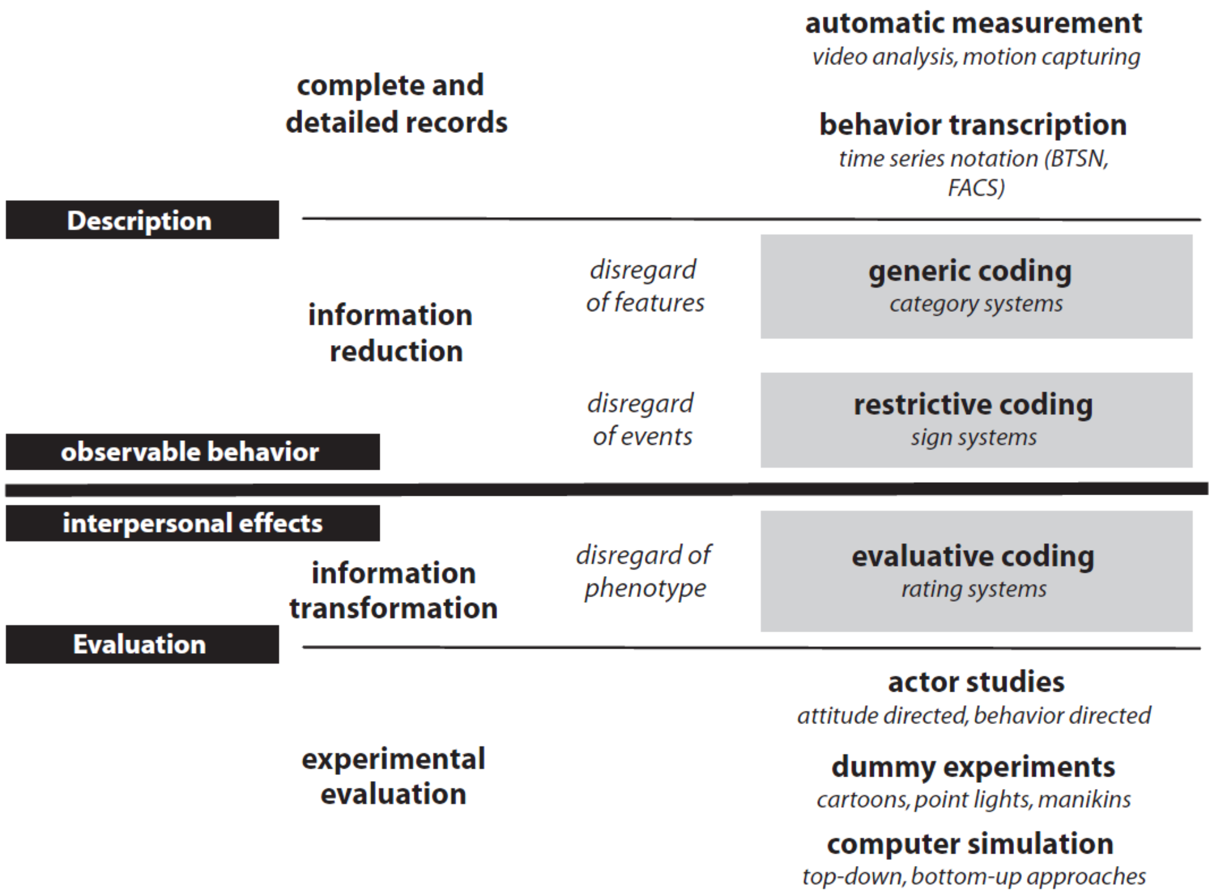


Figure 3. Classification of nonverbal research methods.
Adapted from Bente et al. (2008, p. 271).

Computer simulation. Bente introduced 3D computer animation technology as a nonverbal research method and developed software tools based on the *Bernese System for Time-Series Notation of Human Movement Behavior* in order to control both nonverbal behavior and physical appearance. Initially, Bente (1989) developed a computer program for the simulation of head movements using a simple wireframe model of a human head which sat on static human models. This approach has been successfully used in studies investigating gender-specific nonverbal behavior in dyadic interactions (Bente, Donaghy, & Suwelack, 1998; Bente, Feist, & Elder, 1996). Leuschner showed “that the implicit geometry of the BCS has to be understood in terms of projection angles of an object’s local axes rather than in terms of generic rotation angles" (Bente, Petersen, Krämer, & De Ruiter, 2001, p. 304), and developed a software module (Leuschner, 1999) that transforms the projection angles of the Bernese coding system (BCS) into the Euler rotation angles of 3D software animation tools. Based on this software module, the experimental platform for the computer simulation of nonverbal behavior ICARUS was developed (Bente, Petersen, et al., 2001). This research software tool is able to link the Bernese position time series protocols to a professional 3D computer animation platform (Softimage 3D), allowing for interactive editing of the Bernese projection angles and displaying smooth animations of realistic 3D-models. A subsequent evaluation study showed that 3D character animation of nonverbal behavior leads to the same impressions as the original video sequences (Bente, Krämer, Petersen, & de Ruiter, 2001).

Although accuracy and precision were significantly improved, the transcription procedure remained time-consuming and error-prone—depending on the abilities of human coders. More efficient and precise than manual coding motion capture systems allow for the automated measuring of human motions, as in the software project EVE (Bente & Krämer, 2004). This research tool was also based on the Bernese coding system, but a lot of effort is needed before the software development allows the editing of Bernese codes and controlling of the 3D animation software. Depending on the lifetime of the hardware, operating system, and 3D animation software, the research tools date quickly. Moreover, the latest professional 3D animation tools are excellent and complement each other by using various input devices, editing facilities, and rendering techniques.

Since 2005, Bente and his team have conducted cross-cultural nonverbal researches using high performance 3D character animation. The last research project investigated universalities and differences on nonverbal communication in Germany, the United States, and the United Arab Emirates (Bente, Leuschner, Al Issa, & Blascovich, 2010) and relied primarily on the techniques and methods available with professional 3D animation software (Bente et al., 2008): dyads of interacting people from these three countries were videotaped, and their nonverbal behavior was manually coded with 3D character animation software and reproduced with 3D animated video clips, as depicted in *Figure 4*. The video clips show the coded nonverbal behavior with wooden manikins, which drew on the culture, age, gender, hairstyle, and dress style of the original people, and were displayed to subjects who rated their impressions on several rating scales measuring psychological constructs.

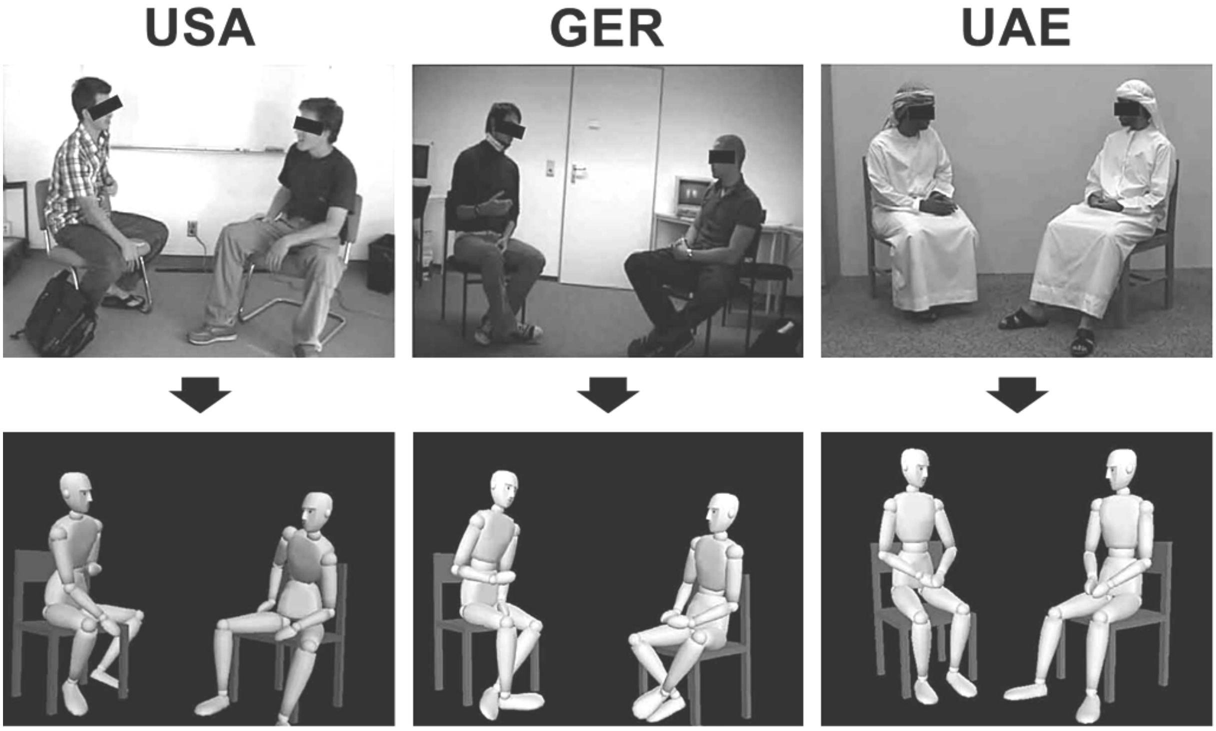


Figure 4. Screenshots of original videos and of 3D animations.
USA = United States of America, GER = Germany, UAE = United Arab Emirates.
Adapted from Bente, Leuschner, Al-Issa, and Blascovich (2010, p. 765).

The last generation of motion capture systems seriously decreased the ecological validity of the experimental situation because of the intrusive nature of motion capture suits and their cabling, but optical motion capture systems that are less intrusive are now available. This new data collecting method allows the development of an improved coding system with accurate metric data quality. The Bernese coding system has been proven to be the most suitable coding system, and therefore provides a basis for the development of the SRL coding system complying with all four requirements of the nonverbal coding system, as described on p. 19.

Chapter 4: Measuring Body Positions and Body Movements

The *SRL coding system* comprises three nonverbal coding systems which describe body positions and body movements on a metric scale. The *static SRL system* is qualified to describe static body positions (Leuschner, 1999). The *dynamic SRL system* is derived from the *static SRL system* and is qualified to describe body movements based on two subsystems: the *global SRL system* and the *local SRL system*. All three coding systems complement each other. Whereas the *static SRL system* accurately describes the position of a body part without any information about the movement that leads to this position, the *global dynamic SRL system* exactly describes the movements of a body part, and the *local dynamic SRL system* detects the origin of every movement. All three coding systems are described in detail in this chapter.

The Static SRL System: Measuring Body Positions

The *static SRL system* precisely describes body positions by measuring the deviation of each body part from its base position, also known as *flexion*, on three commonly used and psychologically meaningful dimensions: nodding, shaking, and tilting the head. These three dimensions were originally used by the Bernese coding system to describe head positions and I decided to use this concept for all body parts. The application of the *static SRL system* to all body parts simplifies the nonverbal coding system and overcomes the restriction of the Bernese coding system to sitting people, as it is able to describe any position of any body part.

Basic concept. The *base position* of a body part, also known as *frame of reference*, can be any position, e.g., the upright and forward-looking position of the head. The deviation of the *actual position* from this *base position* is described by the *sagittal flexion* as the amount the head is tilted forward or backwards, by the *rotational flexion* as the amount the head is turned to the side, and by the *lateral flexion* as the amount the head is tilted to the side. For any other body part, similar considerations can be applied. For example, the base position of the hands could be parallel to the armrests of the chair for a sitting person. The sagittal dimension describes how a hand is pointing up or down, the rotational flexion how a hand is pointing left or right, and the lateral flexion how a hand is rotated about its longitudinal axis.

Geometrical model. To describe the basic concept of the *static SRL system* in mathematical terms, I constructed a geometrical model which uses the Cartesian coordinate system with the left-to-right x-axis, the back-to-front z-axis, and the down-to-up y-axis, as depicted in *Figure 5* (see 1a). The *global point of origin* with the x-, the y-, and the z-axis, which remains always in the upright and straightforward looking position, is the *base position* or the *reference system* of the *local point of origin* with the x^*-, the y^*-, and the z^*-axis, which rotates with movements and is therefore the *actual position* of a body part (see 1b). With these six axes, several planes can be defined, with the SRL flexion angles being given angles between these planes.

Sagittal dimension. The *sagittal dimension* describes up/down movements by rotations around the *sagittal moving* x^*-axis (corresponding to nodding of the head), which results in a specific position of the y^*-axis on the vertical back-to-front *sagittal moving* y^*z^*-plane defined by the y^*- and the z^*-axis (see 1c). The *sagittal flexion* is the angle α between the x^*y^*-plane and the corresponding *sagittal reference* yx^*-plane, which describes the topmost position of the y^*-axis on the *sagittal moving* y^*z^*-plane and is defined by the fixed y-axis and the co-moving x^*-axis (see 2a).

Rotational dimension. The *rotational dimension* describes side-to-side movements by rotations around the *rotational moving* y^**-axis* (corresponding to shaking of the head), which results in a specific position of the z^*-axis on the horizontal *rotational moving* x^*z^**-plane* defined by the x^*- and the z^*-axis (see 1c). The *rotational flexion* is the angle β between the y^*z^*-plane and the corresponding *rotational reference* zy^**-plane*, which describes the foremost position of the z^*-axis on the *rotational moving* x^*z^**-plane* and is defined by the fixed z-axis and the co-moving y^*-axis (see 3a).

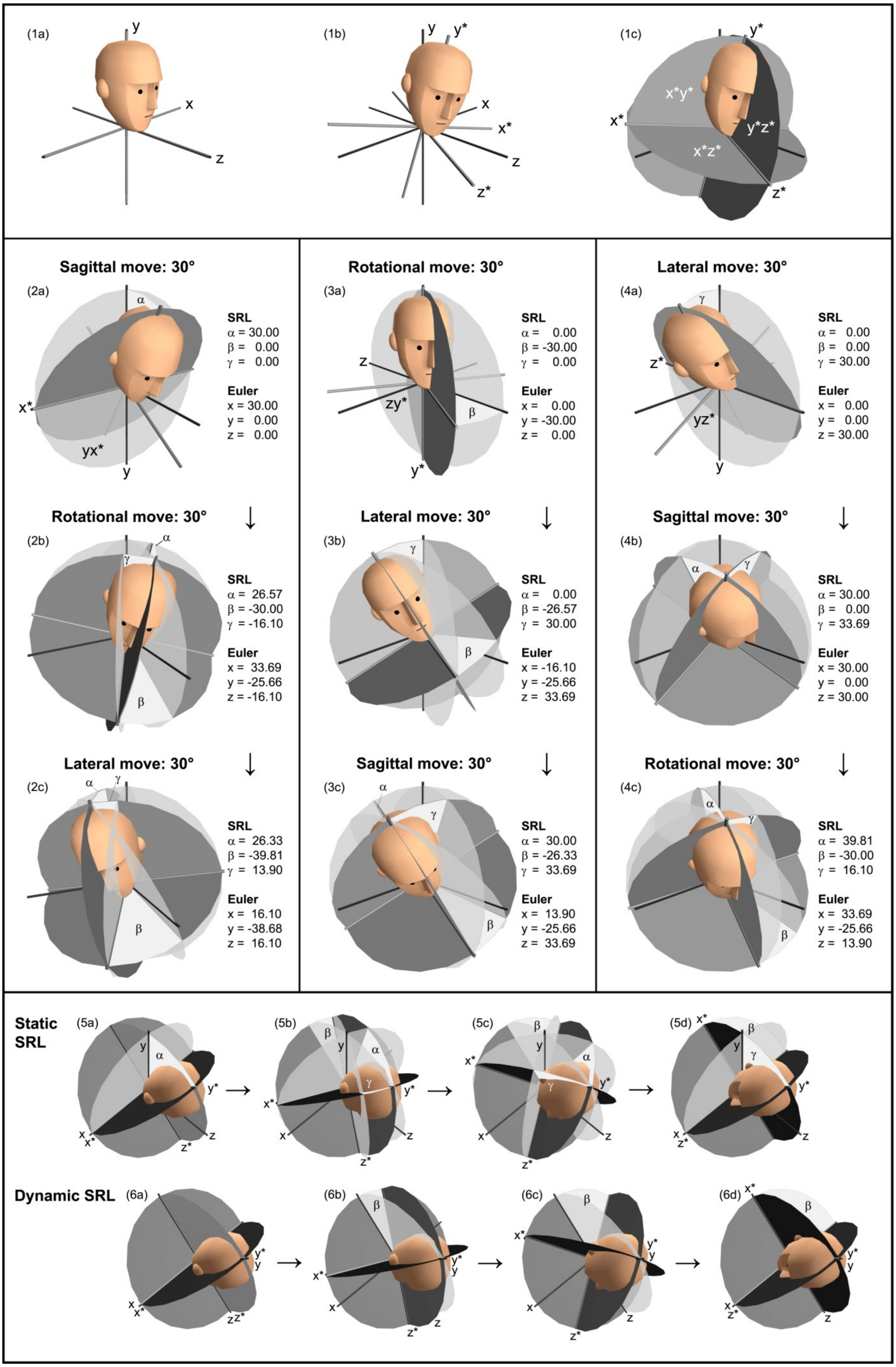


Figure 5. The geometrical model of the SRL coding system.

Lateral dimension. The *lateral dimension* describes the sideways movements by rotations around the *lateral moving* z^*-axis (corresponding to tilting of the head to the shoulder), which results in a specific position of the y^*-axis on the left-to-right vertical *lateral moving* x^*y^*-plane defined by the x^*- and the y^*-axis (see 1c). The *lateral flexion* is the angle γ between the y^*z^*-plane and the corresponding *lateral reference* yz^*-plane, which describes the topmost position of the y^*-axis on the *lateral moving* x^*y^*-plane and is defined by the fixed y-axis and the co-moving z^*-axis (see 4a).

Math terms. In 3D animation software, objects are oriented by Euler rotations. To reach a specific orientation described by the Euler angles x, y, and z, each object is consecutively rotated about the global x-, y-, and z-axis by these angles, which can be exported from the 3D animation software to calculate the SRL angles. The orientation of the unit vectors of the local point of origin can be calculated as the multiplication of three rotation matrices $R_x(x)$, $R_y(y)$, and $R_z(z)$ for the Euler angles x, y, and z (e.g., Vince, 2011, pp. 118–123):

$$R_x(x) = \begin{pmatrix} 1 & 0 & 0 \\ 0 & cos(x) & -sin(x) \\ 0 & sin(x) & cos(x) \end{pmatrix} \tag{1}$$

$$R_y(y) = \begin{pmatrix} cos(y) & 0 & sin(y) \\ 0 & 1 & 0 \\ -sin(y) & 0 & cos(y) \end{pmatrix} \tag{2}$$

$$R_z(z) = \begin{pmatrix} cos(z) & -sin(z) & 0 \\ sin(z) & cos(z) & 0 \\ 0 & 0 & 1 \end{pmatrix} \tag{3}$$

$$R_{xyz} = R_z(z) \cdot R_y(y) \cdot R_x(x) = \begin{pmatrix} m_{11} & m_{12} & m_{13} \\ m_{21} & m_{22} & m_{23} \\ m_{31} & m_{32} & m_{33} \end{pmatrix} \tag{4}$$

In the resulting matrix R_{xyz} of Equation (4), the first column represents the coordinates of the unit vector of the x^*-axis, the second column the coordinates of the unit vector of the y^*-axis, and the third column the coordinates of the unit vector of the z^*-axis. These three vectors plus the three unit vectors of the global point of origin $\vec{x} = (1,0,0)$, $\vec{y} = (0,1,0)$, and

$\vec{z} = (0,0,1)$ are required to define the planes of the SRL model. The SRL angles α, β, and γ can be calculated from Equations (5) – (7), which are derived from the general formula for calculating the angle between two planes (e.g., Vince, 2010, pp. 201–203):

$$cos(\alpha) = \frac{m_{11} \cdot m_{33} - m_{31} \cdot m_{13}}{\sqrt{m_{11}^2 + m_{31}^2}} \qquad sin(\alpha) = \begin{cases} +\sqrt{1 - cos^2(\alpha)} & \text{if } m_{23} \leq 0 \\ -\sqrt{1 - cos^2(\alpha)} & \text{if } m_{23} > 0 \end{cases} \tag{5}$$

$$cos(\beta) = \frac{m_{11} \cdot m_{22} - m_{21} \cdot m_{12}}{\sqrt{m_{22}^2 + m_{21}^2}} \qquad sin(\beta) = \begin{cases} +\sqrt{1 - cos^2(\beta)} & \text{if } m_{31} \leq 0 \\ -\sqrt{1 - cos^2(\beta)} & \text{if } m_{31} > 0 \end{cases} \tag{6}$$

$$cos(\gamma) = \frac{m_{11} \cdot m_{33} - m_{31} \cdot m_{13}}{\sqrt{m_{33}^2 + m_{13}^2}} \qquad sin(\gamma) = \begin{cases} +\sqrt{1 - cos^2(\gamma)} & \text{if } m_{21} \geq 0 \\ -\sqrt{1 - cos^2(\gamma)} & \text{if } m_{21} < 0 \end{cases} \tag{7}$$

Scope and limits. Calculating both the cosine and the sine of each flexion angle allows us to determine angles within a range of –180° to +180°, which are appropriate for describing any orientation of a body part.

The signs of the SRL angles are based on the rotation behavior of the coordinate axes: (a) a positive sign of a sagittal angle indicates a lowered body part, a negative sign a raised body part; (b) a positive sign of a rotational angle reports a turn to the left side, a negative sign a turn to the right side; (c) a positive sign of a lateral angle shows a tilt to the right side, a negative sign a tilt to the left side.

It should be noted that there is a gap in the definition of an SRL reference plane when the co-moving axis matches its fixed axis. Such a singularity occurs, for example, when the head is lowered by 90°. In this position, a rotational deviation from the base position cannot be determined, because a forward-looking position cannot be reached with rotational movements. In the case of singularities, APEx outputs a missing value (i.e., no value at all).

Characteristics. To investigate the characteristics of the SRL system, three consecutive rotations about the local x^*-, y^*-, and z^*-axis were applied to the static SRL model, each at 30 degrees, but in different order, as depicted in *Figure 5* (see picture series 2 to 4). The SRL model has the following characteristics. (a) In all cases, the sagittal angle α indicates the amount the head has to rotate about the x^*-axis to reach the topmost position on the y^*z^*-plane. The same applies to the lateral angle γ about the z^*-axis on the x^*y^*-plane, and the rotational angle β indicates the amount the head has to rotate about the y^*-axis to reach the foremost position on the x^*z^*-plane (see 4b–c), with the Euler angles being meaningless for this purpose. (b) A rotation about a local axis always results in the corresponding flexion angle of the same size as the rotation angle of the movement. (c) A rotational move has a high impact on existing sagittal and lateral flexions because a rotational move changes the direction of the sagittal and lateral reference planes (see 2a–b, 4b–c, and 5a–d). (d) Sagittal or lateral moves have only slight influence on other flexion angles (see 3a–c, 4a–b), except in some special cases, for example, when the y^*-axis tilts laterally to the other side of the corresponding reference plane (see β in 2b–c). (e) The resulting end positions after three identical rotations are not the same if they occur in a different order (compare 2c–3c–4c). Hence, a sequence of moves is not commutative. These characteristics are much more obvious when we view the videos, which are available as supplementary material at www.apex-download.eu.

About the base position. If no base position is specified, the global center of the 3D world is used as the base position. The base position of each model joint is shown in 3D animation software, when all Euler rotation angles are set to zero. For dyadic interactions with sitting individuals, it is recommended that the *static SRL parameters* use the chair as the base position in order to achieve *rotational SRL values* describing flexions from the forward-looking position on the chair. In all other cases, the base positions of the model joints can remain unchanged. In the case of standing individuals, a position directly facing the interaction partner may be used as the base position by placing an object into the 3D world pointing to the interaction partner and specifying this object as the base in APEx. If the subjects are moving around, and if an object pointing in the direction of the camera is used as a common base for both interaction partners, the *rotational SRL values* will describe flexions related to the camera view and therefore may be more comprehensible when viewing animated video clips.

The Global Dynamic SRL System: Measuring Body Movements

The advantage of the *static SRL system* lies in the fact that it accurately describes the static position of a body part in three psychologically meaningful dimensions, and its disadvantage is that it is not qualified to describe body movements. Investigation of the SRL model showed that a movement on a single dimension, such as nodding the head, can result in changes in all three dimensions. In particular, movements in the rotational dimension, such as shaking the head, can cause sagittal flexions to transform into lateral flexions, and vice versa. As shown in *Figure 5* (5a–d), a lowered head with a sagittal flexion of 45° will convert into a tilted head with a lateral flexion of 45° while turning to the side by rotating 90° about the y^*-axis. Since the values of the flexion angles change on all three dimensions, it cannot be determined in which dimension a movement occurs only by looking at the values. If, however, the base position is rotated into the initial position of a movement, the SRL angles of the end position will indicate the movement as the deviation of the end position from the initial position. As depicted in *Figure 5* (6a–d), the rotational flexion angle β correctly indicates a rotational move of 90° at the end of the move. Therefore, the *global dynamic SRL system*, which uses the initial position of a movement as the base position for the SRL angles of the end position, accurately describes body movements.

Basic concept. A body movement is expressed by the three SRL flexion angles indicating the deviation of the end position from the initial position for each body part involved in a movement. In this special case of using the initial position of a movement as the base position of the end position, SRL flexion angles are measurements of body movements.

Geometrical model. The *global dynamic SRL system* uses the SRL model of the *static SRL system*, but sets the local point of origin of the previous time point as the global point of origin (i.e., the base position) of the actual time point to calculate the SRL flexion angles.

Math terms. The method of rotating the base position of a body part into the local point of origin at a previous time point is known as a *coordinate transformation* (e.g., Vince, 2011, pp. 143–154), in which the previous position of a body part is defined as the new *frame of reference* for the actual position. A coordinate transformation can be performed by using the inverse rotation matrix R_{xyz} of Equation (4) with the Euler angles $-x'$, $-y'$, and $-z'$ of the new frame of reference, as shown in Equation (8). To calculate the SRL flexion angles, Equations (5) – (7) are applied on matrix R_{xyz} of Equation (8).

$$R_{xyz} = R_x(-x') \cdot R_y(-y') \cdot R_z(-z') \cdot R_z(z) \cdot R_y(y) \cdot R_x(x) \qquad (8)$$

Scope and limits. Since the *global dynamic SRL system* uses the geometrical model and the formulas of the *static SRL system*, the scope and limits of the *static SRL system* also apply to the *global dynamic SRL system* (see p. 31). The only difference between the *static* and the *global dynamic SRL system* is the frame of reference that is used. Whereas the *static SRL system* uses the origin of the 3D world, a chair, or any other object of the environment, the *global dynamic SRL system* uses the position of the body part at the previous time point.

Characteristics. With a coding resolution of two or five time points per second, this approach results in many flexion angles indicating the type and number of these small units of movements of a body part between two time points. To achieve comparability between measurements of different coding resolutions, the obtained values can be subsequently transformed into *degrees per second* (dps), which is a measure of the actual movement speed.

To demonstrate the difference between the *static* and the *global dynamic SRL system*, the nine movements of Figure 5 (2a–c, 3a–c, 4a–c) are performed once more, but now with a human model sitting on a chair that is rotated 45° about the y-axis. As shown in Table 1, the Euler angles are exported and the SRL angles are calculated with the chair as base position. Compared with Figure 5, the Euler angles are nearly unrecognizable because of the y-rotation of about 45°, whereas the *static SRL angles* remain the same. As expected, the *global dynamic SRL angles* precisely reproduce the movements performed with the 3D animation software.

Table 1

Comparison of Euler angles, static SRL angles, and global dynamic SRL angles

	Euler angles			Static SRL angles			Global dynamic SRL		
Movement	x	y	z	α	β	γ	α	β	γ
Base position	0.00	45.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sagittal 30°	30.00	45.00	0.00	30.00	0.00	0.00	30.00	0.00	0.00
Rotational –30°	21.80	17.83	–15.23	26.57	–30.00	–16.10	0.00	–30.00	0.00
Lateral 30°	27.46	5.07	12.55	26.33	–39.81	13.90	0.00	0.00	30.00
Base position	0.00	45.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rotational –30°	0.00	15.00	0.00	0.00	–30.00	0.00	0.00	–30.00	0.00
Lateral 30°	7.63	12.95	30.87	0.00	–26.57	30.00	0.00	0.00	30.00
Sagittal 30°	37.63	12.95	30.87	30.00	–26.33	33.69	30.00	0.00	0.00
Base position	0.00	45.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lateral 30°	26.57	37.76	39.23	0.00	0.00	30.00	0.00	0.00	30.00
Sagittal 30°	56.57	37.76	39.23	30.00	0.00	33.69	30.00	0.00	0.00
Rotational –30°	43.99	18.21	13.17	39.81	–30.00	16.10	0.00	–30.00	0.00

Note. These are examples (2) – (4) in *Figure 5* with values resulting from a 3D model sitting on a chair initially rotated by 45°.

The Local Dynamic SRL System: Measuring Nodding, Shaking, and Tilting

The *global dynamic SRL system* describes body movements regardless of the origin of the movements. For example, a sagittal lowered head could be the direct result of a head nod or the indirect result of a trunk movement. When a person leans the own body forward without moving the head, the head is lowered in relation to the environment, but remains upright in relation to the trunk. In order to detect the origin of this head movement, the head should be related to the chest, and the hips to the base. In relation to the chest, the head position remains unchanged, but in relation to the base, the hips are rotated and are hence responsible for the lowered head position. This consideration leads to the *local dynamic SRL system*.

Basic concept. In the *local dynamic SRL system*, the both positions of a body part at two time points are related to the corresponding positions of the hierarchically superior body part, before the base position is set equal to the body part position of the previous time point.

Geometrical model. To detect a proper motion, i.e., a movement directly performed by a body part, the local points of origin used at the actual and at the previous time point are both related to the local point of origin of his parent body part that is the immediate superior in the hierarchical structure of the human body skeleton, as depicted in *Figure 6*.

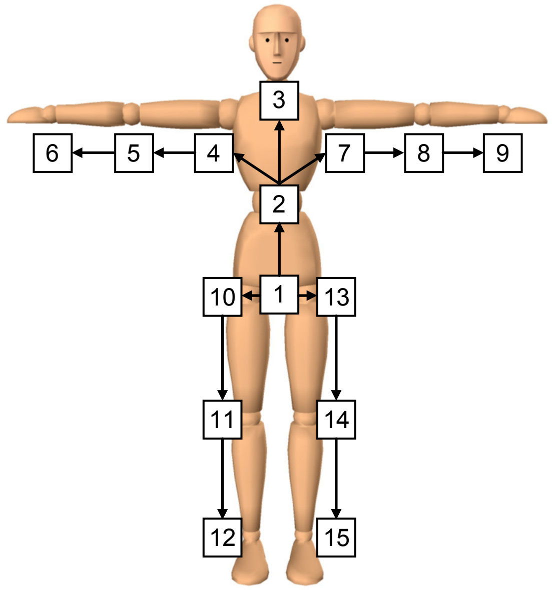


Figure 6. Generic hierarchical skeleton structure of a human 3D model.

Math terms. In order to isolate the activity of a body part, three coordinate transformations have to be performed. As shown in Equation (9), one coordinate transformation relates the body part of interest at time point t to itself at time point $t-1$, and two other coordinate transformations—one for each time point—relate the body part of interest to the Euler angles x, y, and z to the body part superior in the skeleton hierarchy with the Euler angles x', y', and z':

$$\begin{aligned} R_{xyz} = {} & \left[R_x(-x'_{t-1}) \cdot R_y(-y'_{t-1}) \cdot R_z(-z'_{t-1})\right] \cdot \left[R_x(-x'_t) \cdot R_y(-y'_t) \cdot R_z(-z'_t)\right] \\ & \cdot \left[R_x(-x_{t-1}) \cdot R_y(-y_{t-1}) \cdot R_z(-z_{t-1})\right] \cdot \left[R_z(z_t) \cdot R_y(y_t) \cdot R_x(x_t)\right] \end{aligned} \tag{9}$$

Scope and limits. As the *local dynamic SRL system* is based on the geometrical model and formulas of the *static SRL system*, the scope and limits of the *static SRL system* also apply to the *local SRL system* (see p. 31).

Characteristics. Using Equation (9) would lead to the values depicted in Table 1 if the head moved by proper motions. If the trunk is performing the movements instead while the head is fixed on the trunk, the same values would occur for the trunk and the values for the head would be zero, indicating that the head is not moving by its own activity.

Implementation

The SRL coding system with the *static*, *global dynamic*, and *local dynamic subsystem* is implemented for the 15 joints of a generic 3D human model. Table 2 shows the 15 involved joints and the body parts that are influenced by the rotations of these joints. For hierarchical dependencies between body parts, please refer to *Figure 6*.

Table 2

SRL Coding System

Body joints used for all three SRL coding subsystems	Body part primarily involved by moves	Body parts secondarily involved by moves	Range of flexion angles
Hip joint	Hips	all other body parts	–180°…+180°
Chest joint	Chest	whole upper part of the body	–180°…+180°
Head joint	Head	only head	–180°…+180°
Right arm joint	Right upper arm	whole right arm	–180°…+180°
Right elbow joint	Right forearm	right forearm and right hand	–180°…+180°
Right hand joint	Right hand	only right hand	–180°…+180°
Left arm joint	Left upper arm	whole left arm	–180°…+180°
Left elbow joint	Left forearm	left forearm and left hand	–180°…+180°
Left hand joint	Left hand	only left hand	–180°…+180°
Right leg joint	Right thigh	whole right leg	–180°…+180°
Right knee joint	Right lower leg	right lower leg and right foot	–180°…+180°
Right foot joint	Right foot	only right foot	–180°…+180°
Left leg joint	Left thigh	whole left leg	–180°…+180°
Left knee joint	Left lower leg	left lower leg and left foot	–180°…+180°
Left foot joint	Left foot	only left foot	–180°…+180°

Note. The range of the flexion angles applies to the sagittal, rotational, and lateral SRL dimension.

Recommendations

Because of their inherent features, the three different SRL coding subsystems have different uses. The *static SRL coding system* is suitable for describing *body positions*, whereas the *dynamic SRL coding systems* are appropriate for describing *body movements*. The remaining question is *when each of the latter should be used*.

The *local dynamic SRL subsystem* is most appropriate for describing proper motions, because it describes movements of a body part in relation to the hierarchically superior body part. Thus, the *local dynamic sagittal values* are best suited to detecting head nodding by analyzing sign changes of these values. To detect head shaking or head tilting, sign changes of the *local dynamic rotational* or *lateral values* should be taken into account. On the other hand, the *local dynamic SRL subsystem* cannot accurately measure the visual impression of body movements, e.g., if the whole upper part of the body including the chest, head, and both arms, is leaning forward, it is possible that the whole upper part of the body is moved only by the hips. The appropriate coding system for measuring the visual impression of body movements is the *global dynamic SRL system*, which describes movements of body parts in relation to the environment and, therefore, their visual impression. Two examples illustrate this.

In the first example, a person is leaning forward on their elbows. If an interaction partner says something, the person may sit up and look in the direction of the partner. In this motion, two movements are involved: the head is raised to an upright position by the chest and simultaneously turned toward the interaction partner by the neck. Hence, the muscular work is divided between raising part of the chest and turning part of the head, which is accurately measured by the *local dynamic SRL flexion angles* by indicating values on the sagittal dimension of the chest and values on the rotational dimension of the head. This may be interesting for some research questions, but in terms of visual impression it is more important that the head is raised up. The *global dynamic SRL angles* take into account that the head is raised by indicating values on the sagittal dimension of the head; the same applies for the chest.

In the second example, starting from a leaning back position, a person bends forward while the head is kept upright. In this case, the local parameters would measure a reasonable value on the sagittal dimension of the head because the direction of the chest is turning from a raised position to a lowered position, which must be handled by a sagittal counter-movement by the head joint to keep the head upright. In terms of visual impression, this counter-movement is not important, but the unchanged orientation of the head in relation to the environment is important and this would be produced only by the *global dynamic parameters*. Therefore, the *global dynamic SRL subsystem* is appropriate for research questions regarding visual impressions of body movements.

Statistical Parameters

For statistical purposes, the Bernese coding system contains three parameters (Fisch, Frey, & Hirsbrunner, 1983): *complexity of body movements* (CBM), *time spent in motion* (TSM), and *dynamic activation of body movements* (DBM). The original parameters relied on the ordinal Bernese coding system, but have now been extended and adapted to the *SRL coding system*. The three subsystems are not only accurate for describing body positions and movements, but also take full advantage of the metric features of the SRL flexion angles. For the statistical description of body moves, four groups of parameters have been developed, which are described in detail in the following: *complexity parameters*, *time spent in motion parameters*, *magnitude parameters*, and *activation parameters*.

Complexity parameters. The *complexity parameters* (for formulas see Table 3, p. 43) were derived from the Bernese parameters. They describe the complexity of body movements by the number of dimensions or joints involved in body movements. Instead of the Bernese dimensions, however, they use the dynamic SRL dimensions. The group *complexity* consists of four parameters: (1) the *global dynamic complexity* is calculated as the number of *global dynamic SRL dimensions* with flexion angles greater than zero, and hence indicates the number of SRL dimensions that are globally involved in body movements; (2) the *local dynamic complexity* is calculated as the number of *local dynamic SRL dimensions* with flexion angles greater than zero, and hence describes the number of *SRL dimensions* that are locally involved in body movements by proper motions; (3) the *translational complexity* is calculated as the number of joints that are moving through space, which are detected with the non-zero Euclidean distance between the position of a joint at time point t and its position at time point t–1; (4) the *joint complexity* is calculated as the number of joints that are rotating with proper motions, detected by at least one *local dynamic SRL dimension* of a joint with a flexion angle greater than zero. It should be noted that complexity of body movements could also be measured with the media-related parameter *Video Pixel Difference* (see p. 89).

Time spent in motion parameters. The *time spent in motion parameters* (for formulas, see Table 4, p. 44) indicate the percentage of time in which body motions occur. A time point with at least one moving body joint is determined by a *joint complexity* greater than zero. The parameter *Time spent in motion* is calculated for five conditions: (1) regardless of the movements of an interaction partner (TSM); (2) if only the person of interest is moving but not their partner (TSM only A); (3) if only the partner is moving (TSM only B); (4) if both people are simultaneously moving (TSM A and B); and (5) if at least one of both people is moving (TSM A and/or B).

Magnitude parameters. The *magnitude parameters* (for formulas, see Table 5, p. 44) take full advantage of the metric features of the SRL flexion angles. They indicate the extent of body movements and are calculated as the sum of the absolute SRL flexion angle values of involved joints. The parameter group *magnitude* consists of three parameters: (1) the *global dynamic magnitude* is calculated as the sum of the absolute values of the *global dynamic SRL flexion angles*, and hence indicates the extent of both direct and indirect movements; (2) the *local dynamic magnitude* is calculated as the sum of the absolute values of the *local dynamic SRL flexion angles*, and hence is the extent of proper motions; (3) the *translational magnitude* is calculated as the sum of the Euclidean distances between two consecutive time points of involved joints, and hence is the extent of body movements in space. Determined for a single joint, the *translational magnitude* represents its velocity v through space, i.e., the speed of the joint. Therefore this parameter is useful for the calculation of *activation parameters*, which are described in the next section.

Activation parameters. The *activation parameters* (for formulas and details, see Table 6, p. 46) are based on the *translational magnitude*, i.e., the Euclidean distance between the positions of a joint at two time points, and describe characteristics of body movements, such as duration, velocity, or acceleration. The parameter group *activation* consists of seven parameters: (1) the *number of movement phases*; (2) the *average duration of movement phases* (in seconds); (3) the *number of pause phases*; (4) the *average duration of pause phases* (in seconds); (5) the *average velocity of body movements* (per second); (6) the *average acceleration of movements* (per second squared); and (7) the *average deceleration of movements* (per second squared).

Averages of complexity and magnitude parameters. The *complexity* and *magnitude parameters* are calculated for any time point in the given time sequence as well as averaged over the whole time sequence. Two different types of averages are calculated for each parameter of both groups (for formulas, see Table 3, p. 43, and Table 5, p. 44): (1a) first, the *complexity of body movements* (CBM) indicates the average number of dimensions or joints involved in body movements during the whole time sequence; (1b) the *complexity of activation phases* (CAP) has the same meaning, but only averages the time points with active body movements; (2a) second, the *magnitude of body movements* (MBM) averages the extent of direct and indirect body movements during the whole time sequence; (2b) the *magnitude of activation phases* (MAP) has the same meaning, but only accounts for time points with active body movements.

Recommendations for statistical parameters. APEx contains all statistical parameter groups—the *complexity*, the *TSM*, the *magnitude*, and the *activation parameters*—for five subsets of body parts: the head, the trunk (with hips and chest), the upper and the lower extremities, and the whole body with all 15 joints. Within APEx, the user can easily define other subsets with the joints of a typical 3D human model.

Regarding the predefined subsets, 20 *complexity* and 15 *magnitude parameters* are calculated for each time point, and in addition, 40 *complexity*, 30 *magnitude*, 35 *activation*, and 25 *TSM parameters* are determined for the whole time sequence. This results in 35 parameters for each time point and 130 statistical parameters for each time sequence.

The two different *complexity* and *magnitude* parameter groups with their *global dynamic*, *local dynamic* and *translational parameters* have their advantages and disadvantages.

The right choice of parameters depends on the research question. In the following, some general guidelines are given.

Whereas the *complexity parameters* indicate the number of dimensions or joints that are involved in body movements, the *magnitude parameters* take full advantage of the metric characteristics of the SRL flexion angles and take into account the amount of each single angle. Therefore, the *magnitude parameters* are recommended because of their superiority to the *complexity parameters*, which are nevertheless retained for historical reasons, such as compatibility with previously used software and with earlier nonverbal studies.

The *translational parameters* offer the best results for complex body actions, such as walking or dancing, because they directly represent the movement through space. Yet they fail to capture pure rotation movements of the head, hands, and feet, because rotating joints do not move through space. Such pure rotation movements occur frequently with the head nods, hand gestures, and foot tapping of sitting individuals, and are taken into account by the *dynamic SRL parameters*. For research questions regarding impression formation, the *global dynamic parameters* should be preferred to the *local dynamic parameters*, which are fully explained in the section 'Recommendations' on p. 37.

Table 3: *Complexity Parameters*

Parameter	Range	Description	Calculation formula
Global dynamic complexity	0…45	Number of *dynamic SRL dimensions* at a given time point that are *globally* involved in body movements; calculated as the number of *global dynamic SRL dimensions* with flexion angles greater than zero* at time point *t*	$c_t^{glb} = \sum_{j=1}^{15}\sum_{d=1}^{3} c_{t,j,d}^{glb} \quad c_{t,j,d}^{glb} = \begin{cases} 0 & if\ \varphi_{t,j,d}^{glb} < .1 \\ 1 & otherwise \end{cases}$
Global dynamic CBM	0…45	Number of *global dynamic SRL dimensions* involved in body movements, averaged over the whole time sequence with n–1 time points (for the first time point, *global dynamic SRL dimensions* cannot be calculated)	$CBM^{glb} = \frac{1}{n-1}\sum_{t=2}^{n}\sum_{j=1}^{15}\sum_{d=1}^{3} c_{t,j,d}^{glb}$
Global dynamic CAP	0…45	Number of *global dynamic SRL dimensions* involved in body moves, averaged over activation phases, i.e., time points with $\varphi_{t,j,d}^{glb} \geq .1$	$CAP^{glb} = \frac{1}{m}\sum_{t=2}^{n}\sum_{j=1}^{15}\sum_{d=1}^{3} c_{t,j,d}^{glb}$
Local dynamic complexity	0…45	Number of *dynamic SRL dimensions* that are *locally* involved in body movements by proper motions; calculated as the number of *local dynamic SRL dimensions* with flexion angles greater than zero* at time point *t*	$c_t^{loc} = \sum_{j=1}^{15}\sum_{d=1}^{3} c_{t,j,d}^{loc} \quad c_{t,j,d}^{loc} = \begin{cases} 0 & if\ \varphi_{t,j,d}^{loc} < .1 \\ 1 & otherwise \end{cases}$
Local dynamic CBM	0…45	Number of *local dynamic SRL dimensions* involved in proper motions, averaged over the whole time sequence with n–1 time points (for the first time point, *local dynamic SRL dimensions* cannot be calculated)	$CBM^{loc} = \frac{1}{n-1}\sum_{t=2}^{n}\sum_{j=1}^{15}\sum_{d=1}^{3} c_{t,j,d}^{loc}$
Local dynamic CAP	0…45	Number of *local dynamic SRL dimensions* involved in proper motions, averaged over activation phases, i.e., time points with $\varphi_{t,j,d}^{loc} \geq .1$	$CAP^{loc} = \frac{1}{m}\sum_{t=2}^{n}\sum_{j=1}^{15}\sum_{d=1}^{3} c_{t,j,d}^{loc}$
Translational complexity	0…15	Number of joints moving through space at a given time point; calculated as the number of joints with a non-zero* Euclidean distance between the position at time point *t* and the position at time point *t*–1	$c_t^{trn} = \sum_{j=1}^{15} c_{t,j}^{trn} \quad c_{t,j}^{trn} = \begin{cases} 0 & if\ \varepsilon_{t,j}^{trn} < .1 \\ 1 & otherwise \end{cases}$
Translational CBM	0…15	Number of joints moving through space, averaged over the whole time sequence with n–1 time points (for the first time point, the Euclidean distance between the positions of a joint at two time points cannot be calculated)	$CBM^{trn} = \frac{1}{n-1}\sum_{t=2}^{n}\sum_{j=1}^{15} c_{t,j}^{trn}$
Translational CAP	0…15	Number of joints moving through space, averaged over activation phases, i.e., time points with $\varepsilon_{t,j}^{trn} \geq .1$	$CAP^{trn} = \frac{1}{m}\sum_{t=2}^{n}\sum_{j=1}^{15} c_{t,j}^{trn}$
Joint complexity	0…15	Number of joints rotating by proper motion at a given time point; calculated as the number of joints with at least one *local dynamic flexion angle* greater than zero* at time point *t*	$c_t^{jnt} = \sum_{j=1}^{15} c_{t,j}^{jnt} \quad c_{t,j}^{jnt} = \begin{cases} 0 & \forall d : \varphi_{t,j,d}^{loc} < .1 \\ 1 & otherwise \end{cases}$
Joint CBM	0…15	Number of joints rotating by proper motion, averaged over the whole time sequence with n–1 time points (for the first time point, *local dynamic SRL flexion angles* cannot be calculated)	$CBM^{jnt} = \frac{1}{n-1}\sum_{t=2}^{n}\sum_{j=1}^{15} c_{t,j}^{jnt}$
Joint CAP	0…15	Number of joints rotating by proper motion, averaged over activation phases, i.e., time points with $\varphi_{t,j,d}^{loc} \geq .1$	$CAP^{jnt} = \frac{1}{m}\sum_{t=2}^{n}\sum_{j=1}^{15} c_{t,j}^{jnt}$

Note. These formulas apply to the 15 joints of a 3D human model. Five subsets regarding head, trunk, upper and lower extremities, and body are implemented in APEx; more can be defined by the user. *CBM* = complexity of body movements, *CAP* = complexity of activation phases, *glb* = global, *loc* = local, *trn* = translational, *jnt* = joint, j = joint no., d = dimension no., $\varphi_{t,j,d}$ = angle of dimension d of joint j at time point t, $\varepsilon_{t,j}$ = Euclidean distance between the positions t and t–1 of joint j, n = number of time points during whole time sequence, m = number of time points in activation phases; * a threshold value (of .1) filtering influence of micro movements is used to determine a zero value.

Table 4: *Time Spent in Motion Parameters*

Parameter	Range	Description	Calculation formula
TSM	0…100	Time spent in motion of A (regardless of an interaction partner B); calculated as the number of time points of A with a joint complexity greater than zero* as a percentage of n–1 time points of the time sequence	$TSM = \frac{100}{n-1} \cdot \sum_{t=2}^{n} c_t^{tsm} \quad c_t^{tsm} = \begin{cases} 1 & c_{t,A}^{jnt} \geq .1 \\ 0 & otherwise \end{cases}$
TSM only A	0…100	Time spent in motion of A while B is not moving; calculated as the number of time points of A with a joint complexity greater than zero*, whereas the joint complexity of B is equal to zero*, as a percentage of n–1 time points	$TSM = \frac{100}{n-1} \cdot \sum_{t=2}^{n} c_t^{tsm} \quad c_t^{tsm} = \begin{cases} 1 & c_{t,A}^{jnt} \geq .1 \wedge c_{t,B}^{jnt} < .1 \\ 0 & otherwise \end{cases}$
TSM only B	0…100	Time spent in motion of B while A is not moving; calculated as the number of time points of B with a joint complexity greater than zero*, whereas the joint complexity of A is equal to zero*, as a percentage of n–1 time points	$TSM = \frac{100}{n-1} \cdot \sum_{t=2}^{n} c_t^{tsm} \quad c_t^{tsm} = \begin{cases} 1 & c_{t,A}^{jnt} < .1 \wedge c_{t,B}^{jnt} \geq .1 \\ 0 & otherwise \end{cases}$
TSM A and B	0…100	Time spent in motion of A while B is also moving; calculated as the number of time points of A and B, whose joint complexities are both greater than zero*, as a percentage of n–1 time points of the time sequence	$TSM = \frac{100}{n-1} \cdot \sum_{t=2}^{n} c_t^{tsm} \quad c_t^{tsm} = \begin{cases} 1 & c_{t,A}^{jnt} \geq .1 \wedge c_{t,B}^{jnt} \geq .1 \\ 0 & otherwise \end{cases}$
TSM A and/or B	0…100	Time spent in motion of A and/or B; calculated as the number of time points with at least one joint complexity of A and/or B greater than zero*, as a percentage of n–1 time points of the time sequence	$TSM = \frac{100}{n-1} \cdot \sum_{t=2}^{n} c_t^{tsm} \quad c_t^{tsm} = \begin{cases} 1 & c_{t,A}^{jnt} \geq .1 \vee c_{t,B}^{jnt} \geq .1 \\ 0 & otherwise \end{cases}$

Note. *TSM* = Time Spent in Motion, t = time point no., n = number of time points of whole time sequence, n – 1 = maximum number of time points, because joint complexity needs two time points and hence cannot be calculated for the first time point, $c_{t,A}^{jnt}$ = joint complexity of A, $c_{t,A}^{jnt}$ = joint complexity of B, *see notes in Table 3.

These formulas apply to the 15 joints of a 3D human model. Five subsets regarding head, trunk, upper extremities, lower extremities, and body are implemented.

Table 5: *Magnitude Parameters*

Parameter	Range	Description	Calculation formula
Global dynamic magnitude	0…8100	Extent of movements at a given time point; calculated as the sum of absolute values of *global dynamic SRL flexion angles* at time point *t*	$m_t^{glb} = \sum_{j=1}^{15}\sum_{d=1}^{3}\left\|\varphi_{t,j,d}^{glb}\right\| = \sum_{j=1}^{15}\left\|\alpha_{t,j}^{glb}\right\| + \left\|\beta_{t,j}^{glb}\right\| + \left\|\gamma_{t,j}^{glb}\right\|$
Global dynamic MBM	0…8100	Extent of movements, averaged over the whole time sequence with *n*–1 time points (for the first time point, *global dynamic SRL flexion angles* cannot be calculated)	$MBM^{glb} = \frac{1}{n-1}\sum_{t=2}^{n}\sum_{j=1}^{15}\sum_{d=1}^{3}\left\|\varphi_{t,j,d}^{glb}\right\|$
Global dynamic MAP	0…8100	Extent of movements, averaged over activation phases, i.e., *m* time points with $\varphi_{t,j,d}^{glb} \geq .1$	$MAP^{glb} = \frac{1}{m}\sum_{t=2}^{n}\sum_{j=1}^{15}\sum_{d=1}^{3}\left\|\varphi_{t,j,d}^{glb}\right\|$
Local dynamic magnitude	0…8100	Extent of proper motions at a given time point; calculated as the sum of absolute values of *local dynamic SRL flexion angles* at time point *t*	$m_t^{loc} = \sum_{j=1}^{15}\sum_{d=1}^{3}\left\|\varphi_{t,j,d}^{loc}\right\| = \sum_{j=1}^{15}\left\|\alpha_{t,j}^{loc}\right\| + \left\|\beta_{t,j}^{loc}\right\| + \left\|\gamma_{t,j}^{loc}\right\|$
Local dynamic MBM	0…8100	Extent of proper motions, averaged over the whole time sequence with *n*–1 time points (for the first time point, *local dynamic SRL flexion angles* cannot be calculated)	$MBM^{loc} = \frac{1}{n-1}\sum_{t=2}^{n}\sum_{j=1}^{15}\sum_{d=1}^{3}\left\|\varphi_{t,j,d}^{loc}\right\|$
Local dynamic MAP	0…8100	Extent of proper motions, averaged over activation phases, i.e., *m* time points with $\varphi_{t,j,d}^{loc} \geq .1$	$MAP^{loc} = \frac{1}{m}\sum_{t=2}^{n}\sum_{j=1}^{15}\sum_{d=1}^{3}\left\|\varphi_{t,j,d}^{loc}\right\|$
Translational magnitude	≥ 0	Extent of joints moving through space at a given time point; calculated as the sum of the Euclidean distances of all joints between their position at time point *t* and their positions at time point *t*–1	$m_t^{trn} = \sum_{j=1}^{15}\varepsilon_{t,j}^{trn}$
Translational MBM	≥ 0	Extent of joints moving through space, averaged over the whole time sequence with *n*–1 time points (for the first time point, the Euclidean distance between the positions at two time points cannot be calculated)	$MBM^{trn} = \frac{1}{n-1}\sum_{t=2}^{n}\sum_{j=1}^{15}\varepsilon_{t,j}^{trn}$
Translational MAP	≥ 0	Extent of joints moving through space, averaged over activation phases, i.e., *m* time points with $\varepsilon_{t,j}^{trn} \geq .1$	$MAP^{trn} = \frac{1}{m}\sum_{t=2}^{n}\sum_{j=1}^{15}\varepsilon_{t,j}^{trn}$

Note. These formulas apply to the 15 joints of a 3D human model. Five subsets regarding head, trunk, upper and lower extremities, and body are implemented; more can be defined by the user. *MBM* = magnitude of body movements, *MAP* = magnitude of activation phases, *glb* = global, *loc* = local, *trn* = translational, *t* = time point no., *j* = joint no., *d* = dimension no., $\varphi_{t,j,d}$ = angle of SRL dimension *d* of joint *j* at time point *t*, $\alpha_{t,j}$ = sagittal angle of *j* at *t*, $\beta_{t,j}$ = rotational angle of *j* at *t*, $\gamma_{t,j}$ = lateral angle of *j* at *t*, $\varepsilon_{t,j}$ = Euclidean distance between the positions at *t* and *t*–1 of joint *j*, *n* = number of time points within whole time sequence, *m* = number of time points in activation phases.

Table 6: *Activation Parameters*

Parameter	Range	Description	Calculation formula
Number of movement phases	≥ 0	Number of activation phases with body movements; calculated as the number of time points with a translational magnitude m_t^{trn} greater than zero* at time point *t* and a translational magnitude m_{t-1}^{trn} of zero* at *t*–1	$n^{moves} = \sum_{t=2}^{n} n_t^{begin} \quad n_t^{begin} = \begin{cases} 1 & if\ m_{t-1}^{trn} < .1\ and\ m_t^{trn} > .1 \\ 0 & otherwise \end{cases}$
Average duration of movement phases (in seconds)	≥ 0	Average duration of activation phases in seconds; calculated as the number of time points with a translational magnitude m_t^{trn} greater than zero* divided by the number of movement phases and the number of frames per second *fps*	$d^{moves} = \frac{\sum_{t=2}^{n} n_t^{move}}{n^{moves} \cdot fps} \quad n_t^{move} = \begin{cases} 1 & m_t^{trn} > .1 \\ 0 & otherwise \end{cases}$
Number of pause phases	≥ 0	Number of phases without body movements; calculated as the number of time points with a translational magnitude m_t^{trn} equal to zero* and a translational magnitude m_{t-1}^{trn} greater than zero*	$n^{pause} = \sum_{t=2}^{n} n_t^{end} \quad n_t^{end} = \begin{cases} 1 & if\ m_{t-1}^{trn} > .1\ and\ m_t^{trn} < .1 \\ 0 & otherwise \end{cases}$
Average duration of pause phases (in seconds)	≥ 0	Average duration of phases without movements in seconds; calculated as the number of time points with a translational magnitude m_t^{trn} equal to zero* divided by the number of pause phases and the number of frames per second *fps*	$d^{pause} = \frac{\sum_{t=2}^{n} n_t^{pause}}{n^{pause} \cdot fps} \quad n_t^{pause} = \begin{cases} 1 & m_t^{trn} < .1 \\ 0 & otherwise \end{cases}$
Average velocity of movements (per sec)	≥ 0	Average speed of movements per second; calculated as the sum of the translational magnitude m_t^{trn} of all time points, divided by the number of time points with a translational magnitude greater than zero*, and multiplied by the number of frames per second *fps* to extrapolate the result to a full second	$v = \frac{\sum_{t=2}^{n} m_t^{trn}}{\sum_{t=2}^{n} n_t^{move}} \cdot fps \quad n_t^{move} = \begin{cases} 1 & m_t^{trn} > .1 \\ 0 & otherwise \end{cases}$
Average acceleration of movements (per sec²)	≥ 0	Average acceleration of movements per second squared; calculated as the sum of the positive differences* between the translational magnitude m_t^{trn} and the translational magnitude m_{t-1}^{trn}, divided by the number of these positive differences, and multiplied by the number of frames per second *fps* to extrapolate the result to a full second	$a^+ = \frac{\sum_{t=3}^{n} a_t^+}{\sum_{t=3}^{n} n_t^+} \cdot fps \quad a_t^+ = \begin{cases} m_t^{trn} - m_{t-1}^{trn} & if\ m_t^{trn} - m_{t-1}^{trn} > .1 \\ 0 & otherwise \end{cases} \quad n_t^+ = \begin{cases} 1 & if\ m_t^{trn} - m_{t-1}^{trn} > .1 \\ 0 & otherwise \end{cases}$
Average deceleration of movements (per sec²)	≥ 0	Average deceleration of movements per second squared; calculated as the sum of the negative differences* between the translational magnitude m_t^{trn} and the translational magnitude m_{t-1}^{trn}, divided by the number of these negative differences, and multiplied by the number of frames per second *fps* to extrapolate the result to a full second	$a^- = \frac{\sum_{t=3}^{n} a_t^-}{\sum_{t=3}^{n} n_t^-} \cdot fps \quad a_t^- = \begin{cases} m_t^{trn} - m_{t-1}^{trn} & if\ m_t^{trn} - m_{t-1}^{trn} < -.1 \\ 0 & otherwise \end{cases} \quad n_t^- = \begin{cases} 1 & if\ m_t^{trn} - m_{t-1}^{trn} < -.1 \\ 0 & otherwise \end{cases}$

Note. These formulas apply to the 15 joints of a 3D human model. Five subsets regarding head, trunk, upper and lower extremities, and body are implemented in APEx. Because the *translational magnitude* of a subset is the sum of the included joints' values, the *average velocity*, *acceleration*, and *deceleration* can be divided subsequently by the number of joints to get values related to a single average joint. m^{trn} = translational magnitude, n = number of time points, t = present time point t, $t - 1$ = previous time point, *moves* = time points with a non-zero* translational magnitude, *pause* = time points with a zero* translational magnitude, *begin* = beginning of activation phase, *end* = end of activation phase, d = duration, v = velocity, a^+ = acceleration, a^- = deceleration, *a threshold value of .1 filtering micro movement influences is used to determine a zero value.

Chapter 5: Review of the Literature on Nonverbal Cues

Since the 1950s, scholars in the research field of nonverbal communication have developed and published various typologies of nonverbal codes. Inspection of the most recently published textbooks (Andersen, 2008; Burgoon et al., 2010; Harrigan, 2005; Knapp et al., 2013; Moore et al., 2009; Remland, 2009; Richmond et al., 2007) showed that the various typologies describe almost the same set of nonverbal codes which are the subject of scientific research and academic education. The review *Nonverbal communication: Research areas and approaches* by Burgoon, Humphreys, and Moffitt (2008) lists a set of nonverbal codes with the greatest degree of scholarly endorsement, as shown in Table 7.

Table 7

Nonverbal codes

Nonverbal code	Description
Physical appearance	Appearance-perception and use of manipulable aspects of outward appearance such as clothing, hairstyle, cosmetics, fragrances, adornments, and grooming; sometimes includes non-manipulable features such as weight, height, skin color, physiognomy, and body odor.
Kinesics	Perception and use of visual bodily movements, including facial expressions, gestures, postures, gaze, trunk and limb movements, and gait.
Vocalics (Paralanguage)	Perception and use of vocal cues other than the words themselves, including such features as pitch, loudness, tempo, pauses, intonation, dialect, non-fluencies, and resonance.
Haptics	Perception and use of touch as communication, including such aspects as body location, frequency, duration, intensity, and instrument of touch.
Proxemics	Perception, organization, and use of interpersonal distance and spacing as communication; can include arrangements of space in physical environments.
Chronemics	Perception, organization, and use of time as a message system, including such code elements as punctuality, waiting time, lead time, and amount of time spent with someone.
Artifacts	Perception, organization, and use of manipulable objects and environmental features that may convey messages from their designers or users; can include fixed elements such as architecture, semi-fixed features such as furniture and decorations, and mobile features such as an automobile; personal artifacts such as a backpack or pen set are also often included.

Note. Adapted from “Nonverbal communication: Research areas and approaches” by Burgoon et al. (2008, p. 789).

Regarding the nonverbal codes listed in Table 7, kinesics, haptics, and proxemics are supported by motion capture systems and 3D animation software, and within the kinesics code, body postures and movements can be considered. Hand gestures can be taken into account as long as distinct positions of single fingers are not of interest or motion capture systems are able to capture finger motions.

The Importance of Kinesics

The anthropologist Birdwhistell was one of the earliest authorities in the research field of nonverbal communication, and he coined the term *kinesics* (derived from the Greek word for movement). Birdwhistell defined *kinesics* as “the study of body-motion as related to the non-verbal aspects of interpersonal communication” (1952, p. 3). Popular books frequently use the term *body language* for what is scientifically known as *kinesics*. The contemporary definitions used by today’s scholars (Andersen, 2008; Burgoon et al., 2010; Harrigan, 2005; Moore et al., 2009; Richmond et al., 2007) show that the term *kinesics* is still understood in the same way and refers to the study of all visible forms of human body movements, including facial, eye, head, trunk, limb, hand, finger, and foot movements.

Burgoon et al. (2010) stated that “kinesics is perhaps the most commanding and influential of the nonverbal codes” (p. 112). In every situation the face displays useful information which can be used to uncover emotions and mood states (Cohn & Ekman, 2006). People rely more on nonverbal codes than on verbal codes, and in particular more on kinesic cues than any other nonverbal cue for determining social meaning (Burgoon & Hoobler, 2002). With an estimated 700,000 different physical signs (among them 20,000 facial expressions, more than 5,000 hand gestures, and about 1,000 postures), the possibilities of sending kinesic codes seem to be unlimited, and accordingly the visual channel accounts for 80% of sensory perception (20% comes from the other senses), and observers can still identify facial expressions and body movements within 125 microseconds (Pei; Birdwhistell; Krout; Hewes; McLeod & Rosenthal; as cited in Burgoon et al., 2010, p. 113).

The following topics in particular are of interest to researchers: *gestures*, *facial expressions*, *postures*, *movements*, *gaze*, and the non-kinesics codes *proxemics* and *touch*. In the following sections, the history of research and the main findings with regard to these nonverbal cues are summarized.

Gestures

Following Efron (1941), Ekman and Friesen (1969) suggested five categories of gestures: *emblems*, *illustrators*, *regulators*, *adaptors*, and *affect displays*. The head, face, eyes, hands, or any other body part can display them. A gesture can fulfill different functions or convey different meanings at the same time, and as a result can belong to more than one of these five categories. Obviously, hand gestures have the best possibilities of conveying symbolic, illustrative, or regulative information. In the following subsections, the five categories of Ekman and Friesen are described.

Emblems. Emblems have a clear symbolic meaning which is well known to the members of a culture, class, group, or secret society, and therefore they can be replaced by a direct verbal translation or other nonverbal symbols conveying the same meaning. Observers perceive emblems as meaningful und intentionally expressed, and accordingly senders of emblems use them almost intentionally, being aware of their use and taking responsibility for them. Emblems can be used for greetings, requests, promises, insults, threats, or expression of thoughts and emotional states. Emblems are culture-specifically learned, and as a result, their usage and meanings differ from culture to culture.

Illustrators. Illustrators are gestures accompanying the speech to support the understanding of the receiver and capture and maintain their attention. They trace the path of the speech, illustrate elements, emphasize important verbally expressed points, and visualize the rhythm of speech. Ekman and Friesen (1969) described six types of illustrators: (1) *ideographs* clarify the direction or path of speech; (2) *pictographs* draw pictures; (3) *kinetographs* show bodily actions; (4) *deictic movements* point to a present object; (5) *spatial movements* depict a spatial relationship between objects; and (6) *batons* are gestures emphasizing words or phrases and can occur repeatedly in the rhythm of the speech to support and energize what is being said.

Regulators. Regulators are movements designed to maintain the flow of conversation and regulate the turn-taking between conversational partners. The most common regulator is the head nod followed from eye contacts, slight movements forward, small postural shifts, eyebrow raises, and other small nonverbal acts related to the conservational flow and intended to gain and hold a listener's attention and to take, hold or pass the turn.

Adaptors. Adaptors are movements originated in early childhood to satisfy personal needs and are usually not intended for communication. They ensure physical and psychological comfort by performing bodily actions to sit comfortable, protecting against environmental stimuli, eating food and answering the call of nature, managing emotions, achieving and maintaining interpersonal contacts or learning instrumental activities. Ekman and Friesen (1969) described three types of adaptors: (1) *self-adaptors*, such as shading the eyes, scratching the head, shifting the body, smacking the lips, or styling the hair, are learned to manage sensory input, to facilitate food ingestion and digestion, or to properly groom, cleanse, and enhance physical attractiveness; (2) *alter-directed adaptors* are movements related to other people, such as taking from or giving to them, caring for children and older people, establishing intimacy and sexual relationship, or attacking and defending other people; (3) *object adaptors* are originally learned in the manipulation of objects, such as using a tool, smoking a cigarette or driving a car, and this behavior can occur in part as an *object-adaptor* during a conversation if an association with the learned behavior is triggered.

Affect displays. Affect displays are facial displays expressing emotions and conservational signs as described in the following section.

Facial Expressions

The human face is able to express more than 10,000 different facial displays (Ekman, 2003b, p. 14). The face can convey unambiguous and well-known signs, regulate the flow of conversation, and show feelings, emotions, and moods; even the inexpressive face is informative. The face is "commanding", not only because of the rich range of its nonverbal messages, but also because of its permanent presence and visibility (Ekman, Friesen, & Ellsworth, 1972, p. 1). Most contemporary scholars (e.g., Andersen, 2008; Burgoon et al., 2010; Knapp et al., 2013; Remland, 2009; Richmond et al., 2007) agree that people make facial expressions for the *expression of conversational signals* and the *expression of emotions*.

Expression of conversational signals. As described in the previous section, Ekman and Friesen (1969) proposed five categories of kinesic behavior. Of these categories, *emblems*, *illustrators*, and *regulators* are also referred to as *conversational signals* (Ekman, 1979). Although they are derived from hand gestures, they correspond also to facial expression. Bavelas and Chovil (1997, 2000, 2006) found that discourse-oriented facial displays and hand gestures are both interdependent on and fully integrated with the spoken word. Xu, Gannon, Emmorey, Smith, and Brauna (2009) found in a functional MRI study that symbolic gestures are processed in the same areas of the brain as language. They suggest that these parts of the brain initially supported the link between gesture and meaning and were then adapted for the spoken word as humans evolved. When speaking, people use *facial emblems*, symbolic gestures with a clear, socially agreed meaning, such as winking with one eye, *facial regulators*, to control begin, end or turn-taking of a conversation, such as raising an eyebrow or opening the mouth, and *facial illustrators* conveying the meaning or content of the spoken word and hence punctuating it with eyebrow and head movements. Burgoon et al. (2010, p. 128) extended this categorical framework by developing an *integrated taxonomy of gestures and facial expressions* with eight categories, which integrates the work of Bavelas and Chovil (1997, 2000, 2006) and McNeill (as cited in Burgoon et al., 2010).

Expression of emotions. Research on facial expression of emotions produced two theoretical approaches: the *categorical view* and the *dimensional view.*

The categorical view. The English naturalist Darwin (1872) suggested in his work *The Expression of the Emotions in Man and Animals* that human facial displays expressing emotions are innate, inherited, and universal. Inspired by Darwin, the academic psychologist Tomkins (1962–1963; Tomkins & McCarter, 1964) developed his affect theory, postulating nine biologically-based affects. As the academic mentor of Paul Ekman and Caroll Izard, he encouraged them, independently of one another, to verify Darwin's findings empirically about the universal nature of facial expressions (Ekman, 2003b, pp. 3–4). Ekman and Friesen showed photos with facial expressions to people from seven different cultures, among them two original, preliterate cultures untouched by Western culture, to determine whether the same facial expression would be interpreted as the same emotion (Ekman & Friesen, 1971; Ekman et al., 1972; Ekman et al., 1969). They found a set of six *primary* or *basic emotions* that are used and interpreted in very similar ways across different cultures all over the world. At the same time, Izard (1971) worked independently with his own set of faces and achieved comparable results across seven other cultures. He found also differences between cultures, suggesting that facial expressions can be altered or suppressed by cultural display rules. These findings for *nonverbal accents* are supported by Elfenbein and Ambady (2002a, 2002b, 2003) revealing an *in-group advantage* for observers in recognizing and interpreting the facial expressions of people who are from the same culture as they are themselves. On the other hand, studies with blind people evidence the universality and inheritance of the basic facial expressions. Eibl-Eibesfeldt (as cited in Andersen, 2008, Burgoon et al., 2010, Remland, 2009, and Richmond et al., 2007) found that blind children display basic facial expressions similar to those of sighted children. Galati, Scherer, and Ricci-Bitti (1997) confirmed that there were almost no significant differences between congenitally blind and sighted adults in their facial expressions. Burgoon et al. (2010) concluded from this that "although there may be nonverbal accents in people's facial expressions of emotions" (p. 45), "certain emotions are distinct and universal (Ekman, 1971; Izard, 1977; Tomkins, 1962), and all humans are hardwired to experience and express these emotions similarly, beginning in childhood" (p. 290). Most scholars agree that facial expressions relying on the six primary emotions *happiness*, *sadness*, *anger*, *fear*, *surprise*, and *disgust* are universal and carry the same fundamental meaning for all humans (Andersen, 2008; Burgoon et al., 2010; Ekman & Friesen, 1975; Ekman et al., 1987; Knapp et al., 2013; Moore et al., 2009; Remland, 2009; Richmond et al., 2007). Other emotions, such as contempt, pride, shame, guilt, interest, love, and warmth have been suggested to be expressed universally, but may also be culturally learned. Emotions can be blended to produce complex or mixed facial expressions (Burgoon et al., 2010; Moore et al., 2009; Remland, 2009).

Regarding the specific link between emotional experience and facial expression, as originally postulated by Darwin (1872), contemporary scholars have taken four positions (Burgoon et al., 2010, p. 297): (1) the *universalistic perspective* relies on a direct biological link between emotional experience and emotional expression and presumes that the face express directly internal emotions; (2) the *neurocultural perspective* is an extension of the universalistic perspective and supposes that cultural display rules can alter the expression of an internal emotion; (3) the *behavioral perspective* assumes that social motives influence facial expressions, i.e., people show facial displays in order to achieve their goals; (4) the *functionalist perspective* suggests that facial expressions rely on social control, i.e., the anticipated consequences of expressing an emotion in a certain social context. In the latter two cases, facial expressions do not always reflect internal emotions.

The dimensional view. At the beginning of the twentieth century, the Darwin's thesis that facial expressions of emotions are universal became a popular research topic among academic psychologists in the USA (Ekman et al., 1972, p. 7). Like Darwin, they presented pictures with facial displays to people, asking them which emotions they saw (Takehara, 2007, p.

66) or tried to provoke emotions under controlled conditions (Russell & Fernández-Dols, 1997, p. 8). Because of the lack of a conceptual and methodical framework, however, they came to the conclusion that people cannot recognize emotional facial expressions of others (Ekman et al., 1972, p. 8). The low recognition rate improved substantially as Woodworth (1938) reanalyzed the experimental data of Feleky (1914), both academic psychologists at Columbia University, and found that an emotional notion does not denote a dedicated emotion, but belongs to a set of just a few. He devised a linear scale to categorize human facial expressions with the following six items: (1) love, happiness, mirth; (2) surprise; (3) fear, suffering; (4) anger, determination; (5) disgust; (6) contempt.

In order to investigate the characteristics of Woodworth's linear scale, Schlosberg (1941) applied it to Frois-Wittmann's (1930) facial picture set, confirmed that facial expressions can be categorized according to Woodworth's six discrete categories, but concluded from his findings that the scale is rather continuous and circular and can be adequately described by two underlying dimensions: (1) *pleasantness-unpleasantness* and (2) *attention-rejection*. Inspired by Duffy's concepts of *activity* (1951) and Lindsley's *activation* (1951), Schlosberg (1954) added a third dimension, (3) *sleep–tension*, and, without realizing it, verified empirically in subsequent studies (Engen, Levy, & Schlosberg, 1957, 1958; Levy & Schlosberg, 1960; Woodworth & Schlosberg, 1954) the three dimensions of feelings originally suggested by the German academic psychologist Wundt (1896, p. 98, translated from German): (1) *pleasantness-unpleasantness*, (2) *tension-relaxation*, and (3) *excitement-calming*. Triandis and Lambert (1958) confirmed with a cross-cultural study that Schlosberg's conclusions are also valid for Greek subjects and that Schlosberg's method can be used with non-Western groups. Wundt understood the dimension *tension-relaxation* in the sense of increasing and decreasing attention (Blumenthal, 1975, p. 1085)), but in contrast Schlosberg included *rejection* as the opposite of *attention*, and this dimension was subject to several modifications by other researchers.

Using semantic differential and factor analysis techniques and reinterpreting this dimension as control, Osgood (1966) found three expression dimensions and named them (1) *pleasantness*, (2) *control*, and (3) *activation*, and showed that they correspond to the semantic dimensions (1) *evaluation*, (2) *potency*, and (3) *activity* of linguistic signs (Osgood, Suci, & Tannenbaum, 1957), which were later found to measure *affective meanings* in the sense of Wundt's three dimensions of feelings (Osgood, 1962, p. 19). Conducting a major international research project in more than 20 countries over a period of 15 years, Osgood, May, and Miron (1975) provided evidence that the three dimensions of affective meanings are cross-cultural universals. Many researchers in this field agree that judgments of facial expressions can be described in these or similar dimensions (Bales, 2000; Fontaine, Scherer, Roesch, & Ellsworth, 2007; Mehrabian, 1980; Morgan & Heise, 1988; Russell & Mehrabian, 1977; Scherer, 2005; Sokolov & Boucsein, 2000), but authors using multidimensional scaling (Abelson & Sermat, 1962; Feldman, 1995; Reisenzein, 1994; Russell, 1980, 2009; Russell & Bullock, 1985; Shepard, 1962a, 1962b) prefer a two-dimensional structure with the orthogonal dimensions *valence* (corresponding to *pleasantness-evaluation*) and *arousal* (corresponding to *activation-activity*). Scholl (2013) pointed out that several studies showed repeatedly that a third dimension *dominance* or *power* (corresponding to *control-potency*) is necessary, for example, to distinguish between anger as an expression of dominance and fear as an expression of submission. Vogeley and Bente (2010, p. 1079) emphasize that these *three basic dimensions* constitute *socio-emotional functions* such as person perception, impression formation, communication of emotions, and interpersonal attitudes. Scholl (2013) concluded also in his interdisciplinary review of dimensional research that "these three dimensions are likely to function as fundamental dimensions of interaction and communication as perceived and enacted by humans" (p. 3) and came to the conclusion that "humans construct their social world along these three dimensions of socio-emotional perception and action" (p. 5).

Postures, movements, gaze, touch, and proxemics

Mehrabian (1969a, 1969b) reviewed the experimental findings of nonverbal research regarding body posture, position, movement, facial, and implicit verbal cues that are related to the communication of attitudes, status, and responsiveness and found that these correspond to the three facial expression dimensions of Osgood (1966). In compliance with their meaning in nonverbal communication, he named them (1) *evaluation*, (2) *potency* or *status*, and (3) *re-sponsiveness*. According to Mehrabian (1970, 1972), (1) the *pleasantness* of a relationship is communicated through *immediacy* or *proxemic cues* expressing directness, positive attitudes, preference, sympathy, liking, and affiliation of a communicator toward the addressee on the *evaluation dimension*, (2) the direction of *control* within a relationship is communicated through *relaxation cues* expressing power, status and social control in the *potency* or *status dimension*, and (3) the *activation* within a relationship is communicated through *activity cues* expressing *intended* and *perceived persuasiveness* in the *responsiveness dimension*. Subse-quent work by Mehrabian and Russell (Mehrabian & Russell, 1974a, 1974b; Russell & Mehrabian, 1977) provided a set of three orthogonal dimensions of basic emotional states, (1) *pleasure-displeasure*, (2) *dominance-submissiveness*, and (3) *arousal-non-arousal*, also known as the *pleasure-arousal-dominance* (PAD) *emotional state model* (Mehrabian, 1995, 1996; Valdez & Mehrabian, 1994). A set of three scales for measuring *pleasure*, *dominance*, and *arousal* (Mehrabian & Russell, 1974a) is equally suitable for state and trait emotions and has been applied in different fields, such as analysis of emotions (Mehrabian, 1997) and tem-peraments (Mehrabian, 1991, 1995), emotional responses to colors (Valdez & Mehrabian, 1994), conversational agents expressing emotions (Becker, Kopp, & Wachsmuth, 2004, 2007), or three-dimensional coordinate systems for representing emotional states (Tao, Liu, Fu, & Cai, 2008). Kudoh and Matsumoto (1985; 1987) investigated the interpretation of body postures in Japan and found evidence that the nonverbal dimensions also applied to non-Western cultures.

Dimension of evaluation, pleasure, and pleasantness. This dimension is affected by the five *immediacy cues* (touching, distance, forward lean towards the addressee, eye contact, and body orientation) described by Mehrabian (1969b, p. 203; 1972, p. 25) and *nonverbal involvement behavior* (interpersonal distance, gaze, touch, body orientation, forward lean, facial expressiveness, talking duration, interruptions, postural openness, relational gestures, head nods, and paralinguistic cues) outlined by Patterson (1982, p. 233) and others (Coker & Burgoon, 1987; Edinger & Patterson, 1983; Haase & Tepper, 1972; LaCrosse, 1975; Mehrabian & Williams, 1969; Palmer & Simmons, 1995; Rosenfeld, 1966).

The expression of *immediacy cues* and *nonverbal involvement behavior* plays a central role in nonverbal communication: mutual eye contact, leaning forward and turning toward the addressee, close interpersonal distance and touching, and smiling and head nodding create connection and involvement with other people, signal availability and inclusion, communicate sympathy, friendliness, sympathy, liking, and affiliation, and convey feelings of interpersonal warmth, closeness, friendship, and affiliation (Andersen, 2008, p. 191).

Furthermore, positive affection and greater depth of relationship are not only expressed by smiling, closer proximity, mutual eye contact, and mutual touch, but also by similar body postures, similar hand gestures, and similar speech patterns (Burgoon, Buller, Hale, & DeTurck, 1984; Burgoon, Buller, & Woodall, 1989; Coutts, Schneider, & Montgomery, 1980; Hale & Burgoon, 1984; Scheflen, 1964; Street & Giles, 1982). Similarities in nonverbal behavior are identified in the literature as interactional synchrony, posture mirroring, or motor mimicry (Bavelas et al., 1988; Bavelas et al., 1986, 1987; Chartrand & Baaren, 2009; Chartrand & Dalton, 2009). Interactional synchrony is associated with mutual liking, positive affect and rapport in interpersonal interactions (Bernieri & Rosenthal, 1991; Chartrand & Bargh, 1999; LaFrance, 1982; Tickle-Degnen & Rosenthal, 1987; Wallbott, 1995) and occurs in particular when two individuals share the same viewpoint (Scheflen, 1964).

Dimension of potency, status, dominance, power, and control. This so-called *vertical dimension*[*] is "one of the most fundamental dimensions" (Burgoon et al., 2010, p. 343) and is expressed by *relaxation cues*, *expansiveness*, *touch, gaze behavior*, and *head position*.

Relaxation cues were originally discovered by Goffman (1961) and described in detail by Mehrabian (1969b, p. 205; 1972, p. 11). This set of cues consists of asymmetrical placement of the limbs, sideways and/or backward lean of the communicator, and arm openness (see also LaFrance & Mayo, 1978, p. 99). A relaxed face also increases the perception of power (Agunis et al., 1998). According to Mehrabian (1969b, 1972), relaxation cues correspond with status differences: a communicator is more relaxed with an addressee of lower status and less relaxed with an addressee of higher status. The meta-analysis by Hall, Coats, and LeBeau (2005, p. 907) noted that the results of studies examining postural relaxation are contradictory; also an erect and less relaxed posture can be perceived as confident, powerful, and social potent. Carney, Hall, and LeBeau (2005, p. 118) reported that powerful people are seen as having more erect posture and more forward lean. On the other hand, several studies support the finding that powerful people appear as more relaxed and relaxed people appear as more dominant and powerful (Burgoon, Birk, & Pfau, 1990; Burgoon et al., 1998), but Burgoon (1991, p. 254) found some evidence that these findings may only be valid for males.

Expansiveness means generally occupying more space and invading the space of other people. Powerful people stand taller, talk and interrupt more, and use expansive gestures, expansive postures, and expansive placement of limbs, holding the arms and legs apart while sitting or standing, such as the arms-akimbo posture (Andersen, 2008, p. 321; Argyle, 1988, p. 208; Hai, Khairullah, & Coulmas, 1982; Henley, 1977, pp. 28, 127; Leffler, Gillespie, & Conaty, 1982; Mehrabian, 1968, p. 297; 1972, p. 19; Scheflen, 1972, p. 24).

[*] *Status*, *power*, and *dominance* are different but interrelated aspects of the vertical dimension. Many authors emphasize the importance of treating them as different concepts (Agunis, Simonsen, & Pierce, 1998; Andersen, 2008; Burgoon, Johnson, & Koch, 1998; Dunbar, 2004; Edinger & Patterson, 1983; Harper, 1985), but Mehrabian and other authors use these terms interchangeably. The meta-analysis by Hall et al. (2005) uses *vertical dimension* as a collective term.

As a much more direct form of invading the space of other people, powerful people are more likely to *point* to conversational partners and to *touch* them (Carney et al., 2005, p. 117; Henley, 1977, pp. 105, 118, 127; Leffler et al., 1982, p. 159; Moore & Porter, 1988, p. 161). Even as a dominance signal, touch can evoke feelings of composure, immediacy, similarity, equality, informality, trust, affection, depth of relationship, and interpersonal warmth (Burgoon, 1991, p. 254), but in most cases touches enacted by dominant people refer to *control touches*, which are intended to direct the behavior, attitude, or emotional state of other people (Burgoon et al., 2010, p. 157).

The *gaze* of powerful people, known as *visual dominance behavior*, follows distinct patterns of looking while speaking and listening: they look more and stare at the addressee when speaking and look less and avert the gaze when listening, whereas submissive people follow the opposite pattern (Argyle, 1988, p. 97; Dovidio & Ellyson, 1982; Dovidio, Ellyson, Keating, Heltman, & Brown, 1988; Henley, 1977, p. 153). The *head position* also plays an important role. An upward tilted head is perceived as a sign of dominance, a downward tilted head as a sign of submissiveness (Bente et al., 2010, p. 772; Carney et al., 2005, p. 118; Mast & Hall, 2004, p. 158).

Hall et al. (2005) examined in a *meta-analysis* including 120 *decoding studies* and 91 *encoding studies* nonverbal behavior related to the vertical dimension, such as postural relaxation, interpersonal distance, touch, gaze, and others. Despite the very heterogeneous results of the included studies, the meta-analysis revealed clear evidence that decoding of nonverbal behavior relies on a common cause, such as stereotypes or neural correlates. In particular, perceivers associated higher levels of the vertical dimension with

> . . ., more gazing, more lowered brows, a more expressive face, more nodding, less self touching, more touching of others, more hand/arm gestures, more bodily openness, less bodily relaxation, more bodily shifting, smaller interpersonal distances, . . . (Hall et al., 2005, p. 914)

Dimension of responsiveness, arousal, activation, and activity. This dimension is characterized by greater activity, expressiveness, and responsiveness, positively correlating with intended as well as perceived persuasiveness, and is particularly expressed by higher rates of facial expressions, hand gestures, eye contacts, head nods, smaller interpersonal distance, and speech, and is accompanied by more intonation, more speech volume, and lengthier communication (Mehrabian, 1969b, p. 206; 1972, p. 13; Mehrabian & Williams, 1969, p. 52).

Furthermore, Mehrabian and Williams found that persuasive effort was associated with more eye contact, more head nodding, and less backward lean (p. 53). Timney and London (as cited in Kleinke, 1986, p. 82) reported that participants instructed being persuasive to their interaction partners substantially increased their gaze, but this seems only be valid for males, as female participants tend to gesture more (Coker & Burgoon, 1987, p. 468).

It has been shown that higher activity and responsiveness also correlate with positive evaluation and liking (Bentler, 1969). This adds weight to the question of whether activity is an independent dimension, but Mehrabian and Williams (1969) show that a higher level of activity supports immediacy cues and therefore enhances the intensity of liking (p. 54).

McGinley, LeFerve, and McGinley (1975) found in their study about the impact of body postures on persuasiveness that open body postures ("leaning backward, legs stretched out, knees apart, one ankle crossed over the other knee, elbows away from her body, hands held outward, and arms held outward from her body", p. 687) have more power to change other people's opinion than closed body postures ("elbows next to her body, arms crossed, hands folded in her lap, knees pressed together, feet together, and legs crossed at either knees or the ankles", p. 687). Burgoon et al. (1990) investigated several kinesic cues in terms of their impact on credibility and persuasiveness and reported that nonverbal immediacy cues and kinesic expressiveness have a substantial effect on persuasiveness. Facial pleasantness and smiling were mostly persuasive, followed by facial expressiveness, body movements, pitch variety, fluency, and eye contact.

Chapter 6: Measuring Nonverbal Cues

In this chapter, the nonverbal parameters corresponding to the nonverbal cues humans use in relation to the three nonverbal dimensions outlined in Chapter 5 and found realizable through the transformation of motion capture data are described. Operationalization and math terms including scope and limits are given together with a description of their implementation in APEx. Table 8 shows which nonverbal cues can be calculated from which function. The use of these functions to compute nonverbal parameters is explained in Chapter 7.

Table 8

Calculation Functions For Nonverbal Cues

Dimension	*Nonverbal code*	*Nonverbal cue*	*Calculation function*	
Evaluation Pleasure Pleasantness	Immediacy cues	Interpersonal distance	Dyadic Proxemics	p. 76
		Interpersonal touch	Dyadic Proxemics	p. 76
		Forward lean	*Static SRL Sagittal**	p. 27
		Eye contact and gaze	Direction	p. 71
		Body orientation	Direction	p. 71
	Nonverbal involvement behavior (includes also the immediacy cues)	Postural openness	Openness	p. 68
		Relational gestures	Direction	p. 71
		Head nods	*Local Dynamic SRL Sagittal**	p. 35
		Interactional synchrony	Dyadic Mimicry	p. 78
Potency Status Dominance Power Control	Relaxation cues	Asymmetry of limbs	Symmetry	p. 62
		Backward lean	*Static SRL Sagittal**	p. 27
		Sideways lean	*Static SRL Lateral**	p. 27
		Arm openness	Openness	p. 68
		Postural shifts	*Global Dynamic SLR**	p. 33
	Expansiveness	Expansiveness of arms/legs	Expansion	p. 67
		Arms akimbo posture	Distance	p. 66
		Pointing behavior	Direction	p. 71
		Touching behavior	Dyadic Proxemics	p. 76
	Visual dominance behavior	Eye contact and gaze	Direction	p. 71
	Dominant head position	Upward head tilt	*Static SRL Sagittal**	p. 27
	Dominant head motions	Head nods	*Local Dynamic SRL Sagittal**	p. 35
Responsive-ness Arousal Activation Activity	Activity	Rates of movements	*Activation**	p. 40
		Velocity of movements	*Activation**	p. 40
		Acceleration of motions	*Activation**	p. 40
	Responsiveness	Interpersonal distance	Dyadic Proxemics	p. 76
		Eye contact and gaze	Direction	p. 71
		Forward lean	*Static SRL Sagittal**	p. 27
	Body openness	Backward lean	*Static SRL Sagittal**	p. 27
		Expansivity of arms/legs	Expansion	p. 67
		Openness of arms/legs	Openness	p. 68
		Crossed arms/legs	Crossed/Folded	p. 68

* For the nonverbal parameters shown in italics, please refer to Chapter 4: Measuring Body Positions and Body Movements.

Symmetry

Symmetry of body postures or corresponding body parts has been investigated in various nonverbal studies. Asymmetry in the arrangement of arms and legs is associated with body relaxation in order to communicate dominance in status relationships (Hall et al., 2005; Mehrabian, 1969a, 1972), whereas arm symmetry with uncrossed arms and legs as shown by physicians during medical encounters increases satisfaction and lowers anxiety in patients (Beck, Daughtridge, & Sloane, 2002). Asymmetrical postures of babies lying in a supine position can be diagnostically useful for early identification of Asperger's syndrome (Teitelbaum et al., 2004; Teitelbaum, Teitelbaum, Nye, Fryman, & Maurer, 1998) or autism spectrum disorders (Esposito, Venuti, Maestro, & Muratori, 2009).

Operationalization. The term *symmetry* is rarely defined within nonverbal studies (Harrigan, 2005, p. 158), but is commonly used in *bilateral symmetry,* precisely defined and operationalized by Weyl (1989):

> Bilateral symmetry, the symmetry of left and right . . . is so conspicuous in the structure of . . . the human body. Now this bilateral symmetry is a strictly geometric and . . . an absolutely precise concept. A body, a spatial configuration, is symmetric with respect to a given plane E if it is carried into itself by reflection in E. Take any line l perpendicular to E and any point p on l: there exists one and only one point p' on l which has the same distance from E but lies on the other side. (p. 4)

This plane E is also known as the *sagittal plane*, and the perpendicular line as the *sagittal axis* of the human body (e.g., Dorland, 2011), and are denoted as the *sagittal* y^*z^**-plane* and the *sagittal* x^**-axis* in the SRL model (p. 28) and depicted in *Figure 5* (p. 29). As illustrated in *Figure 7*, the 3D human body is bilaterally symmetrical because each of the two corresponding joints of the limbs is equidistant from the sagittal y^*z^*-plane. If the plane in *Figure 7* were half-transparent and half-reflecting, both pictures—one shining through from the other side and one reflected from this side—would match perfectly.

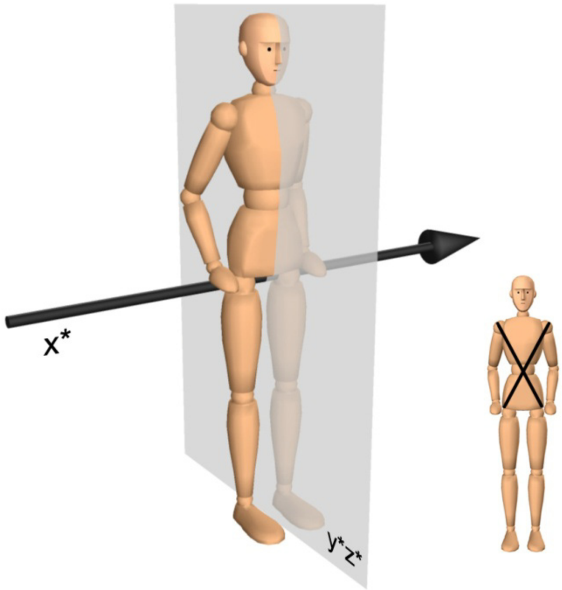


Figure 7. Sagittal plane, sagittal axis, and center of moment of the human body.

To demonstrate the *symmetry* of a 3D human model, the coordinates of the joints of the extremities should be transformed into the reference frame of the *center of moment* first (Cutting & Proffitt, 1981), which is invariant regarding motions. For standing, walking or dancing individuals, the center of moment is the intersection of the lines connecting each shoulder with the hip joint on the opposite side of the torso, as shown in the little illustration on the right in *Figure 7*. These two diagonals intersect close to the chest joint of the 3D human model (the location of the chest joint is marked in *Figure 6*, p. 36). For sitting individuals, the invariant center of moment is usually the hip joint. It is, however, useful to use the chest joint as a *reference frame* for the upper extremities because sitting individuals tend to turn toward their interaction partner, and then the chest joint becomes the center of moment. APEx is able to allow the researcher to define individual *symmetry* parameters and to choose the appropriate *reference frame* for each *symmetry* parameter according to their needs.

After a joint has been referenced to the center of moment, it can be reflected to the other side of the sagittal plane by changing the sign of the x^*-coordinate as the sagittal plane crosses the sagittal x^*-axis of the center of moment at its zero point (see *Figure 7*). If the original point matches the reflected point, we can say that both joints are in bilateral symmetry as defined by Weyl (1989). Otherwise, if they do not match they are not symmetrical, and the degree of asymmetry increases with the distance between both points. By calculating the Euclidean distance between the original and the reflected point of origin of a joint, we have a measurement for the *symmetry* of a pair of corresponding body joints which increases with higher degrees of asymmetry. The perfect bilateral symmetry between two body joints is indicated by a zero value.

Math terms, scope, and limits. To transform the point p into another frame of reference with the point of origin p', the coordinates p_x, p_y, and p_z are translated by subtracting p'_x, p'_y, and p'_z, and then inversely rotated by Euler angles x', y', and z', resulting in the coordinates p^*_x, p^*_y, and p^*_z, as shown in Equation (10):

$$\begin{pmatrix} p^*_x \\ p^*_y \\ p^*_z \end{pmatrix} = R_x(-x') \cdot R_y(-y') \cdot R_z(-z') \cdot \begin{pmatrix} p_x - p'_x \\ p_y - p'_y \\ p_z - p'_z \end{pmatrix} \tag{10}$$

Equation (10) is similar to Equations (8) and (9) (p. 34 and 36), which transform rotation matrices according to Equation (4) (p. 30) into another frame of reference, whereas Equation (10) transforms coordinate values. The Euclidean distance between a point with the coordinates p_x, p_y, and p_z and its reflection with the coordinates $-p^*_x$, p^*_y, and p^*_z is calculated by using Equation (11):

$$d = \sqrt{(-p^*_x - p_x)^2 + (p^*_y - p_y)^2 + (p^*_z - p_z)^2} \tag{11}$$

After calculating the *symmetry* value d for each joint of the extremities, *symmetry* values for the upper, the lower, and the whole body are obtained by adding the *symmetry* values of the corresponding joints.

Implementation. The zero value indicates the perfect symmetry of a pair of body parts. Higher values mean higher degrees of asymmetry. Table 9 (see p. 66) shows the *symmetry* parameters implemented by default in APEx which are computed for each time point of the sequence. To ensure comparability between various 3D human models, all *symmetry* values can be optionally related to a measurement which relies on known body proportions. In his world-renowned drawing *Vitruvian Man* (see *Figure 8*), Leonardo da Vinci illustrated that a man with outstretched arms fits exactly into a square. An empirical study confirmed that the proportion of body height to wingspan is 1.023, which is within the 2.3% error margin of the hypothesized value of one (Johnson & McPherson, 2006). Therefore, all distance parameters such as *Symmetry* can be optionally calculated as the percentage of the body height.

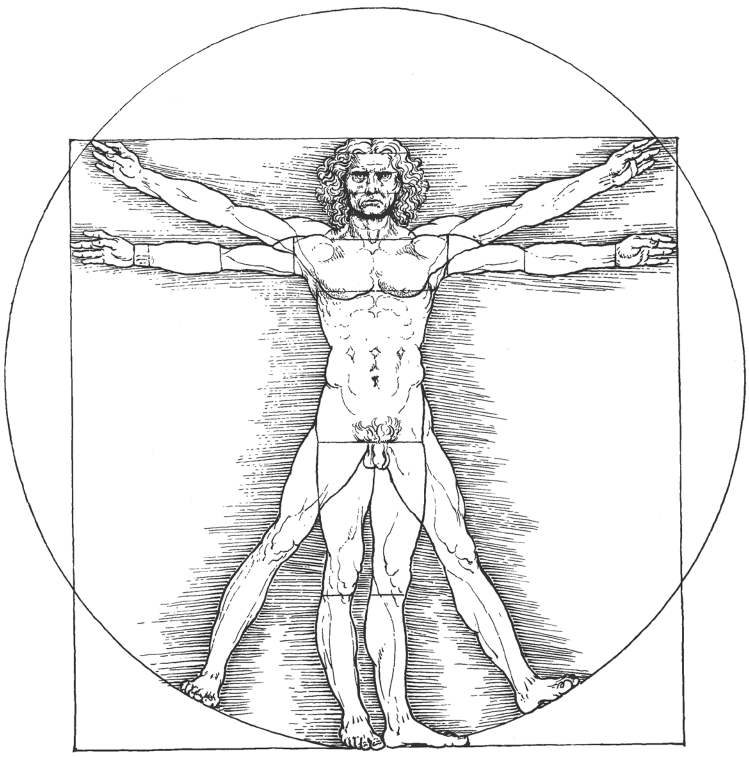


Figure 8. Vitruvian Man by Leonardo da Vinci.
Redrawn by Hans Bernhard, 2010.
Retrieved from Wikimedia Commons.

It is noteworthy that the middle of the circle is the *center of moment* for moving individuals, whereas the middle of the square is the *center of moment* of those sitting (see p. 63).

Table 9

Symmetry Parameters

Parameter	Range	Description
Symmetry Hands	≥ 0%	Euclidean distance between hand joints after mirroring
Symmetry Elbows	≥ 0%	Euclidean distance between elbow joints after mirroring
Symmetry Shoulders	≥ 0%	Euclidean distance between arm joints after mirroring
Symmetry Upper Extr.	≥ 0%	Sum of the values of hands, elbows, and shoulders
Symmetry Feet	≥ 0%	Euclidean distance between foot joints after mirroring
Symmetry Knees	≥ 0%	Euclidean distance between knee joints after mirroring
Symmetry Hips	≥ 0%	Euclidean distance between leg joints after mirroring
Symmetry Lower Extr.	≥ 0%	Sum of the values of feet, knees, and hips
Symmetry Body	≥ 0%	Sum of values of upper and lower extremities

Note. The zero value indicates perfect symmetry of a pair of body parts. Higher values mean higher degrees of asymmetry. To ensure comparability between 3D models, the values can be optionally calculated as the percentage of the body height of the 3D model. By default, all symmetry parameters are computed for each time point of the animated time sequence.

Distance

Operationalization. The distance between two body parts or body joints is a frequent issue of several nonverbal cues, such as expansiveness, openness, self-touch, or arms akimbo. Therefore, a general calculation function *Distance* is realized in order to calculate the Euclidian distance between two joints or markers using their Cartesian coordinates. Furthermore, a function of *Less Than* is provided to detect touches (p. 76) or arms-akimbo postures (p. 116).

Math terms, scope, and limits. The general formula for the Euclidean distance between two points p and q has no limit and is represented by Equation (12):

$$d = \sqrt{(q_x - p_x)^2 + (q_y - p_y)^2 + (q_z - p_z)^2} \quad (12)$$

Implementation. By default, four intermediate values are calculated (see Table 10).

Table 10

Distance Parameters

Parameter	Range	Description
Distance Hands	≥ 0 (0…100%)	Euclidean distance between both hand joints
Distance Elbows	≥ 0 (0…100%)	Euclidean distance between both elbow joints
Distance Feet	≥ 0 (0…100%)	Euclidean distance between both foot joints
Distance Knees	≥ 0 (0…100%)	Euclidean distance between both knee joints

Note. Higher values mean greater distances between body parts. By default, four distance parameters for the hands, elbows, feet, and knees are computed for each time point of the animated time sequence, but do not appear in output files. Instead, they serve as intermediate values in preparation for the calculations for the nonverbal parameter *Openness*.

Expansion

Expansive gestures are often used by dominant people and constrictive gestures by submissive people. The degree of *expansion* communicates the actor's status compared with the status of others (DePaulo & Friedmann, 1998; Remland, 1982; Tiedens & Fragale, 2003). Expansive gestures claiming lots of physical space are often combined with joking and laughter, and they have also been linked to expressiveness and pleasantness, establishing and maintaining the center of attention, and attempting to positively influence interaction partners (Burgoon & Newton, 1991; Coker & Burgoon, 1987; Dunbar & Burgoon, 2005).

Operationalization. Postural *expansion* can be obtained by moving an extremity straight away from the body or by enlarging the body shape with postures such as arm akimbo, whereas constriction is achieved by drawing body parts in or crossing them over the body (Eibl-Eibesfeldt, 1975). To construct a measurement for *expansion*, it is necessary to measure the distance between the body parts of the extremities and the body shape, which is a difficult and complicated task. An acceptable simplification is to calculate the Euclidean distance between the joint of interest and the three central joints of the 3D model, namely the hip, the chest, and the head, and to choose the smallest distance. After calculation of the *expansion* value for each part of the limbs, the *expansion* for the upper, the lower, and the whole body is obtained by adding the values of the corresponding joints.

Math terms, scope, and limits. The general formula for the Euclidean distance between two points p and q expressed by Equation (12) is used (p. 66).

Implementation. Table 11 shows the *expansion* parameters implemented in APEx by default. Higher *expansion* values mean greater distances between extremities and body shape. To ensure comparability between different 3D human models, all *expansion* values can be optionally calculated as the percentage of the body height of the 3D human model.

Table 11

Expansion Parameters

Parameter	Range	Description
Expansion Hand L	≥ 0%	Smallest of the distances of the left hand to the three central joints
Expansion Elbow L	≥ 0%	Smallest of the distances of the left elbow to the three central joints
Expansion Hand R	≥ 0%	Smallest of the distances of the right hand to the three central joints
Expansion Elbow R	≥ 0%	Smallest of the distances of the right to the three central joints
Expansion Upper Extrem.	≥ 0%	Sum of the values of both hands and both elbows
Expansion Foot L	≥ 0%	Smallest of the distances of the left foot to the three central joints
Expansion Knee L	≥ 0%	Smallest of the distances of the left knee to the three central joints
Expansion Foot R	≥ 0%	Smallest of the distances of the right foot to the three central joints
Expansion Knee R	≥ 0%	Smallest of the distances of the right knee to the three central joints
Expansion Lower Extrem.	≥ 0%	Sum of the values of both feet and both knees
Expansion Body	≥ 0%	Sum of the values of upper and lower extremities

Note. R = right, L = left. Higher values mean greater distances between body parts of extremities and body shape. To ensure comparability between different 3D human models, the values can be calculated as the percentage of the body height of the 3D human model. By default, all of the expansion parameters are computed for each time point of the animated time sequence.

Openness

Openness of the arrangement of arms or legs is assumed as a relevant attitude- or affect-communicating variable (Machotka, 1965). An open arrangement of the arms has been found to communicate a positive attitude (Mehrabian, 1969a). Open arms or legs can also indicate the degree of relaxation which is communicated as dominance in terms of status or power relationships (Kudoh & Matsumoto, 1985; Mehrabian, 1972). Within intimate relationships, various levels of body *openness* determine various degrees of mutual openness and serve the function of regulating nonverbal intimacy between partners during interactions (Burgoon, Stern, & Dillman, 1995; Manusov, 2005). *Openness* in combination with other persuasive cues can be a sign of responsiveness (Mehrabian & Williams, 1969).

Operationalization. *Openness* of body postures is defined as the accessibility of the body by means of an open arrangement of the arms and the legs (Mehrabian, 1969a). On the other hand, *closedness* describes the degree to which the hands, arms, legs, and feet meet or intersect (Harrigan, 2005, p. 178). To construct a measurement, the distances between the corresponding body parts of both body sides can be calculated using Equation (12), p. 66 (see also Table 10). For the upper part, the lower part, and the whole body, the calculated values are added. As can be seen in *Figure 9*, this measurement is suitable if the extremities do not intersect or touch each other. In the 3D human model in the middle, the values of the *distance* parameters increase to the left as the body parts move apart from each other (see Body: 39.8, 68.8, and 142.9), but also to the right (39.8, 45.0, and 72.8), where the body parts are used as a barrier and therefore create the impression of *closedness* rather than *openness*.

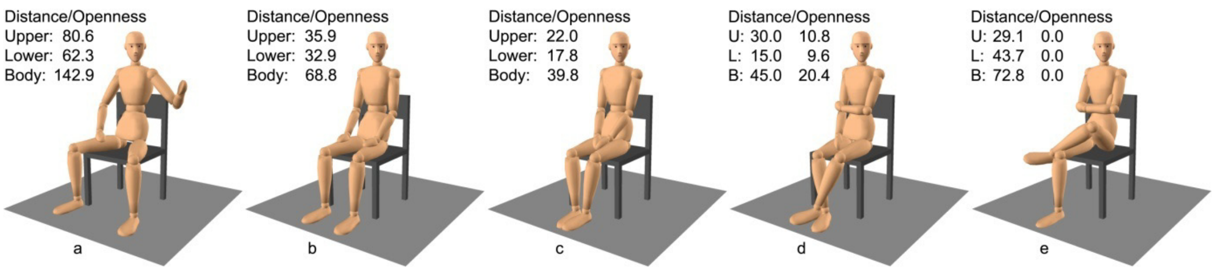


Figure 9. Distance and openness values of different body positions.

It is obvious that body closedness, expressed by the use of arms or legs as barriers, also implies distances between body joints. To solve this problem and obtain a measurement for the *openness* of a body posture, the parameter *Distance* has been refined. Folded arms can be determined by using the Euclidean distance between a hand and its corresponding elbow on the opposite body side. If a hand joint is located within a sphere around the opposite elbow joint by a radius equal to a forearm length, it can be assumed that the hand joint is somewhere on the opposite side of the body and that its forearm serves as a barrier in front of the body (e.g., a hand touches part of the arm on the other side of the body or is simply held in front of the chest), the parameter *Folded Arms* is assigned a value of 0.5, and a value of one if both hands lie near to their opposite elbows. This also applies to the feet: a value of 0.5 indicates that one foot touches the other leg, and a value of one indicates a cross-legged position (e.g., lotus position) for the parameter *Folded Legs*. The commonly used posture in which a lower leg rests on its opposite knee, as shown in the rightmost picture of *Figure 9*, is assigned a value of one for *Crossed Legs*. This position can be assumed if one knee joint is higher than the knee joint used as a pillar and its corresponding foot is on the opposite side of this knee.

By assigning these values to the parameters *Folded Arms*, *Folded Legs*, and *Crossed Legs*, we can use them as weights to correct the values of the nonverbal parameter *Distance*. As summarized in Table 12, the nonverbal parameter *Openness Upper Extremities* equals the sum of the parameters *Distance Hands* and *Distance Elbows* if the corresponding weights are zero. If one arm is folded, this will subtract half of the distance between the hands from the distance between the elbows. In the case of double-folded arms, the full distance between the hands is subtracted, resulting in a zero value for *Openness Upper Extremities*. This also applies to the lower extremities; the higher value of *Folded* and *Crossed Legs* is used as a weight. The parameter *Openness Body* sums up the values of the extremities. The *openness* values depicted in *Figure 9* show useful values: if only one arm or leg is folded, this will reduce the *openness* values by half. In addition, double-folded arms or crossed legs—creating the highest impression of closedness—result in zero values for the parameter *Openness*.

Math terms, scope, and limits. Equation (12) for Euclidian distance is used (p. 66).

Implementation. Table 12 shows the *openness* parameters implemented by default in APEx which are computed for each time point of the animated time sequence. The *openness* values, which are based on the *distance* values, can be optionally calculated as the percentage of the body height of the 3D model. The zero value indicates the maximum level of *closedness*, and higher values mean greater *openness* of body positions.

Table 12

Openness Parameters

Parameter	Range	Description
Folded Arms	0, .5, 1	Indicates whether none (= 0), one (= .5), or both (= 1) arms are folded.
Folded Legs	0, .5, 1	Indicates whether none (= 0), one (= .5), or both (= 1) legs are folded.
Crossed Legs	0, 1	Indicates whether none (= 0) or one lower leg rests on the opposite knee (= 1).
Openness Upper Extremities	≥ 0%	Sum of distance values of elbows and hands. In the case of folded arms, half (= .5) or full (= 1) hand distance is subtracted from elbow distance.
Openness Lower Extremities	≥ 0%	Sum of distance values of knees and feet. In the case of folded or crossed legs, half (= .5) or full (= 1) foot distance is subtracted from knee distance.
Openness Body	≥ 0%	Sum of openness values of upper and lower extremities.

Note. The zero value means maximum level of closedness. Higher values mean greater openness of body positions. To ensure comparability between different 3D models, the openness values can be calculated as the percentage of the body height. 0=not folded/crossed; .5=one arm/leg touches the other arm/leg; 1=both arms/legs touch each other.

Direction

The *direction* parameter refers to body orientation, relational gestures, pointing behavior, and head direction as an approximation for eye contact. Gaze behavior has an impact on the attractiveness of the interaction partner (Mason, Tatkow, & Macrae, 2005; Williams & Kleinke, 1993) or on personality impression (Larsen & Shackelford, 1996), and is most susceptible to gender differences (Bente et al., 1998; Burgoon, Buller, & Woodall, 1996; Henley, 1995). Studies of human visual behavior discovered that people with high status receive more visual attention (Dovidio & Ellyson, 1982; Dovidio et al., 1988). Body orientation influences immediacy and persuasiveness (Mehrabian, 1969b, 1972; Mehrabian & Williams, 1969).

3D head and gaze direction. The *gaze direction* can be determined by using the point of origin of the eyeballs of a 3D human model. Because animation data for eyeballs are usually not available, the gaze can be approximated by the *direction of the head*. The approximation is quite accurate, if the direction is calculated using three invisible markers attached to the head. The direction marker is between the eyes, and the other two markers are near the ears but at the same height as the eye marker.

Operationalization. As depicted in Figure 10, the line labeled $\vec{u}$ denotes the *direction of eye contact*, the line labeled $\vec{v}$ the *head direction*, and the angle δ between both lines estimates the extent to which a person is averting their gaze from the interaction partner.

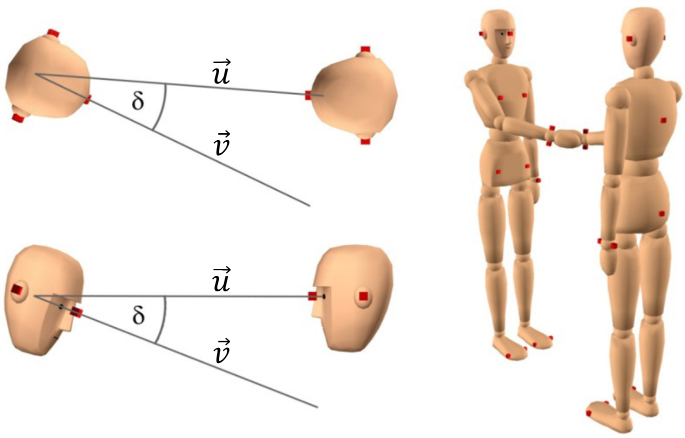


Figure 10. Approximation of the gaze direction.

Math terms. The described lines are vectors intersecting at the halfway point between the two ear markers of the person of interest. Vector $\vec{u}$ aims at the eye marker of the interaction partner, vector $\vec{v}$ at the person of interest's own eye marker. The angle δ between two intersecting vectors can be calculated according to Equation (13) (Vince, 2007, p. 25):

$$\begin{aligned}\delta &= cos^{-1}\left(\frac{\vec{u}\cdot\vec{v}}{\|\vec{u}\|\cdot\|\vec{v}\|}\right)\\ &= cos^{-1}\left(\frac{u_x\cdot v_x+u_y\cdot v_y+u_z\cdot v_z}{\sqrt{u_x^2+u_y^2+u_z^2}\cdot\sqrt{v_x^2+v_y^2+v_z^2}}\right)\end{aligned} \tag{13}$$

Scope and limits. The angle δ is within the range of $0° \leq \delta \leq 180°$ and has no sign. It includes no information about the head direction or if the gaze is averted from the partner.

2D head and gaze direction. For research questions regarding interpersonal dominance in visual interactions, it is of interest to know whether the gaze is raised or lowered and to what extent the gaze is averted horizontally in each case regardless of the other dimension. Therefore, the horizontal and the vertical dimensions should be considered separately.

Operationalization. The solution is to split the 3D angle into two 2D angles, one angle for horizontal gaze averting and one angle for vertical gaze averting. This can be achieved by projecting the 3D angle onto both a horizontal and a vertical plane: (1) the *line of head direction* and the *line of eye contact* are projected onto a horizontal plane so the horizontal deviation of the viewing direction from the eye contact direction can be measured, as depicted top left in *Figure 10*. (2) The line of the *viewing direction* is projected onto a vertical plane which stands upright along the *line of eye contact* so the vertical deviation of the *viewing direction* from *eye contact* can be measured, as depicted bottom left in *Figure 10*.

Math terms. Whereas the projection onto the horizontal plane is done by setting the y-value of the coordinates of all four markers to zero before using Equation (13), the projection of the point of origin p of the eye marker onto the vertical plane requires the calculation of the nearest point p' on the vertical projection plane, as depicted in *Figure 11*. The vertical projection plane is defined by the straight upward pointing unit vector $\vec{y}^0$ and the vector $\vec{u}$, which connects point a, the halfway point between the ear markers of the person of interest, with point b, the eye marker of the interaction partner. The cross-product of both vectors yields the normal vector $\vec{n}$, which is perpendicular to this vertical plane. The point p' is now determined by moving point p in the direction of vector $\vec{n}$ by factor λ (Vince, 2007, p. 115), as shown in *Figure 11* and represented by Equations (14).

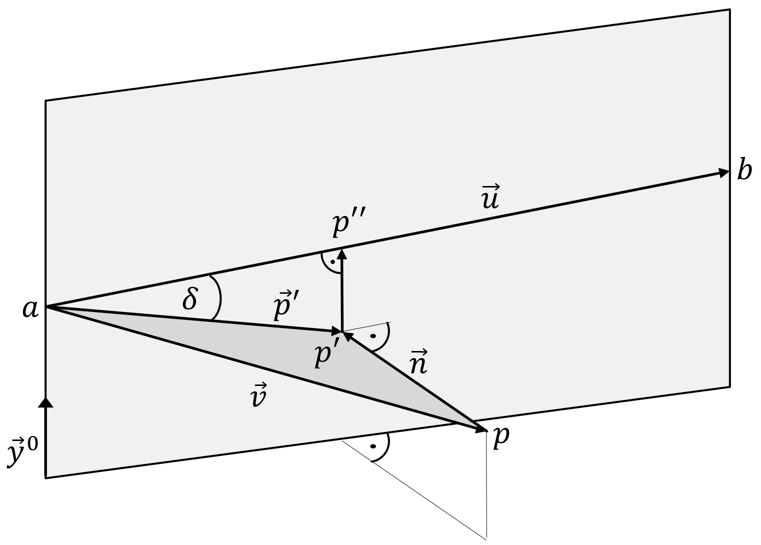


Figure 11. The positions of the nearest points p' on a plane and p'' on a line to a point p.

$$\vec{p}' = \vec{p} - \lambda \cdot \vec{n} = \vec{p} - \frac{\vec{p} \cdot \vec{n} + n_0}{\|\vec{n}\|^2} \cdot \vec{n} \tag{14}$$

Since the normal vector $\vec{n}$ depends on the unit vector $\vec{y}^0 = (0, 1, 0)$, Equation (14) can be simplified to:

$$\begin{pmatrix} p'_x \\ p'_y \\ p'_z \end{pmatrix} = \begin{pmatrix} p_x \\ p_y \\ p_z \end{pmatrix} - \frac{p_x \cdot u_z - p_z \cdot u_x + a_z \cdot u_x - a_x \cdot u_z}{u_x^2 + u_z^2} \cdot \begin{pmatrix} u_z \\ 0 \\ -u_x \end{pmatrix} \tag{15}$$

After location of the coordinates of point p' according to Equation (15), the angle δ between vector $\vec{u}$ and vector $\vec{p}'$ can be calculated using Equation (13). The angle δ is within the range of $0° \leq \delta \leq 180°$ and has no sign indicating whether the gaze is averted by a raised or a lowered head. To get this information, the point p'' on vector $\vec{u}$ nearest to point p' can be determined, as depicted in *Figure 11* and calculated by Equation (16) (Vince, 2007, p. 85):

$$\vec{p}'' = (\vec{p}' \cdot \vec{u}^0) \cdot \vec{u}^0 \qquad \text{with } \vec{u}^0 = \frac{\vec{u}}{\|\vec{u}\|} \tag{16}$$

If the y-value of point p' is greater than the y-value of point p'', then the head is raised and angle δ is assigned a negative sign, similarly to a sagittal SRL flexion. Equation (16) is also used for horizontal projection. A negative sign is assigned if the z-value of point p' is greater than the z-value of point p'', which means that the head is turned away from the interaction partner to the observer. If the sign is not needed, the function *Absolute Value* of APEx can be used to get values without a sign.

Scope and limits. The horizontal and vertical 2D direction parameters cover the range of $-180° \leq \delta \leq +180°$ and indicate how much and where the head is averted. There is a gap in the definition of the vertical projection plane, when vector $\vec{u}$ points in the same or opposite direction as unit vector $\vec{y}^0$, which results in a zero value for the divisor in Equation (15). This singularity occurs when one person's head is exactly above the other person's head, and as a result no vertical deviation from the direct viewing line between them exists. Another singularity occurs if the person's head is averted from the interaction partner by 90°. This angle is meaningless for the vertical dimension, and its projection on the vertical plane may result in distorted values. This also applies to the horizontal angle if the person is looking straight upward. In all cases of singularities, APEx outputs a missing value (i.e., no value at all).

Implementation. Table 13 on p. 75 shows the variables output by APEx for each *direction* parameter. The zero value indicates no deviation from the direct line and, in the case of head direction, could refer to "direct eye contact." Higher values mean higher degrees of averting. The direction of other body parts such as the upper part of the body or relational hand gestures are often the subject of nonverbal research (Harrigan, 2005; Manusov, 2005). Therefore, the *direction* parameter is also implemented for other body parts. By default, the *direction* parameter for the head aims at the nose, for hips at the hips, for the chest, the left, and the right hand aims at the chest of the interlocutor. *Figure 10* indicates the red markers of the five body parts (p. 71) which are used by the calculation function '*Direction (forward)*'. Because the markers measuring the direction of the chest and the hips are placed on the back of the 3D human model, another version of the calculation function has been implemented in APEx: the calculation function '*Direction (backward*'*)* takes into account that vector $\vec{v}$ points in the opposite direction (see Table 20, p. 115).

Table 13

Direction Parameters

Parameter	Range	Description
Direction *Joint*: 3D Deviation	0°…180°	Deviation of the line projected straight from the direct line to the *target* of the interaction partner in three-dimensional space: only positive sign (no negative sign) = any direction in 3D
Direction *Joint*: 2D Deviation Horizontal	–180°…+180°	Deviation from direct line to *target*, projected on a horizontal plane: positive sign = turned away from the interlocutor to the observer negative sign = turned away from the interlocutor as well as the observer
Direction *Joint*: 2D Deviation Vertical	–180°…+180°	Deviation from direct line to *target*, projected on a vertical plane: positive sign = direction is raised above the direct line to partner negative sign = direction is lowered below the direct line to partner

Note. The zero value means no deviation. Higher values mean greater deviation between the line straight ahead and the direct line to the target. By default, all three parameters are calculated for the *joints* the head, the chest, the hips, the right hand, or the left hand. Their *targets* are listed in the text.

Dyadic Proxemics and Touch

Hall (1963, 1974) originated the name *proxemics* and defined the channels *distance*, *touch*, *frontal body orientation*, and *input from the senses* (touch, vision, audition, olfaction, and temperature). He concluded from his studies that humans have four social distances between touch and 30 feet which vary in terms of their perceptual characteristics and type of status, relationship, and the affiliation of the interacting individuals: *intimate*, *personal*, *social*, and *public space*. According to Harrigan (2005, p. 145), *proxemics* is the most frequently investigated nonverbal code, and the measurement of *proxemics* varies from study to study in terms of the reference points used: interpersonal distances between heads and torsos were also measured as well as between hands, feet, or chair edges. The most comprehensive reviews of proxemics research, including more than 700 studies, are provided by Hayduk (1983) and Aiello (1987). Harrigan (2005, p. 148) recommended the measurement of interpersonal distance, frontal body orientation, trunk lean, postural shifts, touch, and gaze.

Operationalization. Whereas the measurements of body orientation, trunk lean, postural shifts, and gaze are operationalized by other calculation functions (see Table 8, p. 61), *interpersonal distance* and *touch* can be operationalized by the Euclidian distance between the body joints of two people. The correct operationalization of *touch* would require consideration of the body surfaces of both. Since motion capture systems track only the position of markers on the body surface which are transformed into the positions of the person's body joints by the motion capture software, *touch* can only be derived from the *interpersonal distance* between the body joints and markers of two people. If the *interpersonal distance* falls below a certain value, it can be assumed that *touch* has occurred.

Math terms, scope, and limits. Equation (12) for Euclidian distance is used (p. 66).

Implementation. APEx's implementation of *proxemics* determines the shortest distance between two people using a specified set of body joints or markers, which could be different for each. As shown in Table 14 (p. 77), eight nonverbal parameters are realized with the calculation function *Dyadic Proxemics* in the default configuration. The nonverbal parameter *Dyadic Proxemics Body* represents the shortest distance between two people, the three nonverbal parameters *Dyadic Proxemics Head, Dyadic Proxemics Chest,* and *Dyadic Proxemics Hips* yield the distances between the heads, chests, and hips of two people, and four more nonverbal parameters measure the distances between hands and feet to the interaction partner.

Table 14

Dyadic Proxemics Parameters

Parameter	Range	Description
Dyadic Proxemics Body	≥ 0	Shortest distance between two people using all joints/markers
Dyadic Proxemics Head	≥ 0	Distance between the heads of two people
Dyadic Proxemics Chest	≥ 0	Distance between the chests of two people
Dyadic Proxemics Hips	≥ 0	Distance between the hips of two people
Dyadic Proxemics Hand R	≥ 0	Shortest distance between right hand and joints/markers of partner
Dyadic Proxemics Hand L	≥ 0	Shortest distance between left hand and joints/markers of partner
Dyadic Proxemics Foot R	≥ 0	Shortest distance between right foot and joints/markers of partner
Dyadic Proxemics Foot L	≥ 0	Shortest distance between left foot and joints/markers of partner

Note. Because body joints lie beneath the body surface, the zero value means the touch of two markers. Higher values mean greater interpersonal distance. To ensure comparability between differently sized 3D models, the values can be calculated as the percentage of the body height of the given 3D model. In this case, the percentage value of two different people can differ, although they are calculated from the same interpersonal distance.

To determine touch, APEx includes a calculation function named *Less Than*, which returns the value one if a distance falls below a given value. The default configuration of APEx includes four nonverbal parameters, as indicated in Table 15.

Table 15

Dyadic Touch Parameters

Parameter	Range	Description
Dyadic Touch Body	0 or 1	Indicates whether touch between two people has happened
Dyadic Touch Hand R	0 or 1	Indicates whether the right hand touched the interlocutor
Dyadic Touch Hand L	0 or 1	Indicates whether the left hand touched the interlocutor
Dyadic Touch Hands	0, 1, or 2	Indicates the number of hands touching the interlocutor

Note. These nonverbal parameters have no own calculation functions. Instead, they use the general function *less than* to determine whether a previously calculated *dyadic proxemics* value falls below a certain cutoff value: 0 = no interpersonal touch, 1 = interpersonal touch probably happened.

Dyadic Mimicry

Research has shown that *interactional synchrony* has considerable social influence (Bavelas et al., 1988; Bavelas et al., 1986). *Interactional synchrony* happens in several communication channels, such as body postures, motions, vocalics, and speech (Chartrand & Dalton, 2009). Chartrand and Baaren (2009) define *motor mimicry* as the "adoption of the mannerisms, postures, gestures, and motor movements of one's interaction partner" (p. 225), and LaFrance (1982) defines *posture mirroring* as "the degree to which two or more people adopt mirror-imaged postures vis-a-vis each other in a face-to-face interaction" (p. 281). Bavelas et al. (1986) found that *motor mimicry* is intended to be seen by the interaction partner as having the social function of creating a "fellow feeling" (Bavelas et al., 1987) of liking, understanding, rapport and togetherness, which leads to positive social outcomes (Scheflen, 1964). *Motor mimicry* has been found to be an unconscious act and therefore notably different from conscious imitation (Bandura, 1962; Chartrand & Bargh, 1999; Decety & Sommerville, 2009). As depicted in *Figure 12*, rotational mimicry (see left side) means that a person mimics the positions of the limbs on the same body side as their counterpart by rotating mentally into the posture of the interaction partner. By contrast, mirror mimicry (see right side) means that a person, like a mirror image, mirrors their counterpart and imitates the positions of the limbs on opposite body sides.

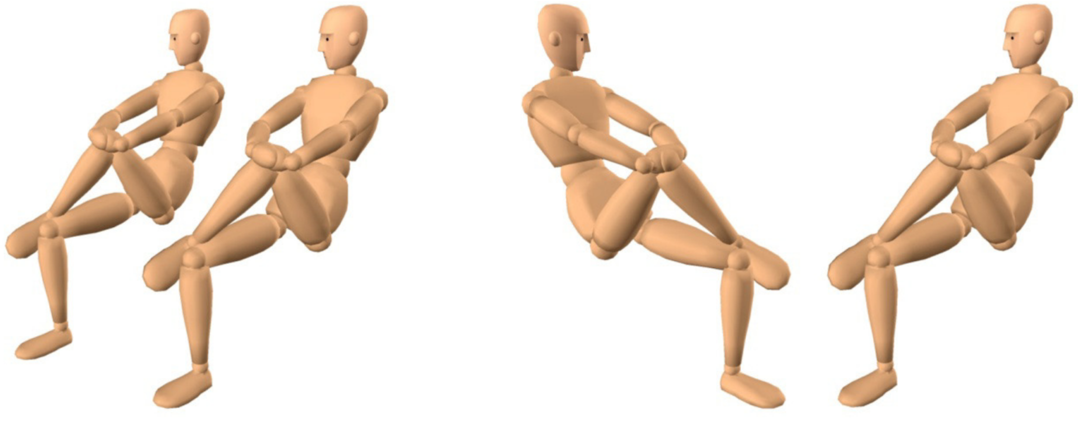


Figure 12. Rotational mimicry (left) and mirror mimicry (right).

Operationalization. *Rotational mimicry* is defined by the degree to which two body postures match. The *static SRL dimensions* measure the orientation of each body joint and have the advantage that they are independent of body size and proportions. If the *static SRL flexion angles* equal each other for each corresponding body joint of two people perfect rotational mimicry can be assumed, whereas differences between the *static SRL flexion angles* represent differences in the body postures. To obtain a *rotational mimicry* measure, the static SRL flexion angles are first calculated and related to the corresponding person's *center of moment* (see p. 63) for all body joints of both people. Then the absolute differences of the *static SRL flexion angles* of each body joint between both 3D human models are formed and added up. In the case of *mirror mimicry*, one of the 3D human models is self-mirrored at its sagittal plane (see *Figure 7*), before application of the same procedure as outlined above.

Math terms. To calculate *static SRL flexion angles* related to the person's *center of moment*, Equation (8) is used (p. 34) before Equations (5) – (7) are applied (p. 31). After the *static SRL flexion angles* are calculated for both people, the absolute angle differences of their corresponding body joints are added according to Equation (17):

$$m_t^{mim} = \sum_{j=1}^{15} \sum_{d=1}^{3} \left| \varphi_{A,t,j,d}^{stat} - \varphi_{B,t,j,d}^{stat} \right| \tag{17}$$

m = measurement, mim = mimicry, t = time point no., j = joint no., d = dimension no.
$\varphi_{A,t,j,d}^{stat}$ = angle of static SRL dimension d of joint j at time point t from Person A (Person B)

In the case of mirror mimicry, one person is mirrored at the sagittal plane by changing the sign of the y- and the z-values of the Euler rotation angles. After calculation of the *SRL flexion angles* of both people, Equation (17) is applied but uses the corresponding joints of the opposite body side of the mirrored person.

Scope and limits. Please refer to the scope and limits of the *static SRL system* (p. 31). For the static SRL formulas, there are singularities in rare cases. In such cases, APEx outputs a missing value for the *rotational* or *mirror mimicry* (i.e., no value at all).

Implementation. Table 16 shows the *Dyadic Mimicry parameters* implemented in APEx by default. The parameter *Dyadic Mimicry Body* considers all 15 body joints and relates them to the hips. The parameter *Dyadic Mimicry Upper Extremities* uses the six arm joints related to the chest joint and the parameter *Dyadic Mimicry Lower Extremities* uses the six leg joints related to the hip joint. The parameter *Dyadic Mimicry All Extremities* is the sum of the parameters *Dyadic Mimicry Upper Extremities* and *Dyadic Mimicry Lower Extremities* which are designed for sitting individuals. It is problematic to relate the upper extremities of sitting individuals to the hips, because people tend to rotate their upper body part and lean backward or forward. In these cases, the measures for *dyadic mimicry* are more valid if they relate the upper extremities to the chest. Each of these four nonverbal parameters yielded in the output file a value for '*Dyadic Rotational Mimicry*' and '*Dyadic Mirror Mimicry*'. The zero value indicates identical or mirrored body postures, whereas higher values indicate different body postures.

Table 16

Dyadic Mimicry Parameters

Parameter	Range	Description
Dyadic Mimicry Upper Extremities	0…3240	Dyadic mimicry of the upper extremities with the six arm joints related to the chest
Dyadic Mimicry Lower Extremities	0…3240	Dyadic mimicry of the lower extremities with the six leg joints related to the hips
Dyadic Mimicry All Extremities	0…6480	Sum of the dyadic mimicry of the upper and the lower extremities
Dyadic Mimicry Body	0…8100	Dyadic mimicry of the whole body with all 15 body joints related to the hips

Note. The zero value indicates perfect mimicry. Higher values mean higher degrees of different body postures. The maximum values are very unlikely to occur because nobody can twist all body joints in each of three dimensions about 180°. The body joint to which the other body parts are related can be selected in APEx under *reference system*.

Generic dyadic parameters

The generic dyadic parameter group consists of four measures giving information about (1) the common nonverbal expression of two people in dyadic interaction, (2) the percentage proportion accounted for by the share contributed by each person, (3) the net contribution, i.e., the contribution additional to the share of the interaction partner, and (4) the percentage proportion accounted for by the net contribution of a person.

Operationalization. At each time point, the interaction partner's value is added in order to achieve the common nonverbal expression A+B, and subtracted to yield the net contribution A–B. For the percentage proportions, the nonverbal parameter value of A and its net contribution A–B are related to the common nonverbal expression A+B.

Meaning of (A+B). The sum (A+B) represents the common dyadic nonverbal expression of person A and person B with reference to the respective nonverbal parameter. If a parameter is unipolar with only positive values, the zero value indicates that neither person expresses the nonverbal behavior of interest. If the used parameter is bipolar, with positive and negative values, the zero value indicates contrary nonverbal expressions of both people and can be investigated by the difference explained below.

Meaning of (A-B). The difference (A–B) indicates the extent of nonverbal behavior of person A in contrast to person B. The sign of this measure has the following meaning: (1) a positive difference means that the nonverbal parameter of person A has a higher value than the nonverbal parameter of person B; (2) a negative difference means that the nonverbal parameter of person A has a lower value than the nonverbal parameter of person B.

Implementation. Table 17 shows the *generic dyadic parameters* predefined by default in APEx. APEx is able to accept requests for generic dyadic parameters of any *non-dyadic* nonverbal parameter, to take into account the corresponding number of output variables, and to ensure the correct application of the calculation routines to each output variable.

Table 17

Generic Dyadic Parameters

Base	Derived dyadic parameter
Symmetry Upper Extremities	Dyadic Symmetry Upper Extremities
Symmetry Lower Extremities	Dyadic Symmetry Lower Extremities
Symmetry All Extremities	Dyadic Symmetry All Extremities
Expansion Upper Extremities	Dyadic Expansion Upper Extremities
Expansion Lower Extremities	Dyadic Expansion Lower Extremities
Expansion All Extremities	Dyadic Expansion All Extremities
Openness Upper Extremities	Dyadic Openness Upper Extremities
Openness Lower Extremities	Dyadic Openness Lower Extremities
Openness All Extremities	Dyadic Openness All Extremities
Direction Head	Dyadic Direction Head 3D Deviation
	Dyadic Direction Head 2D Deviation horizontal
	Dyadic Direction Head 2D Deviation vertical
Direction Chest	Dyadic Direction Chest 3D Deviation
	Dyadic Direction Chest 2D Deviation horizontal
	Dyadic Direction Chest 2D Deviation vertical
Direction Hips	Dyadic Direction Hips 3D Deviation
	Dyadic Direction Hips 2D Deviation horizontal
	Dyadic Direction Hips 2D Deviation vertical
Direction Hand R	Dyadic Direction Hand R 3D Deviation
	Dyadic Direction Hand R 2D Deviation horizontal
	Dyadic Direction Hand R 2D Deviation vertical
Direction Hand L	Dyadic Direction Hand L 3D Deviation
	Dyadic Direction Hand L 2D Deviation horizontal
	Dyadic Direction Hand L 2D Deviation vertical

Camera Parameters

This section describes parameters relating to technical features of video clips. The microanalysis of nonverbal behavior based on 3D character animation includes the presentation of animated video clips to subjects rating their impressions. Research found that camera features like *camera angle*, *camera framing*, and *camera proxemics* have an impact on impression formation as outlined below. The following parameters may be useful for examining the technical features of animated video clips before they are presented as stimulus material.

Camera Angle. The *camera angle* is the angle between the horizontal and the actual camera viewing line. According to Mamer (2009), three basic categories of camera angles can be described: *low-angle shot*, *high-angle shot*, and *eye-level shot*. The *low-angle shot* denotes a camera below the eye level of the subject, and hence points upwards. The subject filmed from this position appears "threatening, powerful, and intimidating" (p. 7). The *high-angle shot* describes a camera position above the eye level of the subject, and hence angles downwards. Subjects filmed in this way tend to look "diminished, intimidated, threatened," and "insignificant" (p. 8). *Eye-level shots* are taken with the camera on the eye level of the subjects, and these appear "neutral" (p. 9) because the observer is visually on the same level as the subject. True eye level appears too confrontational, so the camera position in most shots is slightly above or below eye level.

Operationalization. The *static sagittal SRL flexion angle* measures the angle of the camera pointing upwards or downwards, and as a result can be used to measure the *camera angle*. The sagittal dimension is independent of rotational flexion if no lateral flexion exists, which would be unusual for a camera placement. Therefore, no frame of reference is needed.

Math terms, scope, and limits. For math terms, please refer to Chapter 4, the section entitled "The Static SRL System: Measuring Body Positions", on p. 30. The scope and limits of the math terms are described on p. 31.

Implementation. Table 18 (p. 90) summarizes the implementation of the media-related parameters in APEx. High-angle shots are indicated by remarkable positive values, low-angle shots with remarkable negative values, and eye-level shots with values around zero for the sagittal dimension of the camera. Although output, the rotational dimension is irrelevant, and the lateral dimension might be used to check whether the camera is upright.

Camera Framing. Visual emphasis or intensity can be obtained through *camera framing*, defined as the relative size of the image of an object within the borders of the television frame (Tiemens, 2005), and *camera proxemics*, defined as the distance between subject and camera (Mamer, 2009). In principle, three basic positions can be distinguished (Hayward, 2000; Mamer, 2009): *long shot*, *medium shot*, and *close-up*. The *long shot* includes the full human body, either as a *full-body shot* with a near camera or as an *extreme long shot* with a far camera. Whereas the full-body shot allows us to see both body language and facial expressions, the extreme long shot can be used to diminish the subject because the loss of visual details associated with the decreased relative size of the subject de-emphasizes the subject. The *medium shot* represents how people interact in life because it puts the observer on the same level as the subject being filmed from the waist up and is generally neutral in its presentation of the subject compared with the *long shot* and the *close-up*. The *close-up* is a head shot which gives the subject greater importance by emphasizing details, provides the greatest psychological intimacy and identification with the subject, is suitable for showing dyadic interactions, can create suspense and involvement, and can be used to influence the perceiver (Hayward, 2000; Mamer, 2009; Masters, Frey, & Bente, 1991; Vogeley & Bente, 2011).

Operationalization. According to Tiemens (2005), *camera framing* is the relative size of the image of an object within the borders of the monitor frame. The only body part which is mostly visible and hence can be used in each case, from the extreme long shot to the close-up, is the head of the subject. *Camera framing* is operationalized as the percentage of the height of the head related to the height of the monitor frame. As depicted in *Figure 13*, two invisible markers have to be set up for accurate measurement of the head height, one at the top of the head and one at the lowest point of the chin.

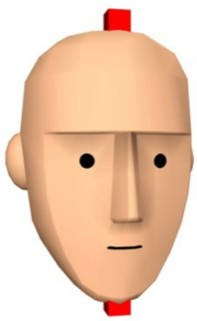


Figure 13. Measuring the head height with markers

Geometrical Model. Camera settings such as camera proximity, camera resolution, and lens perspective influence the screen image displayed by the monitor (Mamer, 2009), i.e., the positions of the points of the 3D world projected onto the screen image (see *Figure 15* on p. 87). The 2D positions on the screen are calculated by the perspective transformations of the viewing pipeline of the 3D animation software which uses a frustum as geometrical model for the projection (Buss, 2003). As colored gray in *Figure 14*, a frustum is a rectangular pyramid with the top portion removed. The bottom and top sides are referred to as the far and near planes and define which part of the 3D world is relevant for the projection. The point (x, y, z) within the frustum of *Figure 14* is projected to the point (x', y', z') on the near plane representing the screen image. This image has a resolution of $w \times h$ and is defined by the left bottom point $(l, b, -n)$ and the right top point $(r, t, -n)$. The so-called *field of view* θ represents the angle between the top-bounding plane and the bottom-bounding plane of the frustum.

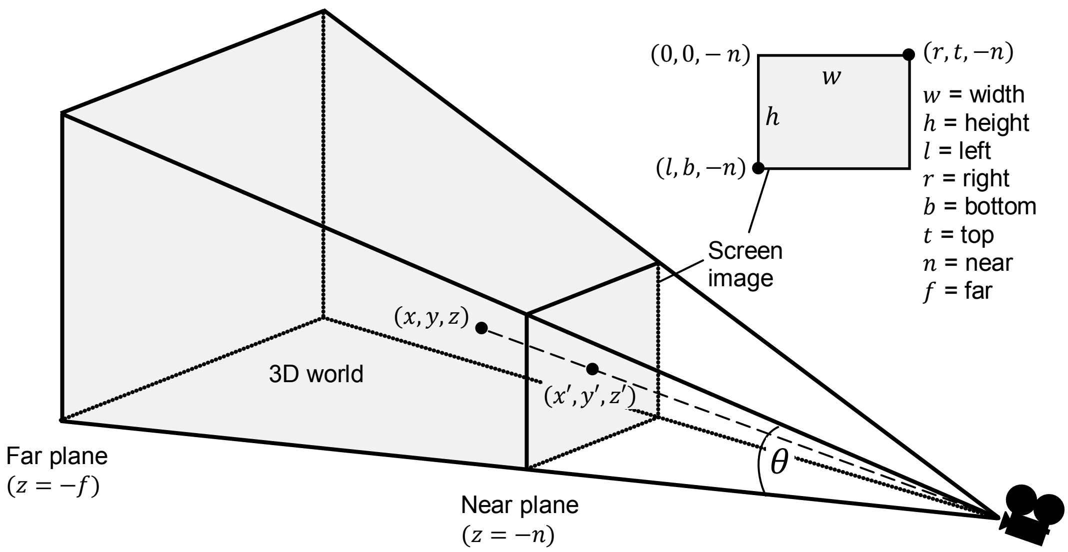


Figure 14. The frustum of the viewing pipeline used in 3D animation software. Adapted from Buss (2003, p. 56).

Math terms. First, the coordinates of all relevant points are referenced to the camera whose base position is pointing in the opposite direction of the z-axis, because this is the assumption of the following math terms. After this coordinate transformation according to Equation (10), the near plane is $z = -n$ and the far plane $z = -f$ far away from the camera. The x'- and y'-coordinates of the projected point result from multiplying the coordinates of the point (x, y, z) by the projection matrix S (Buss, 2003), represented by Equation (18).

$$S = \begin{pmatrix} \frac{2n}{r-l} & 0 & \frac{r+l}{r-l} & 0 \\ 0 & \frac{2n}{t-b} & \frac{t+b}{t-b} & 0 \\ 0 & 0 & \frac{-(f+n)}{f-n} & \frac{-2fn}{f-n} \\ 0 & 0 & -1 & 0 \end{pmatrix} \tag{18}$$

The values t, b, r, and l can be calculated by Equations (19) – (22) (Buss, 2003) using w (width), h (height), n (near plane), f (far plane), and θ (field of view), which are usually provided by the camera settings of the 3D character animation software.

$$t = n \cdot \tan(\theta/2) \tag{19}$$

$$b = -n \cdot \tan(\theta/2) \tag{20}$$

$$r = (w/h) \cdot t \tag{21}$$

$$l = (w/h) \cdot b \tag{22}$$

After the x'- and y'-values of the top marker p and the chin marker q have been obtained, the media-related parameter *Camera Framing* $cf^{\%}$ can be calculated according to Equation (23).

$$cf^{\%} = \frac{\sqrt{(q_{x'} - p_{x'})^2 + (q_{y'} - p_{y'})^2}}{h} \cdot 100 \tag{23}$$

The values of the parameter *Camera Framing* $cf^{\%}$ depicts the percentage of the head height related to the frame height h.

Scope and limits. Mathematical singularities such as a frame height of zero are practically non-existent. If the head is not visible or the user specifies incorrect values for w (width), h (height), n (near plane), f (far plane), or θ (field of view), APEx will output missing values (i.e., no value at all).

Implementation. Following Buss (2003, pp. 54–58), the coding of Equations (18) – (22) applies the OpenGL statements *glViewport* (defines screen image matrix), *gluPerspective* (defines projection matrix S), *gluLookAt* (defines coordinate transformation matrix regarding camera direction), and *gluProject* (projects a 3D point onto the screen image using the previously defined matrices). The graphic standard OpenGL is usually installed on each Windows computer. The field of view θ should be chosen to be equal to the angle that the screen image adopts in the field of view of the person looking at the image (Buss, 2003). Table 18 (p. 90) summarizes the implementation of the media-related parameters. The parameter *Camera Framing* is the percentage of head height related to frame height.

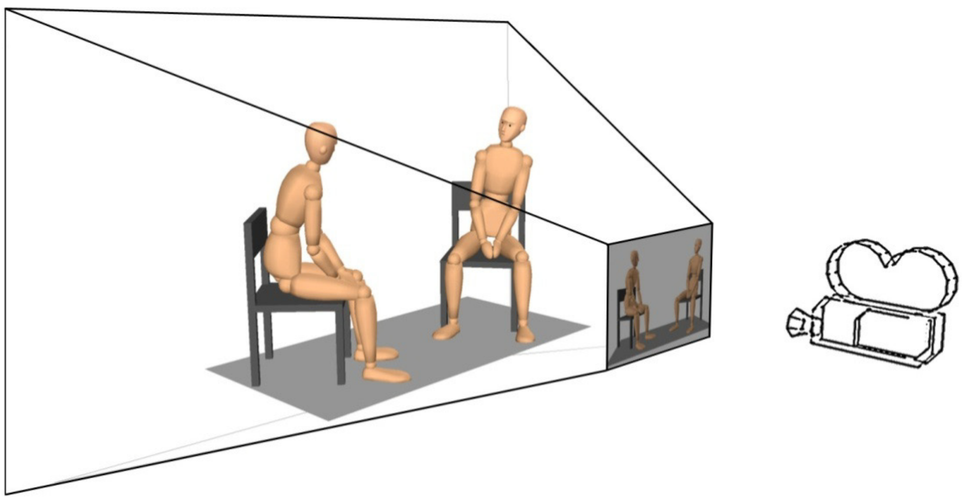


Figure 15. Scene with camera and frustum in a 3D character animation software.

Camera Proxemics. The parameter *Camera Proxemics* complements the parameter *Camera Framing*. Whereas the latter one describes the graduations between all distances very well, especially for the *long shot* and *extreme long shot*, the parameter *Camera Proxemics* is able to distinguish easily between *full-body shot*, *medium shot*, and *close-up*.

Operationalization. The parameter *Camera Proxemics* expresses the proportion of the visible body accounting for the head. To obtain this measurement, the height of the head—measured from the top of the head to the lowest point of the chin—is divided by the height of the visible body—measured from the top of the head to the lowest visible part of the body. The resulting value ranges from zero (the face is not visible) to one (only the face is visible). Following Bammes (1994), the head is one-seventh of the full body height and one-third of the height from above the waist to the top of the head. Expressed in percentages, a value of around 10% to 20% indicates a *full-body shot*, around 30% to 40% a *medium shot*, and greater than 50% a *close-up*. This classification may be useful for analyzing different camera shots.

Geometrical Model. To calculate 2D positions on the screen, the same perspective transformations of the viewing pipeline of the 3D animation software are applied, which uses a frustum as geometrical model (see p. 85). In contrast to the parameter *Camera Framing*, not only are the 3D coordinates of the two head markers (see *Figure 13*, p. 84) transformed into 2D screen coordinates, but the 3D coordinates of the highest and the lowest visible body part are also transformed in order to determine the height of the visible body.

Math terms. After calculation of the 2D coordinates of the top marker p, the chin marker q, the lowest visible body part l, and the highest visible body part h according to Equations (18) – (22) (p. 86), the parameter *Camera Proxemics* $cp^{\%}$ is determined by Equation (24):

$$cp^{\%} = \frac{\sqrt{(q_{x'} - p_{x'})^2 + (q_{y'} - p_{y'})^2}}{l_{y'} - h_{y'}} \cdot 100 \tag{24}$$

Scope and limits. If the body is not visible at all or the user specifies incorrect values for w (width), h (height), n (near plane), f (far plane), or θ (field of view), APEx will output missing values (i.e., no value at all).

Implementation. The implementation of the parameter *Camera Proxemics* uses the same OpenGL statements as the implementation of the parameter *Camera Framing* (p. 87). Table 18 (p. 90) summarizes the implementation of the parameters relating to camera features.

Video Pixel Difference. Since the visual impressions of body movements presented in video clips are based on images sequentially displayed on a monitor screen, the complexity of body movements can technically be determined by calculating the proportion of the monitor screen area that is involved in body movements. The more body parts participate in a complex movement, the greater the proportion of the monitor screen area displaying the movement is.

Operationalization. The area involved in displaying body movements can be determined by selecting the video frames displayed at the coded time points and counting the number of video pixels that changed their color between the present and the last video frame. For example, given a frame rate of 30 fps (frames per second) and a coding resolution of two time points per second, every fifteenth frame would be selected and compared with the previously selected frame.

Math terms, scope, and limits. The image data of two selected frames are compared in order to determine the screen area size involved in movements by counting the number of screen pixels that change their color (between the actual time point t and the previous time point $t-1$) and by relating this number to the total number of screen pixels, as shown in Equation (25):

$$\Delta_t^{\%} = \frac{\sum_{y=1}^{n_y} \sum_{x=1}^{n_x} \varepsilon_t}{n_x \cdot n_y} \cdot 100 \qquad \varepsilon_t = \begin{cases} 1 & \text{if } col_t(x,y) \neq col_{t-1}(x,y) \\ 0 & \text{else} \end{cases} \tag{25}$$

$\Delta_t^{\%}$ = *video pixel difference* as percentage at time point t, x = x-coordinate, y = y-coordinate, n_x = width of screen, n_y = height of screen, $col_t(x,y)$ = color of pixel (x,y) at time point t

Implementation. APEx uses Microsoft's *AVIFile library* to open video clips, select single frames from the video stream, and compare the color information of each video pixel in order to calculate the parameter *Pixel Difference*. Therefore, video clips are only supported that are based on video codecs installed and recognized by Microsoft's *Windows Multimedia System*. These video clips usually have the extension .avi or .wmv. If APEx cannot calculate the parameter *Pixel Difference* and therefore outputs an error message, the user should install the appropriate video codec or use a video processing utility to recompress the video clip with a codec recognized by Microsoft's *Windows Multimedia System*. Table 18 summarizes the implementation of the media-related parameters in APEx.

Table 18

Camera Parameters

Parameter	Range	Description
Camera Angle*	–180°…180°	*Low-angle* (neg. values), *high-angle* (pos. values), or *eye-level shot* (≈0)
Camera Framing	0…100%	Percentage of head height related to frame height
Camera Proxemics	0…100%	Percentage of head height related to visible body height
Pixel difference	0…100%	Percentage of pixels changing their color between two time points

* Only the sagittal dimension of the parameter *Camera Angle* is relevant for the evaluation of the type of camera angle.

Chapter 7: The Program APEx

Introduction

To transform motion capture data and 3D animation data according to the nonverbal parameters described in Chapter 4 and Chapter 6, the software APEx (*Automatic Parameter Extraction of Nonverbal Parameters*) has been developed. APEx is programmed with around 14,500 lines of code resulting in an executable file of 784 KB. Essentially, APEx reads one or more input files containing data exported from professional 3D animation software, calculates nonverbal parameters according to the formulas developed in the previous chapters, writes the resulting nonverbal data into output files, and outputs statistical data for each input file in a common statistics file. To ensure the best possible ease of use, the user interface of APEx allows high flexibility to specify how APEx should process the input files. The following sections describe in detail how the data in the input files should be formatted, and how they can be obtained, which options the user interface provides and how they can be used, how the output files are formatted and how the data can be read by statistical software packages.

Input Files

Data format. APEx supports plain text files with delimiter-separated values (DSV) as input files. DSV is not a single, well-defined format, but refers generally to any file that consists of data lines (records) divided into fields separated by delimiters where every data line has the same sequence of fields. APEx uses the following specific format.

Format line. The input file begins with the format line labeling the data fields of the data lines. The data field labels can use any alphanumeric character, can have any reasonable length, are separated with a delimiter, and must not enclose by quotation marks. The first data field is the time field and the label of the time field must be specified in the dedicated input box labeled ‘Time Field’ of the user interface (see tab page ‘Input Files’). The second data field is the frame number and can be labeled in any way. The following data field labels designate the translation and rotation values of the 3D model joints and markers. These data field labels consist of a data field name and a data field type separated by a colon. The data field name is the name of the corresponding joint or marker. The data field type can be ‘Tx’, Ty’, Tz’, ‘Rx’, Ry’, or ‘Rz’: T denotes translation, R indicates rotation, and the letters x, y, and z specify the dimension. If a sequence of consecutive data field labels belongs to the same joint or marker, only the first label of the sequence must have a name; the other labels can omit a name and comprise only the data field type. Several comment lines can be inserted before the format line. The data lines immediately follow the format line.

Data lines. Each time point of a 3D animated time sequence has an own data line in the input file. Each data line begins with a time value and a frame number; the following data fields consist of the translation and rotation values of the 3D model joints and markers for a single time point. The first field of the data line identifies the time point of the time sequence. With regard to each data line in an input file, the time value should have the same distance to the time value of the previous data line. All data fields are separated by a delimiter.

Delimiter. The delimiter used to separate data field labels in the format line or data field values in a data line can be any character. Regardless of the file extension, APEx uses the first character immediately following the time field of the format line as delimiter. Therefore, most delimiter-separated value file formats, such as comma separated values (CSV) or tab separated values (TSV), are supported.

Values. The input files consist of global translation and rotation values of the joints and markers of the hierarchical skeleton structure of a human 3D model in professional 3D animation software (see *Figure 6*, p. 36, *Figure 10*, p. 71, and *Figure 13*, p. 84). *Global values* means that the translation and rotation values of joints are referenced by the global scene origin of the 3D world. In contrast, local values of a joint are referenced to the corresponding parent joint hierarchically superior to it. APEx is designed to process global values; if local values are used, the nonverbal data that APEx calculates and outputs will be incorrect.

Decimal point. A dot must be used as decimal point.

```
Exported global values of scene 'USA No. 3: Chief & Employee'
Time [sec];Frame;Hips:Tx;Ty;Tz;Rx;Ry;Rz;Chest:Tx;Ty;Tz;Rx;Ry;Rz;Head:Tx;Ty;Tz;Rx;Ry;Rz;
0;1;-2.257270336;21.98801804;4.980587006;-173.3709717;72.34246063;-172.6352844;-2.01799
0.01;2;-2.257270336;21.98801804;4.980587006;-173.3709717;72.34246063;-172.6352844;-2.01
0.02;3;-2.260074615;21.9872818;4.982691765;-173.515152;72.25010681;-172.7256622;-2.0239
0.03;4;-2.260074615;21.9872818;4.982691765;-173.515152;72.25010681;-172.7256622;-2.0239
0.04;5;-2.265665531;21.98579216;4.986915588;-173.8012085;72.06500244;-172.9040375;-2.03
0.05;6;-2.267072916;21.98533058;4.988647461;-173.9111328;71.99916077;-172.9831696;-2.03
0.06;7;-2.267025709;21.98513412;4.990031719;-173.9806061;71.9641037;-173.0478668;-2.039
0.07;8;-2.265933514;21.9851284;4.991160393;-174.0215454;71.95108795;-173.1026459;-2.037
0.08;9;-2.264173031;21.98531532;4.992023468;-174.0555878;71.94772339;-173.1595154;-2.03
0.09;10;-2.262120962;21.98569489;4.992609978;-174.1042633;71.94156647;-173.2303467;-2.0
0.1;11;-2.259544849;21.98632431;4.992821693;-174.1746368;71.93434143;-173.3225708;-2.02
0.11;12;-2.256354809;21.98718071;4.992695808;-174.2548676;71.93097687;-173.4284973;-2.0
```

Figure 16. Example of an input file with comment line, format line, and data lines.

Example. *Figure 16* shows the first data fields and first data lines of an input data file. The first line is a comment line, which will be ignored by APEx. The second line is the format line beginning with the time field label ‘Time [sec]’, the frame no. label ‘Frame’, and the data field labels for the global values of the hips, the chest, and the head. Then follow some data lines, numbered from one to twelve, with a frame rate of 10 fps.

Export from 3D animation software. Professional 3D animation software, such as MotionBuilder, has generally no possibility of exporting global data in a DSV format suitable for APEx. That 3D software uses proprietary binary data formats, which are additionally subject of changes between different versions. Because those proprietary data files cannot be used as input files, a script has been developed to export the 3D global data to DSV files.

Installation of the Script ‘Export Global Data’. Appendix B (p. 110) contains a python script written for MotionBuilder 2012 and subsequent versions. If this script is placed in a text file with the name ‘ExportGlobalData.py’ in the subfolder ‘bin\config\PythonStartup’ of MotionBuilder’s installation folder, a menu item ‘Export Global Data’ will be available in the ‘Python Tools’ menu of MotionBuilder (from which also a free student version exists).

Usage of the Script 'Export Global Data'. (1) Start MotionBuilder 2012 (or higher) and open a scene with animated 3D models. (2) As shown in *Figure 17*, select the joints and markers of a human 3D model. If camera parameters are of interest, mark additionally a camera and a camera interest. If intending to use the *static SRL system*, you may mark additionally a chair or another object (for more details, please refer to the section entitled "About the base position", on p. 32). (3) Select the menu item 'Export Global Data' in the 'Python Tools' menu of MotionBuilder. (4) A tools window with the title 'Export Global Data' and a button 'Start' appear. Click on the 'Start' button. (5) A file dialog window appears which proposes to store the exported data in a file in the user's home directory with the name of the scene and the extension '.csv'. Please ensure that the extension of the data file for one person is '.L.csv' (left person) or '.A.csv' (other cases) and for the other it is '.R.csv' (right person) or '.B.csv' (other cases). Then hit on 'Save'. (6) Repeat Steps (1) to (5) for the other person in the dyad.

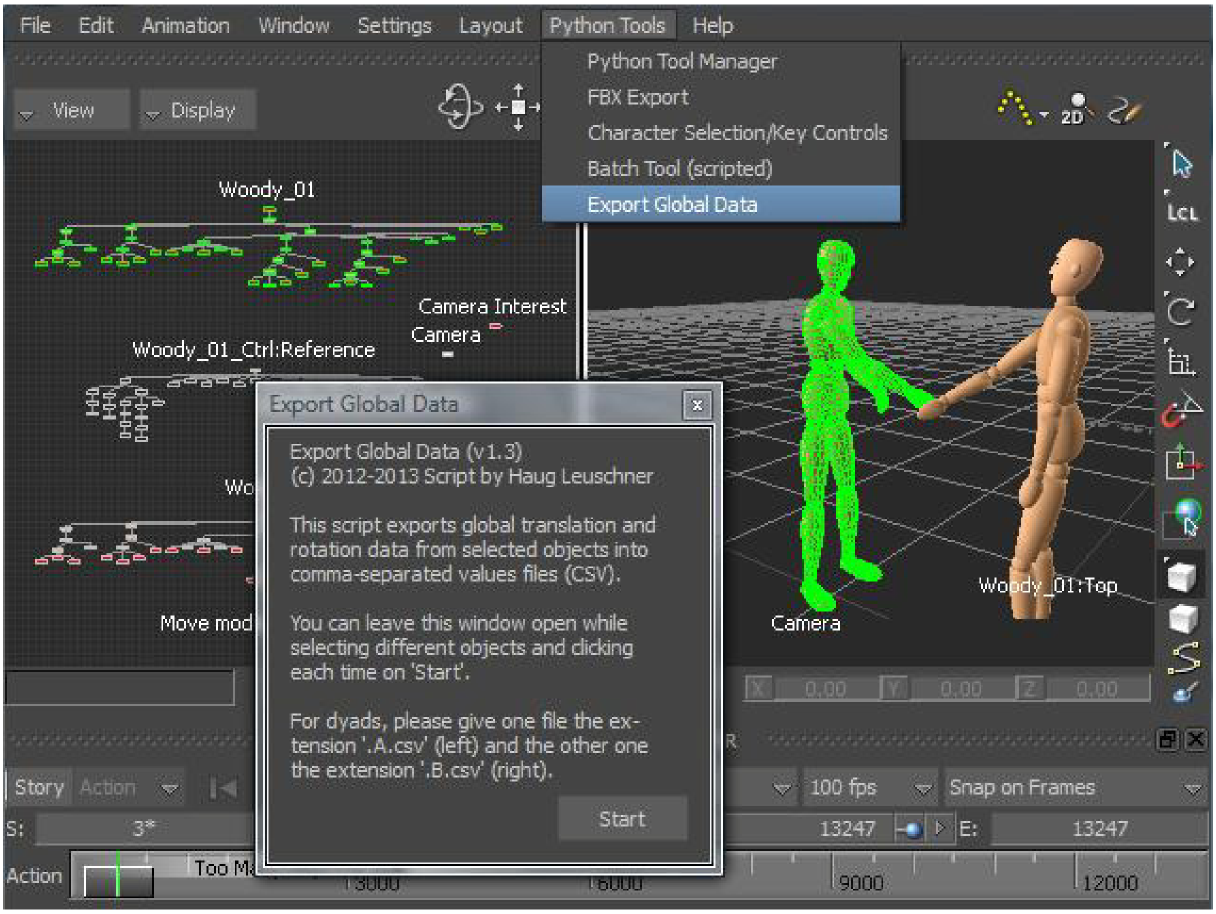


Figure 17. Menu item 'Export Global Data' in MotionBuilder's 'Python Tools' menu.

User Interface

The user interface of APEx consists of three tab pages: the ‘Input Files’ tab page, the ‘Data Fields’ tab page, and the ‘Parameters’ tab page. All tab pages allow specific options to be set for how APEx should process the data of the input files. This includes the option to modify and enhance the default set of nonverbal parameters by using a base set of freely combinable calculation functions. After all options are chosen and the calculation is started by clicking on ‘Calculate’, APEx processes all specified input files at once and, if necessary, writes error messages in the output files and points to them at the end of the job.

Tab page ‘Input Files’. As shown in *Figure 18*, the input files are specified in the tab page ‘Input Files’. In the center of the window, the *input file list* displays the input files and the options chosen for them. On the right side of the *input file list*, a set of buttons and input fields allow the user to modify the *input file list* and to open the files with an external editor.

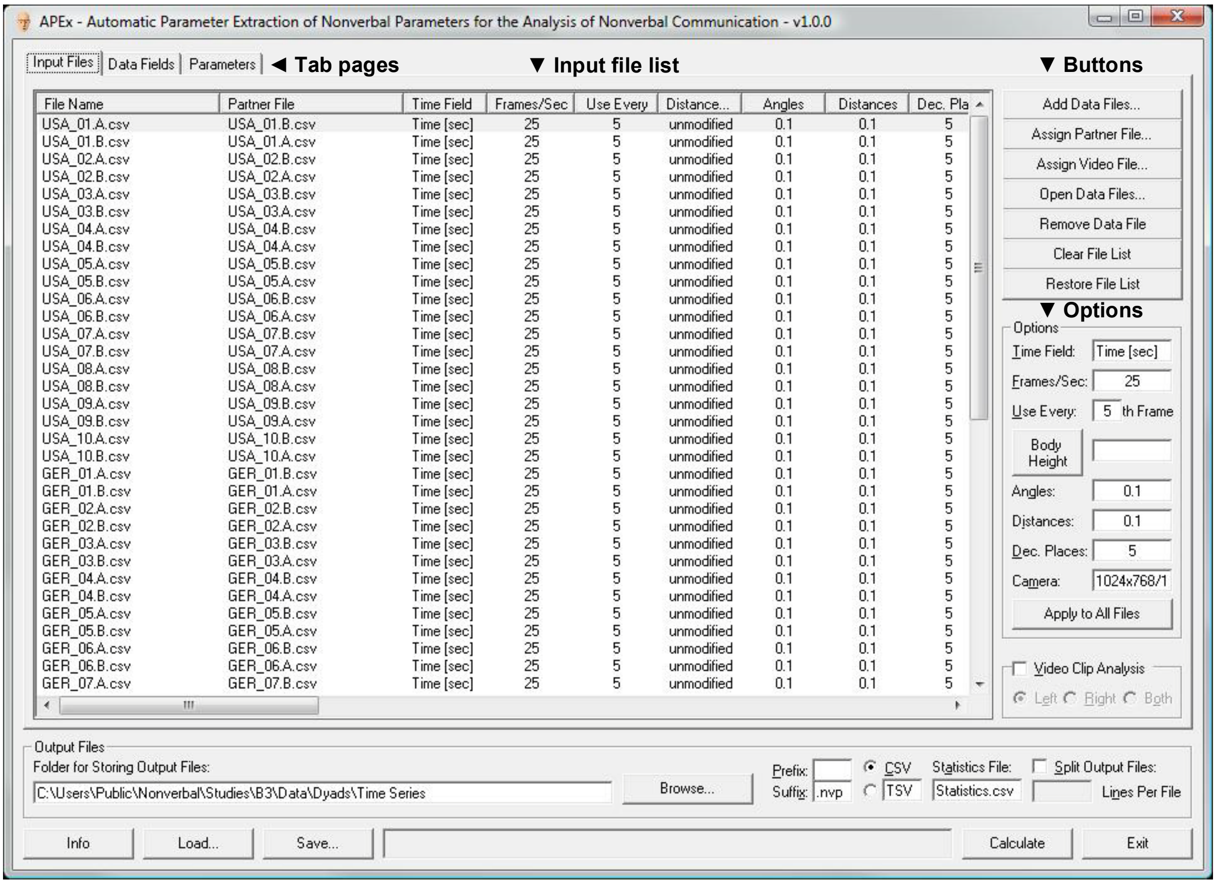


Figure 18. The tab page ‘Input files‘ of APEx’s user interface.

Options. Input file options are available for each input file separately. They are shown in the *input file list* and can be preset before adding one or multiple data files or can be modified after selecting a data file in the *input file list* by changing the values in the input fields on the right side of the window. The following options are available for each input file.

Time Field. This option identifies the name of the first data field in the format line of the input file. If the entered string does not match the first data field name of the format line, APEx will show an error message that it could not find the format line.

Frames/Sec. This option shows the frame rate as 'frames per second' (fps) . The fps value is calculated from the first two data lines while an input file is being added, but can be modified afterwards, if desired. The fps values of the two input files of a dyad must match. Otherwise, APEx shows a message that the files cannot be assigned to each other.

Use Every. This option offers the possibility to adjust the magnitude of the calculated nonverbal parameter values. Very small periods between two frames can reduce the calculated values of dynamic nonverbal parameters to virtually nothing. With this option, it is possible to enhance the period between two time points: 'Use Every 2nd Frame' will omit each 2nd frame.

Body Height. This option specifies the height of the real actor to recalculate all distance measures (*Symmetry*, *Expansion*, *Distance*, *Openness*, *Dyadic Proxemics*, *Translational Complexity*, and *Translational Magnitude*) of the 3D model into the metric of the real person. Entering no value will result in unmodified distance measures. By pressing this button, all distance measures can be alternatively calculated as the percentage of the 3D model body height or its limb length ensuring comparability between differently sized models (see p. 65).

Angles and Distances. For statistical nonverbal parameters, a threshold value is used to filter invisible micro movements not relevant for nonverbal impression formation. This applies to distances as well as angles. All *Complexity*, *Magnitude*, *Activation*, and *Time Spent in Motion parameters* use these threshold values (see p. 43-44); only values greater than the threshold value are taken into account. The recommended default threshold value is 0.1.

Decimal Places. This option specifies the number of decimal places in the output files. APEx calculates internally to 15 decimal places, but for most purposes, it is sufficient to use between two and five decimal places for the output.

Camera. This option lists the camera settings used for *camera-related parameters* (see Table 18, p. 90). The camera settings comprise the values for *width*, *height*, *near plane*, *far plane*, and *field of view*, which can be read from the tab page ‘Camera Settings’ of the navigator window in MotionBuilder, as shown in *Figure 19*. The values are entered in the input field ‘Camera’ in the format: ‘*width* x *height* / *near plan* / *far plane* / *field of view*’. Regarding *Figure 19*, the camera settings should be entered without spaces as ‘1024x768/10/4000/40’.

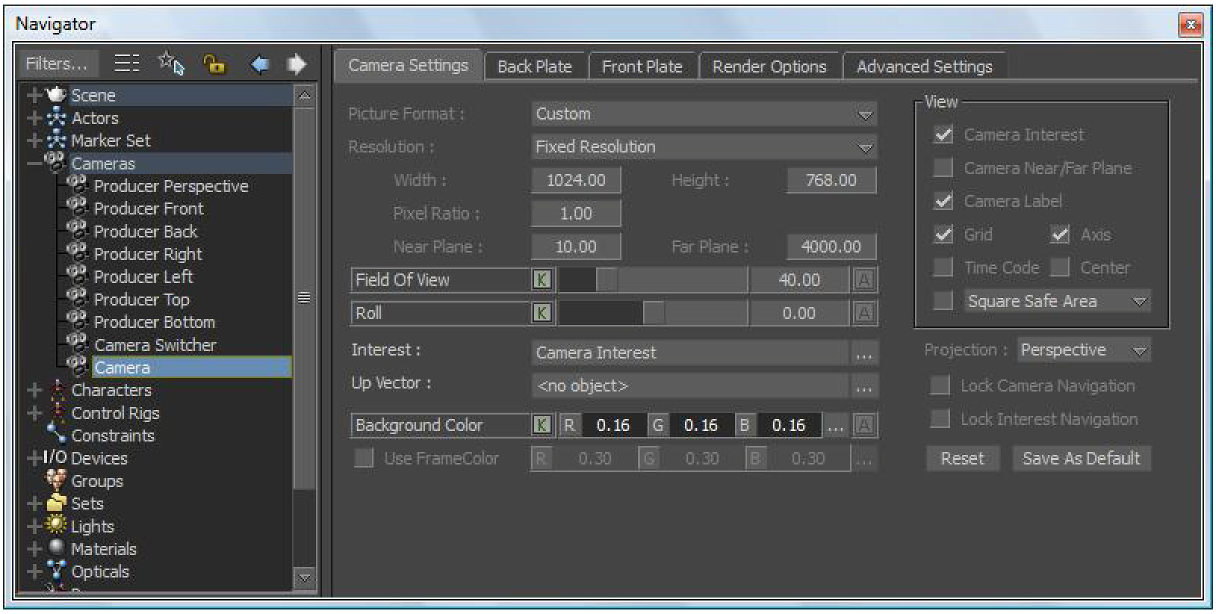


Figure 19. The tab page ‘Camera Settings‘ in the navigator window of MotionBuilder.

Video Clip Analysis. The parameter *Pixel Difference* (p. 89) counts the number of changed pixels between two frames of a video file. By switching the option ‘Video Clip Analysis’ on, a file dialog appears to select a video file for a input file; only AVI files are supported. The option ‘Left Side’ is automatically assigned to input files with the extension ‘.L.*’ or ‘.A.*’, and the option ‘Right Side’ to input files with the extension ‘.R. *’ or ‘.B. *’. In all other cases, the user can choose one of the options ‘Left’, ‘Right’, or ‘Both’ sides.

Buttons. With the buttons of the tab page ‘Input Files’ the content of the *input file list* can be modified by adding and removing input files, or assigning partner and video files. Holding the ‘Ctrl’ key shows the keys associated with the buttons for keyboard control.

Add Data Files. This button opens a file dialog window to add one or more input files to the *input file list*. All selected input files are inspected for a valid format line. If two input file names have the same name with the extensions ‘.L.*’ and ‘.R.*’ (or ‘.A.*’ and ‘.B.*’), they are automatically assigned to each other as partner files. It is necessary that all input files have the same data field names, and that the partner files of a dyad have the same frame rate.

Assign Partner File. This button allows the user to assign a partner file to a selected input file without the need to have same file names with the extensions ‘.L./.R.’ or ‘.A./.B.’.

Assign AVI File. This button offers the same functionality as the option ‘*Video Clip Analysis*’, but allows the user to change the assignment of a video file.

Open Data Files. This button opens a dialog enabling the user to open the input data file, the output data file, and/or the statistics file. APEx transfers the file names to the operating system that launches the programs associated with the extensions of the chosen files.

Remove Data File. This button removes the selected input file.

Clear File List. This button removes all input files from the *input file list*.

Restore File List. This restores the *input file list* loaded automatically at program start.

Apply to All Files. This allows the user to change the options for all files at once.

Tab page ‘Data Fields’. The nonverbal parameters are implemented with a set of base functions that require particular input variables. While the names of the predefined default input variables are fixed (e.g., ‘Head’, ‘Chest’, or ‘Hips’, as listed in Table 19, p. 113), the data field names of the input file are exported from a human 3D model and hence are arbitrary and variable. With the tab page ‘Data Fields’, the variable names of the input data fields can be mapped to the fixed names of the input variables. Moreover, the user can specify a set of user-defined input variables for other 3D model joints (e.g., fingers or eyes).

Default input variables. As shown in *Figure 20*, the joints of the generic human 3D model are underlined; the non-underlined input variables are markers (see *Figure 6*, p. 36, and Table 19, p. 113). Every data field of the input files can be assigned to an input variable by the user choosing its name from the appropriate selection field. If a calculation function relies on the data of an input variable that has not been assigned to a data field, APEx writes error messages into the output files, with the exception of 'Base'. If 'Base' is not specified, the global scene origin of the 3D world is used as 'Base'.

User-defined input variables. The tab page 'Data Fields' offers the user the possibility to specify up to 50 additional input variables by selecting a data field from a selection field within the area of user-defined input variables and uniquely naming the new input variable. *Figure 20* shows two user-defined input variables for the ankles of a human 3D model. A user-defined variable can be removed by deselecting its data field name, i.e., choosing the empty item of the selection field, and can be deleted by removing all characters in its name field.

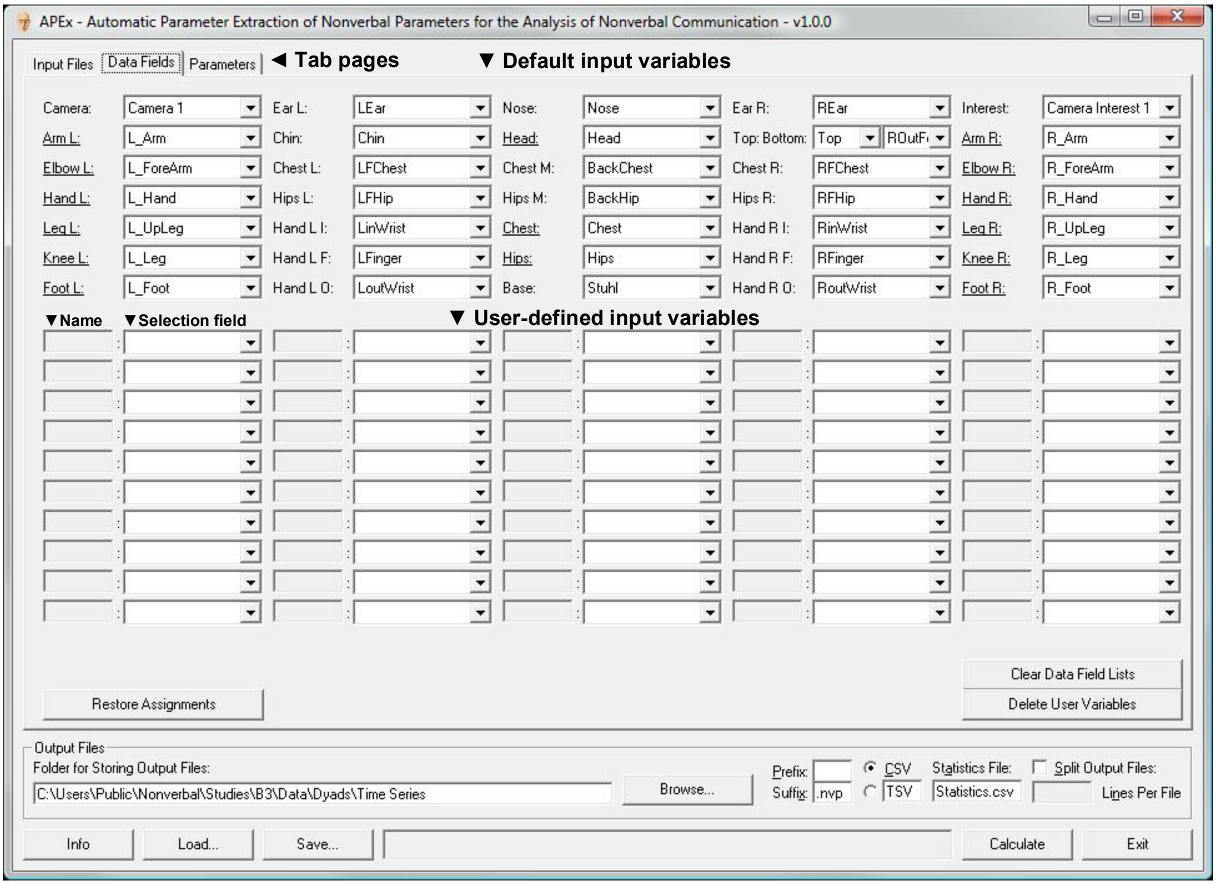


Figure 20. The tab page 'Data fields' of APEx's user interface.

Buttons. The selection fields of the tab page 'Data Fields' collect the data field names of all input files ever read. Before a new project with new input files is set up, the selection fields should be emptied. Furthermore, all user-defined variables can be deleted at once by pressing the appropriate button. Holding the 'Ctrl' key means the keys associated with the buttons are displayed and thus can be used if keyboard control is desired.

Clear Data Field Lists. Use this button to empty all selection fields.

Delete User Variables. Use this button to delete all user-defined variables.

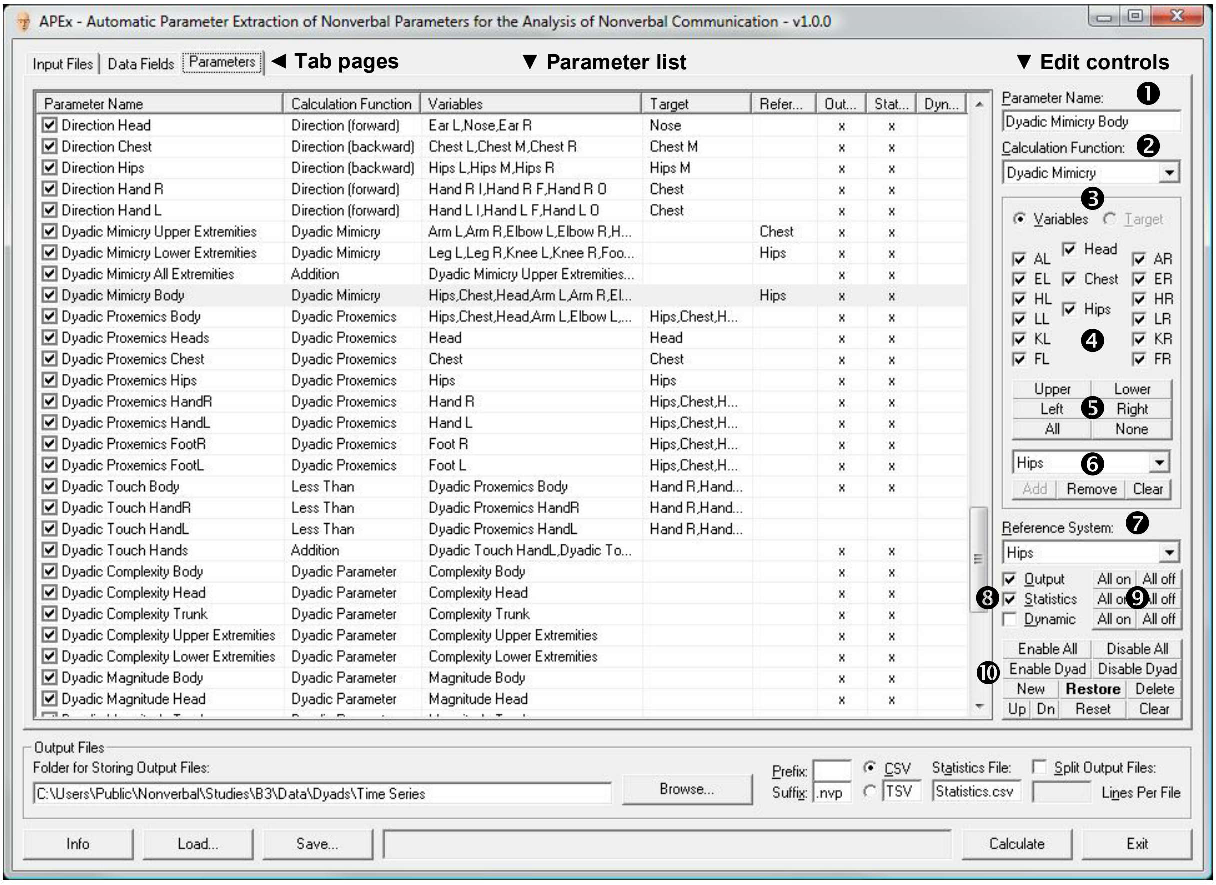


Figure 21. The tab page 'Parameters' of APEx's user interface.

Tab page 'Parameters'. The calculation functions for the nonverbal parameters described in Chapter 4 and Chapter 6 are used in the parameter list of the tab page 'Parameters'. This parameter list defines how APEx processes the data of the input variables that are mapped to the data fields of the input files using the tab 'Data Fields'. By default, this parameter list includes a set of 150 predefined parameters which can be modified and extended.

Parameter list and edit controls. As shown in *Figure 21*, each line of the parameter list represents a nonverbal parameter definition comprising eight items, which can be modified by selecting the definition line in the parameter list and using the edit controls on the right side of the tab page ‘Parameters’. Any changes made with the edit controls have an immediate effect on the definition of the selected nonverbal parameter.

Parameter Name. The ‘Parameter Name’ names the data fields in the output file and can be used as input variable by subsequent nonverbal parameters in the parameter list. The parameter name must be uniquely specified not only for other nonverbal parameters, but also for the input variables defined on the tab page ‘Data Fields’ (see *Figure 21*, symbol ❶).

Calculation function. This identifies the function used to calculate a nonverbal parameter. The calculation function outputs one or more values for each nonverbal parameter and uses the parameter name to name the data fields in the output files; e.g., the nonverbal parameter ‘Static SRL Hips’ outputs the values ‘Static SRL Hips Sagittal’, ‘Static SRL Hips Rotational’, and ‘Static SRL Hips Lateral’ (see ❷).

Variables and Targets. ‘Variables’ and ‘Target’ list the input variables used by calculation functions. Some calculation functions need two different sets of input variables; the second one can be understood as the ‘target’ of a nonverbal behavior. Input variables can be either data fields specified on the tab page ‘Data Fields’ or nonverbal parameters defined previously in the parameter list. If users want to change an input variable specified for a nonverbal parameter, they select the appropriate definition line and pick either ‘Variables’ or ‘Target’ (see ❸). Then they choose the desired input variable from the selection field for input variables (see ❻). If only one input variable can be specified for a calculation function, the selection takes immediate effect. If more than one input variable can be specified, the button ‘Add’ below the selection field can be used to add the chosen input variable to the variable list, and the button ‘Remove’ removes the selected input variable from the variable list. To add and remove the joints of a human 3D model with a single click, check boxes for single joints (see ❹) and buttons for the joints of extremities or body sides (see ❺) can be used. The button 'Clear' removes all input variables from a nonverbal parameter definition (see ❻).

Reference system. This selection specifies the frame of reference needed by the calculation functions *Static SRL*, *Local Dynamic SRL*, *Symmetry*, *Dyadic Mimicry*, and *Coordinate Transformation* (see ❼).

Output. This option specifies whether result values of a calculation function should be written to the output file (see ❽). On the right side, the buttons 'All on' and 'All off' can be used to enable or disable this option for all nonverbal parameters (see ❾).

Statistics. This option specifies whether APEx should calculate statistics on the result values and output them to the statistics file (see ❽). On the right side, the buttons 'All on' and 'All off' can be used to enable or disable this option for all nonverbal parameters (see ❾).

Dynamic. This option specifies whether differences between result values of two consecutive time points should be calculated (see ❽). This option is not available for dynamic calculation functions and works only with the 'Output' or the 'Statistics' option, i.e., the differences of result values will only appear in the output file if the option 'Output' is chosen, and in the statistics file if the option 'Statistics' is chosen. On the right side, the buttons 'All on' and 'All off' can be used to enable or disable this option for all parameters (see ❾).

Enable/Disable All/Dyad. The button 'Enable All' sets the check marks of all nonverbal parameters and hence enables all definitions of nonverbal parameters, and the button 'Disable All' removes the check marks of all nonverbal parameters and disables them. The button 'Enable Dyad' sets the check marks of all parameters involved in dyadic interactions, and the button 'Disable Dyad' removes the check marks of all dyadic parameters (see ❿).

New. The button 'New' allows the user to define a new nonverbal parameter. When this button is clicked, a new entry appears at the end of the parameter list. Before the new nonverbal parameter can be enabled by setting its check mark, a unique name must be given, a calculation function chosen and the input variables specified (see ❿).

Del. This button deletes the selected nonverbal parameter definition (see ➓).

Up/Down. The order of nonverbal parameter definitions in the parameter list matters, because nonverbal parameters serving as input variables for other nonverbal parameters must be defined before them. With the buttons 'Up' and 'Down' each nonverbal parameter can be moved up and down in the parameter list to ensure the correct order of calculations (see ➓).

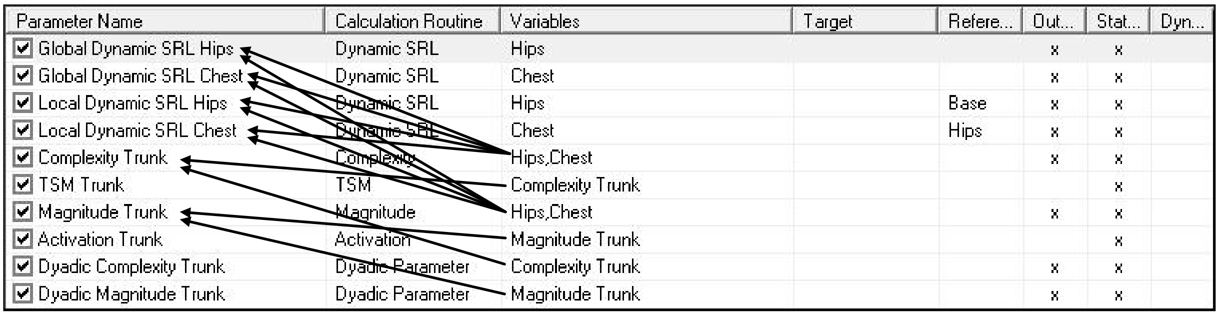
Restore/Reset/Clear. The button 'Restore' restores the parameter list to the nonverbal parameter definitions loaded at program start. The button 'Reset' generates the default parameter list of APEx. The button 'Clear' removes all parameter definitions from the list (see ➓).

Saving, restoring, resetting. Every modification to the parameter list takes immediate effect by overwriting the existing nonverbal parameter definitions. The following strategies are recommended to deal with user mistakes: (1) the user can read the meanings of all buttons by holding the mouse pointer above them for more than one second; (2) the user can restore the set of nonverbal parameters loaded at program start by clicking on 'Restore'; (3) the user can load the default set of nonverbal parameters by clicking on 'Reset'. Furthermore, the following procedures are available to save or drop modifications to the parameter list: (1) the user can save changes to all settings including modifications to the parameter list by leaving APEx and answering 'Yes' to the question about saving the settings; (2) the user can keep the settings loaded at program start including nonverbal parameter definitions by leaving APEx and answering 'No' to the question about saving the settings. Most importantly, the following file operations are available for handling several sets of nonverbal parameter definitions: (1) the user can save all settings together with their own set of nonverbal parameter definitions in a file by clicking on 'Save'; (2) the user can load previously saved settings together with their own set of nonverbal parameter definitions by clicking on 'Load'.

Calculation functions. Table 19 and Table 20 (see Appendix C, p. 113) present detailed information about the implemented set of calculation functions and their input and output variables. In addition, two examples of user-defined nonverbal parameters are given.

Number of variables of the default set. The default set of 150 nonverbal parameters calculates 380 different output variables for each input line and 1,504 different statistical variables for each input file. Enabling the options 'Output' and 'Statistics' for all nonverbal parameters of the default set, APEx will compute 485 different output variables and 1,922 different statistical variables. Additionally, by using the option 'Dynamics' for all nonverbal parameters, APEx will calculate 830 output variables and 3,255 statistical variables.

Dependencies between Parameters. A nonverbal parameter using another nonverbal parameter as input or target variable requires that the used variable should have been previously defined in the list and checked as active. The complexity and activation parameters constitute special cases. They require the *global* as well as the *local dynamic SRL parameters* of all specified body joints. *Figure 22* shows a simplified case with only the hip and chest joints.



Parameter Name	Calculation Routine	Variables	Target	Refere...	Out...	Stat...	Dyn...
Global Dynamic SRL Hips	Dynamic SRL	Hips			x	x	
Global Dynamic SRL Chest	Dynamic SRL	Chest			x	x	
Local Dynamic SRL Hips	Dynamic SRL	Hips		Base	x	x	
Local Dynamic SRL Chest	Dynamic SRL	Chest		Hips	x	x	
Complexity Trunk	Complexity	Hips,Chest			x	x	
TSM Trunk	TSM	Complexity Trunk				x	
Magnitude Trunk	Magnitude	Hips,Chest			x	x	
Activation Trunk	Activation	Magnitude Trunk				x	
Dyadic Complexity Trunk	Dyadic Parameter	Complexity Trunk			x	x	
Dyadic Magnitude Trunk	Dyadic Parameter	Magnitude Trunk			x	x	

Figure 22. Dependencies between nonverbal parameters.

Rule-checking system. A rule-checking system checks the nonverbal parameter definitions of completeness and consistency for each user action. Therefore, the rule-checking system ensures that APEx can calculate each nonverbal parameter. If the user tries to modify the parameter list in an inconsistent way, APEx displays an error message and cancels the modification made by the user. The rule-checking system checks only active nonverbal parameters and can be completely turned off by using the button 'Disable All'. Using the button 'Enable All' means the rule-checking system will proof every nonverbal parameter against rule violations. Rule violations prevent nonverbal parameter definitions from being enabled.

Output Files

User Interface. The frame 'Output Files' is visible under the area of tab pages and allows the user to specify an output folder, output file names, and output file format. In addition, it is possible to activate the processing mode 'Split Output Files'.

Output folder. By entering a path into the input field 'Folder for Storing Output Files' or by clicking on 'Browse…' to select a path, the user can specify the folder for the output and statistics files. If the output folder is identical to the input folder, a prefix or a suffix should be entered for the output file names; otherwise, an error message will be displayed later.

Prefix/Suffix. Output files are named as follows: *Prefix* + *Input file name* + *Suffix*.

CSV/TSV. Comma separated values (CSV) using semicolons as data delimiter or tab separated values (TSV) using the tab character as data delimiter are supported. For the TSV option, an extension can be entered. The selection of the data format applies to all output files. CSV output files will have the extension '.csv', TSV output files the entered extension.

Statistics file. The name of the common statistics file can be entered in this field.

Split output files. Checking this option will activate the split output file processing mode. In this mode, the output file of each input file will be split into multiple output files with a maximum number of lines according to the number which the user entered in the input field 'Lines per File'. For each output file, the means of the nonverbal parameters will be calculated and written in a separate file. The output files names contain the label 'part' and a consecutive number, the mean file name the label 'means'. According to the output files, assigned video files will be cut into corresponding video files. The split output file processing mode may be useful for finding sequences of body movements with certain characteristics.

Output and statistical variables. The output variables in the output files and the statistical variables in the common statistics file are listed in Table 20 (p. 114) with cross references to the sections where the variables are explained.

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Chapter 8: Limitations and Future Directions

The technique of high-performance 3D character animation allows a high degree of independence in the experimental design of stimulus rating studies presenting nonverbal stimuli to observers in order to rate them. In particular, the possibility of rapidly collecting behavioral data with optical motion capture systems allows us more than ever before to integrate encoding and decoding studies in the common framework of lens modeling (Brunswik, 1956). It also allows the researcher to draw inferences about how universals, stereotypes, and constructs shape the sender's nonverbal communication, how the perceiver decodes the stream of nonverbal cues to infer the sender's attitudes, preferences, mental state, and personality trait, and whether perceivers can accurately interpret the relevant cues. The nonverbal parameters developed in this work enhance this research method by allowing the identification of the nonverbal cues responsible for distinct impressions by means of multiple regression analysis with impression as criterion and nonverbal parameters as predictors.

The strength of this approach averaging the stimuli ratings resulting in stronger effects with smaller and controlled random error is its withdraw: A chance of being detected have primarily the cues that dominates movement sequences, whereas the subtle cues could disappear. A possible solution to this dilemma could be the method of Fourier decompositions used by Troje (2002, 2008)—whereas Troje decomposed Cartesian coordinates of point light spots into a structural part and a kinematic part describing group differences, it should now be possible to decompose body postures expressed in flexion angles into a structural and a kinematic part. For instance, the visualization of body posture differences between certain groups could provide animated video clips with body motions using different body postures corresponding to the well-known point light displays, but with the added improvement of displaying different head postures and different hand gestures during specific movement sequences. This approach could be investigated in future along with other possibilities of pattern analyses and recognition relying on time series of body movements measured with the SRL coding system and nonverbal parameters of APEx.

The nonverbal parameters rely solely on data available for the main body joints and some markers. Therefore, APEx detects certain nonverbal cues such as eye contact or touch only by approximation. It can be assumed that touch or eye contact happens when the distance between two body joints falls below a certain cutoff value or the head is directed towards the interlocutor. Future developments could consider additional data sources: using the 3D model surface data would allow detection of collisions between two 3D models much more precisely. Facial and hand gesture capture technology is already available (Busso et al., 2008; Condell & Moore, 2009) and gaze behavior could probably be tracked by optically motion capture systems in future.

Nonverbal communication is multichanneled and context-dependent (Vogeley & Bente, 2010): the same nonverbal cue can express different meanings in relation to the context and nonverbal cues send on other nonverbal channels. Therefore, since research on nonverbal communication relies also on the ability to integrate nonverbal information provided on multiple channels, APEx could be further developed to integrate multiple data channels stemming from various motion, facial, and hand gestures capture systems capturing the other nonverbal channels such as facial expressions, hand gestures, gaze behavior, and probably also vocalics.

Appendix A: Technical Data

Name of executable file:	APEx.exe
Platform:	PC with Windows XP, Vista, 7, or higher
Size:	784 KB (802,816 bytes)
Programming language:	Visual Basic 6
Code:	14,500 program code lines (without blank lines)
Version:	1.0.0
Date of compilation:	04/14/2013
Time of compilation:	14:04 AM
Download location:	www.apex-download.eu
Name of setup file:	APEx-Setup-v1.0.0.exe
Install instructions:	Download and use the setup file to install APEx.

Appendix B: Python Script for Exporting Global Values

```
#*****************************************************************************
# Copyright (C) 2012-2013 Dipl.-Psych. Haug Leuschner, h.leuschner@uni-koeln.de *
#*****************************************************************************
from pyfbsdk import *
import pyfbsdk_additions, os, math
from pyfbsdk_additions import *
gExportGlobalData = "Export Global Data"
gExportDirectory = os.path.expanduser('~')+"\documents"

def ExportGlobalData(control, event):
    global gExportGlobalData
    global gExportDirectory
    lSystem = FBSystem()
    lStartTime = lSystem.SystemTime.GetSecondDouble()
    lModelList = FBModelList()
    lVector = FBVector3d()
    lVectorIndex = 0
    lJointCount = 0
    lFrameCount = 0
    lStep = 0.0
    lTime = 0.0
    lSuccess = True

    ## Check prerequisites
    if FBPlayerControl.IsPlaying == True or \
       FBPlayerControl.IsPlotting == True or \
       FBPlayerControl.IsRecording == True:
       FBMessageBox(gExportGlobalData,"While playing, plotting, or recording, \
                                       this script is not executable.","OK")
    else:
        FBGetSelectedModels(lModelList)
        if len(lModelList) == 0:
            FBMessageBox(gExportGlobalData,\
                             "Please select some joints to export their global data.","OK")
        else:
            ## Prompt file name
            lApp = FBApplication()
            lFileDialog = FBFilePopup()
            lFileDialog.Style = FBFilePopupStyle.kFBFilePopupSave
            lFileDialog.Caption = "Export global data to comma separated values file (CSV)"
            lFileDialog.Path = gExportDirectory
            lFileDialog.FileName = lApp.FBXFileName[:-4] + ' - ' + \
                                   lSystem.CurrentTake.Name + '.AB.csv'
            lFileDialog.Filter = '*.csv'
            if lFileDialog.Execute():
                gExportDirectory = lFileDialog.Path
                ## Check if file exists
                lSuccess = True
                if os.path.exists(lFileDialog.FullFilename) == True:
```

```
        if FBMessageBox(gExportGlobalData,"\nThe file " + lFileDialog.FileName + \
             " already exists.\nDo yout want to overwrite it?", "Yes", "No") == 2:
            lSuccess = False
    if lSuccess == True:
        ## Write variable names
        f = open(lFileDialog.FullFilename, "w")
        line = "Time [sec];Frame"
        for eachJoint in lModelList:
            line +=  ";" + eachJoint.Name + ":Tx;Ty;Tz;Rx;Ry;Rz"
            lJointCount += 1
        f.write(line+'\n')
        ## get frame count and step
        if hasattr(pyfbsdk, 'FBContainer'):
            lFrameNo = FBPlayerControl().ZoomWindowStart.GetFrame(True)
            lFrameStop = FBPlayerControl().ZoomWindowStop.GetFrame(True)
            lTranslation = FBModelTransformationMatrix.kModelTranslation
            lRotation    = FBModelTransformationMatrix.kModelRotation
        else:
            lFrameNo = FBPlayerControl().ZoomWindowStart.GetFrame()
            lFrameStop = FBPlayerControl().ZoomWindowStop.GetFrame()
            lTranslation = FBModelTransformationType.kModelTranslation
            lRotation    = FBModelTransformationType.kModelRotation
        lFrameCount = lFrameStop - lFrameNo + 1
        lStep = 1.0 / FBPlayerControl().GetTransportFpsValue()
        ## Write global data
        lSuccess = True
        lProgressBar = FBProgress()
        lProgressBar.ProgressBegin()
        lProgressBar.Caption = "Exporting global data of selected objects..."
        FBPlayerControl().GotoStart()
        while lSuccess == True and lFrameNo <= lFrameStop:
            line = str(lTime) + ";" + str(lFrameNo)
            for eachJoint in lModelList:
                eachJoint.GetVector(lVector, lTranslation, True)
                if len(lVector) == 3:
                    for lVectorIndex in xrange(3):
                        line += ";" + str(lVector[lVectorIndex])
                else:
                    line += ";;;"
                eachJoint.GetVector(lVector, lRotation, True)
                if len(lVector) == 3:
                    for lVectorIndex in xrange(3):
                        line += ";" + str(lVector[lVectorIndex])
                else:
                    line += ";;;"
            f.write(line+'\n')
            lFrameNo += 1
            lTime += lStep
            lProgressBar.Percent = int(100.0 * float(lFrameNo)/float(lFrameStop))
            lSuccess = FBPlayerControl().StepForward()
            if (lProgressBar.UserRequestCancell()):
                break;
```

```
                    f.close()
                    FBPlayerControl().GotoStart()
                    lProgressBar.Caption = "Export of global data finished."
                    FBMessageBox(gExportGlobalData,"\nData are successfully written to:\n" + \
                      lFileDialog.FileName + "\nNumber of objects: " + str(lJointCount) + \
                      ", number of frames: "+str(lFrameCount)+"\nDuration of data export: "+\
                      str(round(lSystem.SystemTime.GetSecondDouble() - lStartTime, 0)) + \
                      " seconds.","OK")
                    lProgressBar.Percent = 0
                    lProgressBar.ProgressDone()

gDEVELOPMENT = False
if gDEVELOPMENT:
    FBDestroyToolByName(gExportGlobalData)
if gExportGlobalData not in pyfbsdk_additions.FBToolList:
    tool = pyfbsdk_additions.FBCreateUniqueTool(gExportGlobalData)
    tool.StartSizeX = 235
    tool.StartSizeY = 270
    x = FBAddRegionParam(-80,FBAttachType.kFBAttachRight,"")
    y = FBAddRegionParam(-35,FBAttachType.kFBAttachBottom,"")
    w = FBAddRegionParam(70,FBAttachType.kFBAttachNone,"")
    h = FBAddRegionParam(25,FBAttachType.kFBAttachNone,"")
    tool.AddRegion("button","button", x, y, w, h)
    lExportButton = FBButton()
    lExportButton.Caption = "Start"
    lExportButton.Justify = FBTextJustify.kFBTextJustifyCenter
    tool.SetControl("button",lExportButton)
    lExportButton.OnClick.Add(ExportGlobalData)
    x = FBAddRegionParam(5,FBAttachType.kFBAttachLeft,"")
    y = FBAddRegionParam(5,FBAttachType.kFBAttachNone,"")
    w = FBAddRegionParam(220,FBAttachType.kFBAttachNone,"")
    h = FBAddRegionParam(185,FBAttachType.kFBAttachNone,"")
    tool.AddRegion("comment","comment", x, y, w, h)
    lComment = FBHBoxLayout()
    tool.SetControl("comment",lComment)
    lLabel = FBLabel()
    lLabel.WordWrap = True
    lLabel.Caption= gExportGlobalData + \
    " (v1.3)\n(c) 2012-2013 Script by Haug Leuschner\n\nThis script exports global " + \
    "translation and\nrotation data from selected objects into\ncomma-separated values "+ \
    "files (CSV).\n\nYou can leave this window open while\nselecting different objects "+ \
    "and clicking\neach time on 'Start'.\n\nFor dyads, please give one file the "+ \
    "ex-\ntension '.A.csv' (left) and the other one\nthe extension '.B.csv' (right)."
    lComment.Add (lLabel, 240)
else:
    ShowToolByName(gExportGlobalData)
```

Usage: If you copy a text file named ‘ExportGlobalData.py’ containing this script into the subfolder ‘bin\config\PythonStartup’ of MotionBuilder’s installation folder, a menu item ‘Export Global Data’ will be available in the ‘Python Tools’ menu of MotionBuilder.

Appendix C: Calculation Functions and Their Variables

Table 19

Default Input Variable Names and Their Meanings

Default Input Variable Label	Default Input Variable Name	Meaning
Joints		
Base	Base	Object used as base (leave blank or specify object, e.g., chair)
Hips	Hips	Root joint (at the bottom of the hips)
Chest	Chest	Chest joint (at the bottom of the chest)
Head	Head	Head joint (at the bottom of the head)
Arm L	Arm Left	Left shoulder joint
Elbow L	Elbow Left	Left elbow joint
Hand L	Hand Left	Left hand joint
Leg L	Leg Left	Left hip joint
Knee L	Knee Left	Left knee joint
Foot L	Foot Left	Left ankle joint
Arm R	Arm Right	Right shoulder joint
Elbow R	Elbow Right	Right elbow joint
Hand R	Hand Right	Right hand joint
Leg R	Leg Right	Right hip joint
Knee R	Knee Right	Right knee joint
Foot R	Foot Right	Right ankle joint
Markers		
Chin	Chin	Marker at the bottommost point of the head
Top	Top	Marker at the topmost point of the head
Nose	Nose	Marker between the eyes (same height as ears)
Ear R	Ear Right	Marker at the right ear
Ear L	Ear Left	Marker at the left ear
Chest L	Chest Left	Marker at left nipple of chest
Chest M	Chest Middle	Marker at the back (same height as nipples)
Chest R	Chest Right	Marker at right nipple of chest
Hips L	Hips Left	Marker at left hip joint (‘Leg L’)
Hips M	Hips Middle	Marker at the back (same height as hip joints)
Hips R	Hips Right	Marker at right hip joint (‘Leg R’)
Hand L O	Hand Left Outside	Marker at outer side of left wrist
Hand L F	Hand Left Finger	Marker at the top of the left middle finger
Hand L I	Hand Left Inside	Marker at inner side of left wrist
Hand R O	Hand Right Outside	Marker at outer side of right wrist
Hand R F	Hand Right Finger	Marker at the top of the right middle finger
Hand R I	Hand Right Inside	Marker at inner side of right wrist
Camera	Camera	Camera of 3D animation world
Interest	Interest	Interest of camera

Note. The input variable names of human 3D model joints rely more on the body parts being moved than their anatomically notions used with human joints, e.g. the left shoulder joint is named ‘Arm L’ and the right hip joint is named ‘Leg R’.

Table 20

Calculation Functions With Their Input, Output, and Statistical Variables

Calculation function	*Description, tables, and formulas*	*Input variables (min.–max. number)*	*Target variables (min.–max. number)*	*Reference system (min.–max. number)*	*Output variables (in output file)*	*Statistical variables (in statistics file)*
Static SRL	Description p. 27, 37 Equation (4), p. 30 Equation (5)-(7), p. 31	Every input variable, but should be a joint (1–1)	-	Every input variable, usually 'Base' (0–1)	Static SRL Sagittal Static SRL Rotational Static SRL Lateral	M, SD, MIN, and MAX of each output variable
Dynamic SRL (global version)	Description p. 33, 37 Equation (8), p. 34 Equation (5)-(7), p. 31	Every input variable, but should be a joint (1–1)	-	Leave blank (0–0)	Global Dynamic SRL Sagittal Global Dynamic SRL Rotational Global Dynamic SRL Lateral	M, SD, MIN, and MAX of each output variable
Dynamic SRL (local version)	Description p. 35, 37 Equation (9), p. 36 Equation (5)-(7), p. 31	Every input variable, but should be a joint (1–1)	-	Input variable of parent (1–1)	Local Dynamic SRL Sagittal Local Dynamic SRL Rotational Local Dynamic SRL Lateral	M, SD, MIN, and MAX of each output variable
Complexity	Description p. 39, 41 Table 3, p. 43	Each set of input variables with dynamic SRL parameters (both global and local version) (1–n)	-	-	Global Dynamic Complexity Local Dynamic Complexity Translational Complexity Joint Complexity	CBM and CAP of each output variable
TSM	Description p. 40, 41 Table 4, p. 44	Each complexity parameter previously on the list (1–1)	-	-	-	TSM TSM (only A) TSM (only B) TSM (A and B) TSM (A and/or B)
Magnitude	Description p. 40, 41 Table 5, p. 45	Each set of input variables with dynamic SRL parameters (both global and local version) (1-n)	-	-	Global Dynamic Magnitude Local Dynamic Magnitude Translational Magnitude	MBM and MAP of each output variable
Activation	Description p. 40, 41 Table 6, p. 46	Each magnitude parameter previously on the list (1–1)	-	-	-	7 statistical variables, see 'Activation parameters' on p. 40
Symmetry	Description p. 67 Equation (10), p. 64 Equation (11), p. 64 Table 9, p. 66	Every input variable, usually a joint of a extremity (1–1)	Every input variable, usually the appropriate joint of the other body side (1–1)	Every input variable, but should be central, usually chest for upper and hips for lower extremities (1–1)	Symmetry	M, SD, MIN, and MAX of the output variable
Distance	Description p. 68 Equation (12), p. 66 Table 10, p. 66	Every input variable, usually a joint of a extremity (1–1)	Every input variable, usually the corresponding joint of the other body side (1–1)	-	Distance	M, SD, MIN, and MAX of the output variable
Expansion	Description p. 67 Equation (12), p. 66 Table 11, p. 68	Every set of input variables, usually the joints of the trunk (1-n)	Every input variable, usually a joint of a extremity (1–1)	-	Expansion	M, SD, MIN, and MAX of the output variable

Calculation function	*Description, tables, and formulas*	*Input variables (min.–max. number)*	*Target variables (min.–max. number)*	*Reference system (min.–max. number)*	*Output variables (in output file)*	*Statistical variables (in statistics file)*
Folded	Description p. 68 Equation (12), p. 66 Table 12, p. 70	Folded arms: 'Hand L, Elbow L' Folded legs: 'Foot L, Knee L' (*for other values edit registry*)	Folded arms: 'Hand R, Elbow R' Folded legs: 'Foot R, Knee R' (*for other values edit registry*)	-	Folded	M, SD, MIN, and MAX of the output variable
Crossed	Description p. 68 Equation (12), p. 66 Table 12, p. 70	Crossed legs: 'Foot L, Knee L' (*for other values edit registry*)	Crossed legs: 'Foot R, Knee R' (*for other values edit registry*)	-	Crossed	M, SD, MIN, and MAX of the output variable
Openness	Description p. 68 Equation (12), p. 66 Table 12, p. 70	Arms: Distance Elbows & Hands Legs: Distance Knees & Feet (2–2)	Arms: Folded Arms Legs: Folded & Crossed Legs (1–2)	-	Openness	M, SD, MIN, and MAX of the output variable
Direction (forward) Direction (backward)	Description p. 71 Equation (13), p. 72 Equation (14), p. 73 Equation (15), p. 73 Equation (16), p. 74 Table 13, p. 75	Three input variables in the following order: (1) left marker (2) middle marker* (3) right marker	Every input variable, usually nose, chest, or hips **Note: if the middle marker is on the backside, then choose function 'Direction (backward)'!*	-	3D Deviation 2D Deviation Horizontal 2D Deviation Vertical	M, SD, MIN, and MAX of each output variable
Dyadic Proxemics	Description p. 76 Equation (12), p. 66 Table 14, p. 77 Table 15, p. 77	Each set of input variables (1–n)	Each set of input variables (1–n)	-	Dyadic Proxemics	M, SD, MIN, and MAX of the output variable
Dyadic Mimicry	Description p. 40 Equation (5)-(7), p. 31 Equation (8), p. 34 Equation (17), p. 79 Table 16, p. 80	Each set of input variables, should be body joints (1–n)	-	Every input variable, should be chest or hips (0–1)	Dyadic Rotational Mimicry Dyadic Mirror Mimicry	M, SD, MIN, and MAX of each output variable
Dyadic Parameter	Description p. 81 Table 17, p. 82	Each nonverbal parameter previously on the list	-	-	*For each output variable of the selected parameter:* Common Expression A and B Percentage contribution of A Net Contribution of A Net Percentage Contribution of A	M, SD, MIN, and MAX of each output variable
Camera Framing	Description p. 83 Equation (18)-(22), p. 86 Equation (23), p. 86	Every input variable, usually top of head (1–1)	Every input variable, usually bottom of head (1–1)	-	Camera Framing	M, SD, MIN, and MAX of the output variable
Camera Proxemics	Description p. 88 Equation (18)-(22), p. 86 Equation (24), p. 88	Every input variable, usually top of head (1–1)	Every input variable, usually bottom of head (1–1)	-	Camera Proxemics	M, SD, MIN, and MAX of the output variable
Pixel Difference	Description p. 89 Equation (25), p. 89	-	-	-	Pixel Difference	MBM and MAP of the output variable

Calculation function	*Description, tables, and formulas*	*Input variables (min.–max. number)*	*Target variables (min.–max. number)*	*Reference system (min.–max. number)*	*Output variables (in output file)*	*Statistical variables (in statistics file)*
Less Than	Returns 1, if nonverbal parameter is less than number or distance	Each nonverbal parameter previously on the list (1–1)	Choose "(Enter number)" or choose two joints meaning the distance between them	-	*For each output variable of the selected parameter:* Label + "Less Than" + Target	M, SD, MIN, and MAX of each output variable
Greater Than	Returns 1, if nonverbal parameter is greater than number or distance	Each nonverbal parameter previously on the list (1–1)	Choose "(Enter number)" or choose two joints meaning the distance between them	-	*For each output variable of the selected parameter:* Label + "Greater Than" + Target	M, SD, MIN, and MAX of each output variable
Addition	Sum of parameters	List of nonverbal parameters previously on the list (1–n)	-	-	*For each output variable of the selected parameters:* Label + "plus" + Label + …	M, SD, MIN, and MAX of each output variable
Subtraction	Difference of parameters	List of nonverbal parameters previously on the list (1–n)	Nonverbal parameter, from which each parameter of the variable list is subtracted (1–1)	-	*For each output variable of the selected parameters:* Target + "minus" + Label + …	M, SD, MIN, and MAX of each output variable
Multiplication	Product of parameters	List of nonverbal parameters each calculated previously (1–n)	-	-	*For each output variable of the selected parameters:* Label + "times" + Label + …	M, SD, MIN, and MAX of each output variable
Division	Quotient of parameters	List of nonverbal parameters each calculated previously (1–n)	Nonverbal parameter, which is successively divided by the parameters of the list (1–1)	-	*For each output variable of the selected parameters:* Target + "by" + Label + …	M, SD, MIN, and MAX of each output variable
Absolute Value	Absolute value of nonverbal parameter	Each nonverbal parameter previously on the list (1–1)	-	-	*For each output variable of the selected parameter:* Label + "(Absolute Value)"	M, SD, MIN, and MAX of each output variable
Dynamic Parameter	Difference of a value to the value of the previous time point	Each nonverbal parameter previously on the list (1–1)	-	-	*For each output variable of the selected parameter:* Label + "(Dynamic)"	M, SD, MIN, and MAX of each output variable
Coord. Transf.	Coordinate transformation of joint data	Every input variable (1–1)	*Note: Can also be used to load data, leave "Reference" blank.*	Every input variable (1–1)	TransX, TransY, TransZ, RotX, RotY, RotZ	M, SD, MIN, and MAX of each output variable

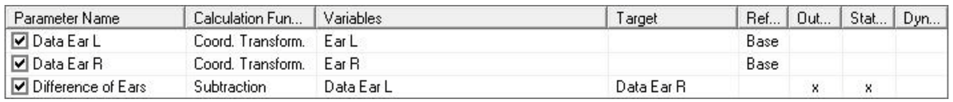
Appendix D: Examples of User-Defined Nonverbal Parameters

Arms-Akimbo Posture

Parameter Name	Calculation Fun...	Variables	Target	Ref...	Out...	Stat...	Dyn...
☑ Distance Hand-Leg R	Distance	Hand R	Leg R				
☑ Distance Hand-Leg L	Distance	Hand L	Leg L				
☑ Distance Hands to Hips	Addition	Distance Hand-Leg R,Distance Hand-Leg L					
☑ Arms-Akimbo	Less Than	Distance Hands to Hips	Hand R,Hand R F		x	x	

Figure 23. Settings for a user-defined parameter 'Arms-Akimbo'.

Height Difference of Ears



Parameter Name	Calculation Fun...	Variables	Target	Ref...	Out...	Stat...	Dyn...
☑ Data Ear L	Coord. Transform.	Ear L		Base			
☑ Data Ear R	Coord. Transform.	Ear R		Base			
☑ Difference of Ears	Subtraction	Data Ear L	Data Ear R		x	x	

Figure 24. Settings for a user-defined parameter 'Ear height difference'.

References

Abelson, R. P., & Sermat, V. (1962). Multidimensional scaling of facial expressions. *Journal of Experimental Psychology, 63*(6), 546–554. doi: 10.1037/h0042280

Ada, M. S., Suda, K., & Ishii, M. (2003). Expression of emotions in dance: Relation between arm movement characteristics and emotion. *Perceptual and motor skills, 97*(3), 697–708. doi: 10.2466/pms.2003.97.3.697

Agunis, H., Simonsen, M. M., & Pierce, C. A. (1998). Effects of nonverbal behavior on perceptions of power bases. *Journal of Social Psychology, 138*(4), 455–469.

Aiello, J. R. (1987). Human spatial behavior. In D. Stokols & I. Altman (Eds.), *Handbook of environmental psychology* (Vol. 1, pp. 389–504). New York, NY: John Wiley & Sons.

Andersen, P. A. (2008). *Nonverbal communication: Forms and functions*. Long Grove, IL: Waveland Press.

Andersen, P. A., Garrison, J. P., & Andersen, J. F. (1979). Implications of a neurophysiological approach for the study of nonverbal communication. *Human Communication Research, 6*(1), 74–89. doi: 10.1111/j.1468-2958.1979.tb00293.x

Argyle, M. (1975). *Bodily communication*. Oxford, UK: International Universities Press.

Argyle, M. (1988). *Bodily communication* (2nd ed.). New York, NY: Methuen & Co.

Atkinson, A. P., Dittrich, W. H., Gemmell, A. J., & Young, A. W. (2004). Emotion perception from dynamic and static body expressions in point-light and full-light displays. *Perception, 33*(6), 717–746. doi: 10.1068/p5096

Bales, R. F. (2000). Social interaction systems: Theory and measurement: Book review. *Group Dynamics: Theory, Research, and Practice, 4*(2), 199–208. doi: 10.1037/1089-2699.4.2.199

Bammes, G. (1994). *The artist's guide to human anatomy: An illustrated reference to drawing humans including work by amateur artists, art teachers and students*. Edison, NJ:

Chartwell Books.

Bandura, A. (1962). Social learning through imitation. In M. R. Jones (Ed.), *Nebraska symposium on motivation* (pp. 211–274). Oxford, UK: University Nebraska Press.

Barclay, C. D., Cutting, J. E., & Kozlowski, L. T. (1978). Temporal and spatial factors in gait perception that influence gender recognition. *Perception & Psychophysics, 23*(2), 145–152.

Barliya, A., Omlor, L., Giese, M., Berthoz, A., & Flash, T. (2013). Expression of emotion in the kinematics of locomotion. *Experimental Brain Research, 225*(2), 159–176. doi: 10.1007/s00221-012-3357-4

Bavelas, J. B., Black, A., Chovil, N., & Lemery, C. R. (1988). Form and function in motor mimicry: Topographic evidence that the primary function is communicative. *Human Communication Research, 14*(3), 275–299. doi: 10.1111/j.1468-2958.1988.tb00158.x

Bavelas, J. B., Black, A., Lemery, C. R., & Mullett, J. (1986). 'I show how you feel': Motor mimicry as a communicative act. *Journal of Personality and Social Psychology, 50*(2), 322–329. doi: 10.1037/0022-3514.50.2.322

Bavelas, J. B., Black, A., Lemery, C. R., & Mullett, J. (1987). Motor mimicry as primitive empathy. In N. Eisenberg & J. Strayer (Eds.), *Empathy and its development.* (pp. 317–338). New York, NY: Cambridge University Press.

Bavelas, J. B., & Chovil, N. (1997). Faces in dialogue. In J. A. Russel & J. M. Fernández-Dols (Eds.), *The psychology of facial expressions*. Cambridge, UK: Cambridge University Press.

Bavelas, J. B., & Chovil, N. (2000). Visible acts of meaning: An integrated message model of language in face-to-face dialogue. *Journal of Language and Social Psychology, 19*(2), 163–194. doi: 10.1177/0261927x00019002001

Bavelas, J. B., & Chovil, N. (2006). Nonverbal and verbal communication: Hand gestures and facial displays as part of language use in face-to-face dialogue. In V. L. Manusov &

M. L. Patterson (Eds.), *Handbook of nonverbal communication* (pp. 97–115). Thousand Oaks, CA: Sage.

Beck, R. S., Daughtridge, R., & Sloane, P. D. (2002). Physician-patient communication in the primary care office: A systematic review. *The Journal of the American Board of Family Medicine, 15*(1), 25.

Becker, C., Kopp, S., & Wachsmuth, I. (2004). Simulating the emotion dynamics of a multimodal conversational agent. *Affective Dialogue Systems*, 154–165.

Becker, C., Kopp, S., & Wachsmuth, I. (2007). Why emotions should be integrated into conversational agents. In T. Nishida (Ed.), *Conversational informatics: An engineering approach* (pp. 49-68). Chichester, UK: John Wiley & Sons.

Benesh, R., & Benesh, J. (1983). *Reading dance: The birth of choreography*. New York, NY: McGraw-Hill.

Bente, G. (1989). Facilities for the graphical computer simulation of head and body movements. *Behavior Research Methods, Instruments & Computers, 21*(4), 455–462.

Bente, G., Donaghy, W. C., & Suwelack, D. (1998). Sex differences in body movement and visual attention: An integrated analysis of movement and gaze in mixed-sex dyads. *Journal of Nonverbal Behavior, 22*(1), 31–58.

Bente, G., Feist, A., & Elder, S. (1996). Person perception effects of computer-simulated male and female head movement. *Journal of Nonverbal Behavior, 20*(4), 213–228.

Bente, G., & Krämer, N. C. (2004). Inhaltsanalyse medialer Angebote. In R. Mangold, P. Vorderer & G. Bente (Eds.), *Lehrbuch der Medienpsychologie* (pp. 201–228). Göttingen: Hogrefe.

Bente, G., Krämer, N. C., Petersen, A., & de Ruiter, J. P. (2001). Computer animated movement and person perception: Methodological advances in nonverbal behavior research. *Journal of Nonverbal Behavior, 25*(3), 151–166.

Bente, G., Leuschner, H., Al Issa, A., & Blascovich, J. J. (2010). The others: Universals and cultural specificities in the perception of status and dominance from nonverbal behavior. *Consciousness and Cognition: An International Journal, 19*(3), 762–777. doi: 10.1016/j.concog.2010.06.006

Bente, G., Petersen, A., Krämer, N. C., & De Ruiter, J. P. (2001). Transcript-based computer animation of movement: Evaluating a new tool for nonverbal behavior research. *Behavior Research Methods, Instruments, & Computers, 33*(3), 303–310.

Bente, G., Senokozlieva, M., Pennig, S., Al-Issa, A., & Fischer, O. (2008). Deciphering the secret code: A new methodology for the cross-cultural analysis of nonverbal behavior. *Behavior Research Methods, 40*(1), 269–277.

Bentler, P. M. (1969). Semantic space is (approximately) bipolar. *Journal of Psychology: Interdisciplinary and Applied, 71*(1), 33–40.

Berlo, D. K. (1960). *The process of communication*. New York, NY: Holt, Rinehart, & Winston.

Bernieri, F. J., & Rosenthal, R. (1991). Interpersonal coordination: Behavior matching and interactional synchrony. In R. S. Feldman & B. Rimé (Eds.), *Fundamentals of nonverbal behavior* (pp. 401–432). New York, NY: Cambridge University Press.

Berry, D. S., Kean, K. J., Misovich, S. J., & Baron, R. M. (1991). Quantized displays of human movement: A methodological alternative to the point-light display. *Journal of Nonverbal Behavior, 15*(2), 81–97.

Bicho, E., Louro, L., & Erlhagen, W. (2010). Integrating verbal and nonverbal communication in a dynamic neural field architecture for human-robot interaction. *Frontiers in Neurorobotics, 4*(5). doi: 10.3389/fnbot.2010.00005

Birdwhistell, R. L. (1952). *Introduction to kinesics*. Louisville, KY: University of Louisville.

Birdwhistell, R. L. (1970). *Kinesics and context*. Philadelphia: University of Pennsylvania.

Blumenthal, A. L. (1975). A reappraisal of Wilhelm Wundt. *American Psychologist, 30*(11), 1081–1088.

Brownlow, S., Dixon, A. R., Egbert, C. A., & Radcliffe, R. D. (1997). Perception of movement and dancer characteristics from point-light displays of dance. *The Psychological Record, 47*(3), 411–421.

Brunswik, E. (1956). *Perception and the representative design of psychological experiments*. Berkeley and Los Angeles, CA: University of California Press.

Burgoon, J. K. (1980). Nonverbal communication research in the 1970s: An overview. In D. Nimmo (Ed.), Communication Yearbook 4: An annual review by the International Communication Association (pp. 179–197). New Brunswick, NJ: Transaction Books.

Burgoon, J. K. (1985). Nonverbal signals. In L. Knapp & G. R. Miller (Eds.), *Handbook of interpersonal communication* (1st ed., pp. 344–390). Beverly Hills, CA: Sage.

Burgoon, J. K. (1991). Relational message interpretations of touch, conversational distance, and posture. *Journal of Nonverbal Behavior, 15*(4), 233–259. doi: 10.1007/bf00986924

Burgoon, J. K. (1994). Nonverbal signals. In L. Knapp & G. R. Miller (Eds.), *Handbook of interpersonal communication* (2nd ed., pp. 229–285). Thousand Oakes, CA: Sage.

Burgoon, J. K., Birk, T., & Pfau, M. (1990). Nonverbal behaviors, persuasion, and credibility. *Human Communication Research, 17*(1), 140–169. doi: 10.1111/j.1468-2958.1990.tb00229.x

Burgoon, J. K., Buller, D. B., Hale, J. L., & DeTurck, M. A. (1984). Relational messages associated with nonverbal behaviors. *Human Communication Research, 10*(3), 351–378. doi: 10.1111/j.1468-2958.1984.tb00023.x

Burgoon, J. K., Buller, D. B., & Woodall, W. G. (1989). *Nonverbal communication: The unspoken dialogue* (1st ed.). New York, NY: Harper & Row.

Burgoon, J. K., Buller, D. B., & Woodall, W. G. (1996). *Nonverbal communication: The unspoken dialogue* (2nd ed.). New York, NY: McGraw-Hill.

Burgoon, J. K., Guerrero, L. K., & Floyd, K. (2010). *Nonverbal communication*. Boston, MA:

Allyn & Bacon.

Burgoon, J. K., & Hoobler, G. D. (2002). Nonverbal signals. In M. L. Knapp & J. Daly (Eds.), *Handbook of interpersonal communication* (3rd ed., pp. 240–299). Thousand Oaks, CA Sage.

Burgoon, J. K., Humpherys, S., & Moffitt, K. (2008). 46. Nonverbal communication: Research areas and approaches. In U. Fix, A. Gardt & J. Knape (Eds.), *Rhetoric and Stylistics* (Vol. 1, pp. 787–812). New York, NY: Mouton de Gruyter.

Burgoon, J. K., Johnson, M. L., & Koch, P. T. (1998). The nature and measurement of interpersonal dominance. *Communication Monographs, 65*(4), 308–335. doi: 10.1080/03637759809376456

Burgoon, J. K., & Newton, D. A. (1991). Applying a social meaning model to relational message interpretations of conversational involvement: Comparing observer and participant perspectives. *Southern Communication Journal, 56*(2), 96–113. doi: 10.1080/10417949109372822

Burgoon, J. K., Stern, L. A., & Dillman, L. (1995). *Interpersonal adaptation: Dyadic interaction patterns*. New York, NY: Cambridge University Press.

Buss, S. R. (2003). *3-D computer graphics: A mathematical introduction with OpenGL*. New York, NY: Cambridge University Press.

Busso, C., Bulut, M., Lee, C.-C., Kazemzadeh, A., Mower, E., Kim, S., . . . Narayanan, S. S. (2008). IEMOCAP: Interactive emotional dyadic motion capture database. *Language Resources & Evaluation, 42*(4), 335–359. doi: 10.1007/s10579-008-9076-6

Carney, D. R., Hall, J. A., & LeBeau, L. S. (2005). Beliefs about the nonverbal expression of social power. *Journal of Nonverbal Behavior, 29*(2), 105–123. doi: 10.1007/s10919-005-2743-z

Castelli, L., Carraro, L., Pavan, G., Murelli, E., & Carraro, A. (2012). The power of the unsaid: The influence of nonverbal cues on implicit attitudes. *Journal of Applied*

Social Psychology, 42(6), 1376–1393. doi: 10.1111/j.1559-1816.2012.00903.x

Chartrand, T. L., & Baaren, R. v. (2009). Human mimicry. *Advances in Experimental Social Psychology, 41*, 219–274.

Chartrand, T. L., & Bargh, J. A. (1999). The chameleon effect: The perception–behavior link and social interaction. *Journal of Personality and Social Psychology, 76*(6), 893–910. doi: 10.1037/0022-3514.76.6.893

Chartrand, T. L., & Dalton, A. N. (2009). Mimicry: Its ubiquity, importance, and functionality. In E. Morsella, J. A. Bargh & P. M. Gollwitzer (Eds.), *Oxford handbook of human action* (pp. 458–483). New York, NY: Oxford University Press.

Choi, V. S., Gray, H. M., & Ambady, N. (2005). The glimpsed world: Unintended communication and unintended perception. In R. R. Hassin, J. S. Uleman & J. A. Bargh (Eds.), *The new unconscious* (pp. 309–333). New York, NY: Oxford University Press.

Chouchourelou, A., Matsuka, T., Harber, K., & Shiffrar, M. (2006). The visual analysis of emotional actions. *Social Neuroscience, 1*(1), 63–74. doi: 10.1080/17470910600630599

Cohn, J. F., & Ekman, P. (2006). Measuring facial action. In J. A. Harrigan, R. Rosenthal & K. R. Scherer (Eds.), *The new handbook of methods in nonverbal behavior research* (pp. 9–64). New York, NY: Oxford University Press.

Coker, D. A., & Burgoon, J. K. (1987). The nature of conversational involvement and nonverbal encoding patterns. *Human Communication Research, 13*(4), 463–494. doi: 10.1111/j.1468-2958.1987.tb00115.x

Condell, J., & Moore, G. (2009). Handpuppet3D: Motion capture and analysis for character animation. *Artificial Intelligence Review, 31*(1–4), 45–59. doi: 10.1007/s10462-009-9126-5

Cook, T. D., Shadish, W. R., & Campbell, D. T. (2002). *Experimental and quasi-experimen-*

tal designs for generalized causal inference. Boston, MA: Houghton Mifflin.

Coutts, L. M., Schneider, F. W., & Montgomery, S. (1980). An investigation of the arousal model of interpersonal intimacy. *Journal of Experimental Social Psychology, 16*(6), 545–561. doi: 10.1016/0022-1031(80)90057-8

Crane, E., & Gross, M. (2007). Motion capture and emotion: Affect detection in whole body movement. In A. R. Paiva, R. Prada & R. Picard (Eds.), *Affective computing and intelligent interaction* (Vol. 4738, pp. 95–101). Berlin, Germany: Springer.

Cutting, J. E., & Kozlowski, L. T. (1977). Recognizing friends by their walk: Gait perception without familiarity cues. *Bulletin of the Psychonomic Society, 9*(5), 353–356.

Cutting, J. E., & Proffitt, D. R. (1981). Gait perception as an example of how we may perceive events. In R. D. Walk & H. L. Pick (Eds.), *Intersensory perception and sensory integration* (pp. 249–273). New York, NY: Plenum.

Cutting, J. E., Proffitt, D. R., & Kozlowski, L. T. (1978). A biomechanical invariant for gait perception. *Journal of Experimental Psychology: Human Perception and Performance, 4*(3), 357–372. doi: 10.1037/0096-1523.4.3.357

Darwin, C. (1872). *The expression of the emotions in man and animals*. New York, NY: D. Appleton and Company.

Das, S. R., Lazarewicz, M. T., Wilson, R. C., & Finkel, L. H. (2009). Sensitivity to motion features in point light displays of biological motion. *Spatial Vision, 22*(2), 105–125. doi: 10.1163/156856809787465627

Decety, J., & Sommerville, J. A. (2009). Action representation as the bedrock of social cognition: A developmental neuroscience perspective. In E. Morsella, J. A. Bargh & P. M. Gollwitzer (Eds.), *Oxford handbook of human action* (pp. 250–282). New York, NY: Oxford University Press.

DePaulo, B. M., & Friedmann, H. S. (1998). Nonverbal communication. In D. T. Gilbert, S. T. Fiske & G. Lindzey (Eds.), *The handbook of social psychology* (4th ed., Vol. 2, pp.

3–40). Boston, MA: McGraw-Hill.

Dimberg, U., Thunberg, M., & Elmehed, K. (2000). Unconscious facial reactions to emotional facial expressions. *Psychological Science, 11*(1), 86–89. doi: 10.1111/1467-9280.00221

Donaghy, W. C. (1989). Nonverbal communication measurement. In P. Emmert & L. Barker (Eds.), *Measurement of communication behavior* (pp. 296–332). White Plains, NY: Longman.

Dorland, W. (2011). *Dorland's illustrated medical dictionary* (32nd ed.). New York, NY: Elsevier.

Dovidio, J. F., & Ellyson, S. L. (1982). Decoding visual dominance: Attributions of power based on relative percentages of looking while speaking and looking while listening. *Social Psychology Quarterly, 45*(2), 106–113. doi: 10.2307/3033933

Dovidio, J. F., Ellyson, S. L., Keating, C. F., Heltman, K., & Brown, C. E. (1988). The relationship of social power to visual displays of dominance between men and women. *Journal of Personality and Social Psychology, 54*(2), 233–242.

Duffy, E. (1951). The concept of energy mobilization. *Psychological Review, 58*(1), 30–40. doi: 10.1037/h0054220

Dunbar, N. E. (2004). Theory in progress: Dyadic power theory: Constructing a communication-based theory of relational power. *Journal of Family Communication, 4*(3/4), 235–248. doi: 10.1080/15267431.2004.9670133

Dunbar, N. E., & Burgoon, J. K. (2005). Measuring nonverbal dominance. In V. Manusov (Ed.), *The sourcebook of nonverbal measures - going beyond words*. Mahwah, NY: Lawrence Erlbaum Associates.

Edinger, J. A., & Patterson, M. L. (1983). Nonverbal involvement and social control. *Psychological Bulletin, 93*(1), 30–56. doi: 10.1037/0033-2909.93.1.30

Efron, D. (1941). *Gesture and environment*. New York, NY: King's Crown Press.

Eibl-Eibesfeldt, I. (1975). *Ethology: The biology of human behavior*. New York, NY: Holt, Rinehart & Winston.

Ekman, P. (1973). *Darwin and facial expression: A century of research in review*. Oxford, UK: Academic Press.

Ekman, P. (1979). About brows: Emotional and conversational signals. In M. v. Cranach, K. Foppa, W. Lepenies & D. Ploog (Eds.), *Human ethology* (pp. 169–248). Cambridge, UK: Cambridge University Press.

Ekman, P. (2003a). Emotions inside out: 130 Years after Darwin's "The Expression of the Emotions in Man and Animal". *Annals of the New York Academy of Sciences, 1000*, 1–6.

Ekman, P. (2003b). *Emotions revealed: Recognizing faces and feelings to improve communication and emotional life*. New York, NY: Times Books.

Ekman, P., & Friesen, W. V. (1969). The repertoire of nonverbal behavior: Categories, origins, usage, and coding. *Semiotica, 1*(1), 49–98.

Ekman, P., & Friesen, W. V. (1971). Constants across cultures in the face and emotion. *Journal of Personality and Social Psychology, 17*(2), 124–129. doi: 10.1037/h0030377

Ekman, P., & Friesen, W. V. (1975). *Unmasking the face: A guide to recognizing emotions from facial clues*. Upper Saddle River, NJ: Prentice-Hall.

Ekman, P., Friesen, W. V., & Ellsworth, P. C. (1972). *Emotion in the human face*. New York, NY: Pergamon Press.

Ekman, P., Friesen, W. V., O'Sullivan, M., Chan, A., Diacoyanni-Tarlatzis, I., Heider, K., . . . Tzavaras, A. (1987). Universals and cultural differences in the judgments of facial expressions of emotion. *Journal of Personality and Social Psychology, 53*(4), 712–717. doi: 10.1037/0022-3514.53.4.712

Ekman, P., Sorenson, E. R., & Friesen, W. V. (1969). Pan-cultural elements in facial displays of emotion. *Science, 164*(3875), 86–88. doi: 10.1126/science.164.3875.86

Elfenbein, H. A., & Ambady, N. (2002a). Is there an in-group advantage in emotion recognition? *Psychological Bulletin, 128*(2), 243–249.

Elfenbein, H. A., & Ambady, N. (2002b). On the universality and cultural specificity of emotion recognition: A meta-analysis. *Psychological Bulletin, 128*(2), 203–235. doi: 10.1037/0033-2909.128.2.203

Elfenbein, H. A., & Ambady, N. (2003). When familiarity breeds accuracy: Cultural exposure and facial emotion recognition. *Journal of Personality and Social Psychology, 85*(2), 276–290. doi: 10.1037/0022-3514.85.2.276

Engen, T., Levy, N., & Schlosberg, H. (1957). A new series of facial expressions. *American Psychologist, 12*(5), 264–266. doi: 10.1037/h0049283

Engen, T., Levy, N., & Schlosberg, H. (1958). The dimensional analysis of a new series of facial expressions. *Journal of Experimental Psychology, 55*(5), 454–458. doi: 10.1037/h0047240

Eshkol, N., & Wachmann, A. (1958). *Movement notation*. London, UK: Weidenfeld and Nicolson.

Esposito, G., Venuti, P., Maestro, S., & Muratori, F. (2009). An exploration of symmetry in early autism spectrum disorders: Analysis of lying. *Brain and Development, 31*(2), 131–138.

Feldman, L. A. (1995). Valence focus and arousal focus: Individual differences in the structure of affective experience. *Journal of Personality and Social Psychology, 69*(1), 153–166. doi: 10.1037/0022-3514.69.1.153

Feleky, A. M. (1914). The expression of the emotions. *Psychological Review, 21*(1), 33–41. doi: 10.1037/h0076058

Fisch, H.-U., Frey, S., & Hirsbrunner, H.-P. (1983). Analyzing nonverbal behavior in depression. *Journal of Abnormal Psychology, 92*(3), 307–318.

Fontaine, J. R. J., Scherer, K. R., Roesch, E. B., & Ellsworth, P. C. (2007). The world of emotions is not two-dimensional. *Psychological Science (Wiley-Blackwell), 18*(12), 1050–1057. doi: 10.1111/j.1467-9280.2007.02024.x

Frey, S., Hirsbrunner, H.-P., Florin, A., Daw, W., & Crawford, R. (1983). A unified approach to the investigation of nonverbal and verbal behavior in communication research. In W. Doise & S. Moscovici (Eds.), *Current issues in European social psychology* (pp. 143–199). Cambridge, UK: Cambridge University Press.

Frey, S., & Pool, J. (1976). *A new approach to the analysis of visible behavior*. Bern, Switzerland: University of Bern, Department of Psychology.

Frois-Wittman, J. (1930). The judgment of facial expression. *Journal of Experimental Psychology, 13*(2), 113–151. doi: 10.1037/h0070158

Galati, D., Scherer, K. R., & Ricci-Bitti, P. E. (1997). Voluntary facial expression of emotion: Comparing congenitally blind with normally sighted encoders. *Journal of Personality and Social Psychology, 73*(6), 1363–1379. doi: 10.1037/0022-3514.73.6.1363

Goffman, E. (1961). *Encounters: Two studies in the sociology of interaction*. Oxford, UK: Bobbs-Merrill.

Golani, I., Zeidel, S., & Eshkol, N. (1969). *The golden jackal*. Tel Aviv, Israel: The Movement Notation Society.

Grammer, K., Filova, V., & Fieder, M. (1997). The communication paradox and possible solutions: Toward a radical empiricism. In A. Schmitt, K. Atzwanger, K. Grammer & K. Schäfer (Eds.), *New aspects of human ethology* (pp. 91–120). New York, NY: Plenum.

Grammer, K., Honda, M., Juette, A., & Schmitt, A. (1999). Fuzziness of nonverbal courtship communication unblurred by motion energy detection. *Journal of Personality and Social Psychology, 77*(3), 487–508.

Gross, M., Crane, E., & Fredrickson, B. (2010). Methodology for assessing bodily expression of emotion. *Journal of Nonverbal Behavior, 34*(4), 223–248. doi: 10.1007/s10919-010-0094-x

Gross, M., Crane, E. A., & Fredrickson, B. L. (2012). Effort-shape and kinematic assessment of bodily expression of emotion during gait. *Human Movement Science, 31*(1), 202–221. doi: 10.1016/j.humov.2011.05.001

Guerrero, L. K., Andersen, P. A., & Afifi, W. A. (2010). *Close encounters: Communication in relationships* (3rd ed.). Thousand Oaks, CA: SAGE Publications.

Haase, R. F., & Tepper, D. T. (1972). Nonverbal components of empathic communication. *Journal of Counseling Psychology, 19*(5), 417–424. doi: 10.1037/h0033188

Hai, D. M., Khairullah, Z. Y., & Coulmas, N. (1982). Sex and the single armrest: Use of personal space during air travel. *Psychological Reports, 51*(3), 743–749. doi: 10.2466/pr0.1982.51.3.743

Hale, J. L., & Burgoon, J. K. (1984). Models of reactions to changes in nonverbal immediacy. *Journal of Nonverbal Behavior, 8*(4), 287–314. doi: 10.1007/bf00985984

Hall, J. A., Coats, E. J., & LeBeau, L. S. (2005). Nonverbal behavior and the vertical dimension of social relations: A meta-analysis. *Psychological Bulletin, 131*(6), 898–924. doi: 10.1037/0033-2909.131.6.898

Harper, R. (1985). Power, dominance, and nonverbal behavior: An overview. In S. L. Ellyson & J. F. Dovidio (Eds.), *Power, dominance, and nonverbal behavior* (pp. 29-48). New York, NY: Springer.

Harrigan, J. A. (2005). Proxemics, kinesics, and gaze. In J. A. Harrigan, R. Rosenthal & K. R. Scherer (Eds.), *The new handbook of methods in nonverbal behavior research* (pp. 137–198). New York, NY: Oxford University Press.

Harrigan, J. A., Rosenthal, R., & Scherer, K. R. (2005). Introduction. In J. R. Harrigan, R. Rosenthal, & K. R. Scherer (Eds.), *The new handbook of methods in nonverbal behavior research* (pp. 1–6). New York, NY: Oxford University Press.

Hayduk, L. A. (1983). Personal space: Where we now stand. *Psychological Bulletin, 94*(2), 293–335. doi: 10.1037/0033-2909.94.2.293

Hayward, S. (2000). *Cinema studies: The key concepts* (2nd ed.). New York, NY: Routledge.

Heider, F., & Simmel, M. (1944). An experimental study of apparent behavior. *The American Journal of Psychology, 57*, 243–259.

Henley, N. M. (1977). *Body politics: Power, sex, and nonverbal communication*. Englewood Cliffs, NJ: Prentice-Hall.

Henley, N. M. (1995). Body politics revisited: What do we know today? In P. J. Kalbfleisch & M. J. Cody (Eds.), *Gender, power, and communication in human relationships* (pp. 27–61). Hillsdale, NJ: Erlbaum.

Hofmann, W., Gschwendner, T., & Schmitt, M. (2009). The road to the unconscious self not taken: Discrepancies between self-and observer-inferences about implicit dispositions from nonverbal behavioural cues. *European Journal of Personality, 23*(4), 343–366. doi: 10.1002/per.722

Hutchinson, A. (1961). *Labanotation*. New York, NY: New Directions.

Izard, C. E. (1971). *The face of emotion*. New York, NY: Appleton-Century-Crofts.

Jacobs, A., Pinto, J., & Shiffrar, M. (2004). Experience, context, and the visual perception of human movement. *Journal of Experimental Psychology: Human Perception and Performance, 30*(5), 822–835. doi: 10.1037/0096-1523.30.5.822

Johansson, G. (1973). Visual perception of biological motion and a model for its analysis. *Perception & Psychophysics, 14*(2), 201–211. doi: 10.3758/bf03212378

Johansson, G. (1976). Spatio-temporal differentiation and integration in visual motion perception: An experimental and theoretical analysis of calculus-like functions in visual data processing. *Psychological Research, 38*(4), 379–393. doi: 10.1007/bf00309043

Johnson, S., & McPherson, K. (2006). Size of a human: Body proportions. In G. Elert (Ed.), *The Physics Factbook*. Retrieved from http://hypertextbook.com/facts/2006/bodyproportions.shtml.

Kleinke, C. L. (1986). Gaze and eye contact: A research review. *Psychological Bulletin, 100*(1), 78–100. doi: 10.1037/0033-2909.100.1.78

Knapp, M. L. (2006). A historical overview of nonverbal research. In V. L. Manusov & M. L. Patterson (Eds.), *The SAGE handbook of nonverbal communication* (pp. 3–19). Thousand Oaks, CA: Sage Publications.

Knapp, M. L., Hall, J. A., & Horgan, T. G. (2013). *Nonverbal communication in human interaction*. Belmont, CA: Wadsworth/Cengage Learning.

Kozlowski, L. T., & Cutting, J. E. (1977). Recognizing the sex of a walker from a dynamic point-light display. *Perception & Psychophysics, 21*(6), 575–580.

Kudoh, T., & Matsumoto, D. (1985). Cross-cultural examination of the semantic dimensions of body postures. *Journal of Personality and Social Psychology, 48*(6), 1440–1446. doi: 10.1037/0022-3514.48.6.1440

Laban, R. (1956). *Principles of dance and movement notation*. London: Macdonald & Evans.

LaCrosse, M. B. (1975). Nonverbal behavior and perceived counselor attractiveness and persuasiveness. *Journal of Counseling Psychology, 22*(6), 563–566. doi: 10.1037/0022–0167.22.6.563

LaFrance, M. (1982). Posture mirroring and rapport. In M. Davis (Ed.), *Interaction rhythms: periodicity in communicative behavior* (pp. 279–298). New York, NY: Human Sciences Library.

LaFrance, M., & Mayo, C. A. W. (1978). *Moving bodies: Nonverbal communication in social relationships*. Belmont, CA: Brooks/Cole Pub. Co.

Lakin, J. L. (2006). Automatic cognitive processes and nonverbal communication. In V. L. Manusov & M. L. Patterson (Eds.), *The SAGE handbook of nonverbal communication* (pp. 59–77). Thousand Oaks, CA: SAGE Publications.

Larsen, R. J., & Shackelford, T. K. (1996). Gaze avoidance: Personality and social judgments of people who avoid direct face-to-face contact. *Personality and Individual Differences, 21*(6), 907–917.

Leffler, A., Gillespie, D. L., & Conaty, J. C. (1982). The effects of status differentiation on nonverbal behavior. *Social Psychology Quarterly, 45*(3), 153–161. doi: 10.2307/3033648

Leuschner, H. (1999). Vom Transkript zur Computeranimation nonverbalen Verhaltens: Notationsprinzipien - Modellierungswerkzeuge - Konvertierungsalgorithmen [From transcript to computer animation of nonverbal behavior: Coding principles - modeling tools - conversion algorithmen]. In G. Bente (Series Ed.), *Virtuelle Realität und parasoziale Interaktion [Virtual reality and parasocial interaction]: Vol. 2* (DFG Report No. BE 1745/2–1). University of Cologne, Germany: Department Psychology.

Levy, N., & Schlosberg, H. (1960). Woodworth scale values of the Lightfoot pictures of facial expression. *Journal of Experimental Psychology, 60*(2), 121–125. doi: 10.1037/h0043130

Lewis, R. J., Derlega, V. J., Shankar, A., Cochard, E., & Finkel, L. (1997). Nonverbal correlates confederates' touch: Confounds in touch research. *Journal of Social Behavior & Personality, 12*(3), 821–830.

Lindsley, D. B. (1951). Emotion. In S. S. Stevens (Ed.), *Handbook of experimental psychology* (pp. 473–516). New York, NY: Wiley.

Loula, F., Prasad, S., Harber, K., & Shiffrar, M. (2005). Recognizing people from their movement. *Journal of Experimental Psychology: Human Perception and Performance, 31*(1), 210–220. doi: 10.1037/0096-1523.31.1.210

Ma, Y., Paterson, H. M., & Pollick, F. E. (2006). A motion capture library for the study of identity, gender, and emotion perception from biological motion. *Behavior Research Methods, 38*(1), 134–141. doi: 10.3758/bf03192758

Machotka, P. (1965). Body movement as communication. *Dialogues, behavioral science research, 2*, 33–65.

Mamer, B. (2009). *Film production technique: Creating the accomplished image*. Bellmont, CA: Wadsworth.

Manusov, V. L. (2005). *The sourcebook of nonverbal measures: Going beyond words*. Mahwah, NJ: Lawrence Erlbaum Assoc Inc.

Manusov, V. L., & Patterson, M. L. (2006). *The SAGE handbook of nonverbal communication*. Thousand Oaks, CA: Sage Publications.

Mason, M. F., Tatkow, E. P., & Macrae, C. N. (2005). The look of love: Gaze shifts and person perception. *Psychological Science, 16*(3), 236–239.

Mast, M. S., & Hall, J. A. (2004). Who is the boss and who is not? Accuracy of judging status. *Journal of Nonverbal Behavior, 28*(3), 145–165. doi: 10.1023/b:jonb.0000039647.94190.21

Masters, R. D., Frey, S., & Bente, G. (1991). Dominance & attention: Images of leaders in German, French, & American TV news. *Polity, 23*(3), 373–394.

Mather, G., & Murdoch, L. (1994). Gender discrimination in biological motion displays based on dynamic cues. *Proceedings of the Royal Society of London. Series B: Biological Sciences, 258*(1353), 273–279.

Matsumoto, D., & Kudoh, T. (1987). Cultural similarities and differences in the semantic dimensions of body postures. *Journal of Nonverbal Behavior, 11*(3), 166–179. doi: 10.1007/bf00990235

McGinley, H., LeFevre, R., & McGinley, P. (1975). The influence of a communicator's body position on opinion change in others. *Journal of Personality and Social Psychology, 31*(4), 686–690. doi: 10.1037/0022-3514.31.4.686

Mehrabian, A. (1968). Inference of attitudes from the posture, orientation, and distance of a communicator. *Journal of Consulting and Clinical Psychology, 32*(3), 296–308. doi:

10.1037/h0025906

Mehrabian, A. (1969a). Significance of posture and position in the communication of attitude and status relationships. *Psychological Bulletin, 71*(5), 359–372.

Mehrabian, A. (1969b). Some referents and measures of nonverbal behavior. *Behavior Research Methods & Instrumentation, 1*(6), 203–207. doi: 10.3758/BF03208096

Mehrabian, A. (1970). A semantic space for nonverbal behavior. *Journal of Consulting and Clinical Psychology, 35*(2), 248–257. doi: 10.1037/h0030083

Mehrabian, A. (1972). *Nonverbal communication*. Chicago, IL: Aldine.

Mehrabian, A. (1980). *Basic dimensions for a general psychological theory: Implications for personality, social, environmental, and developmental studies*. Cambridge, MA: Oelgeschlager, Gunn & Hain.

Mehrabian, A. (1981). *Silent messages: Implicit communication of emotions and attitudes* (2nd ed.). Belmont, CA: Wadsworth.

Mehrabian, A. (1991). Outline of a general emotion-based theory of temperament. In J. Strelau & A. Angleitner (Eds.), *Explorations in temperament: International perspectives on theory and measurement* (pp. 75–86). New York, NY: Plenum Press.

Mehrabian, A. (1995). Framework for a comprehensive description and measurement of emotional states. *Genetic, social, and general psychology monographs , 121*(3), 339–361.

Mehrabian, A. (1996). Pleasure-arousal-dominance: A general framework for describing and measuring individual differences in temperament. *Current Psychology, 14*(4), 261–292. doi: 10.1007/BF02686918

Mehrabian, A. (1997). Analysis of affiliation-related traits in terms of the PAD temperament model. *Journal of Psychology: Interdisciplinary and Applied, 131*(1), 101–117. doi: 10.1080/00223989709603508

Mehrabian, A., & Russell, J. A. (1974a). *An approach to environmental psychology.*

Cambridge, MA: M.I.T. Press.

Mehrabian, A., & Russell, J. A. (1974b). The basic emotional impact of environments. *Perceptual and motor skills, 38*(1), 283–301. doi: 10.2466/pms.1974.38.1.283

Mehrabian, A., & Williams, M. (1969). Nonverbal concomitants of perceived and intended persuasiveness. *Journal of Personality and Social Psychology, 13*(1), 37–58. doi: 10.1037/h0027993

Montepare, J. M., & Zebrowitz-McArthur, L. (1988). Impressions of people created by age-related qualities of their gaits. *Journal of Personality and Social Psychology, 55*(4), 547–556. doi: 10.1037/0022-3514.55.4.547

Montepare, J. M., & Zebrowitz, L. A. (1993). A cross-cultural comparison of impressions created by age-related variations in gait. *Journal of Nonverbal Behavior, 17*(1), 55–68. doi: 10.1007/bf00987008

Moore, H. A., & Porter, N. K. (1988). Leadership and nonverbal behaviors of Hispanic females across school equity environments. *Psychology of Women Quarterly, 12*(2), 147–163. doi: 10.1111/j.1471-6402.1988.tb00933.x

Moore, N. J., Hickson, M., & Stacks, D. W. (2009). *Nonverbal communication: Studies and applications*. New York, NY: Oxford University Press.

Morgan, R. L., & Heise, D. (1988). Structure of emotions. *Social Psychology Quarterly, 51*(1), 19–31. doi: 10.2307/2786981

Morris, D., Collett, P., Marsh, P., & O'Shaughnessy, M. (1980). *Gestures: Their origins and distribution*. New York, NY: Scarborough.

Naugle, K. M., Hass, C. J., Joyner, J., Coombes, S. A., & Janelle, C. M. (2011). Emotional state affects the initiation of forward gait. *Emotion, 11*(2), 267–277. doi: 10.1037/a0022577

Osgood, C. E. (1962). Studies on the generality of affective meaning systems. *American Psychologist, 17*(1), 10–28. doi: 10.1037/h0045146

Osgood, C. E. (1966). Dimensionality of the semantic space for communication via facial expressions. *Scandinavian Journal of Psychology, 7*(1), 1–30. doi: 10.1111/j.1467-9450.1966.tb01334.x

Osgood, C. E., May, W. H., & Miron, M. S. (1975). *Cross-cultural universals of affective meaning*. Champaign, IL: University of Illinois Press.

Osgood, C. E., Suci, G. J., & Tannenbaum, P. H. (1957). *The measurement of meaning*. Urbana, IL: University of Illinois Press.

Palmer, M. T., & Simmons, K. B. (1995). Communicating intentions through nonverbal behaviors: Conscious and nonconscious encoding of liking. *Human Communication Research, 22*(1), 128–160. doi: 10.1111/j.1468-2958.1995.tb00364.x

Patterson, M. L. (1982). A sequential functional model of nonverbal exchange. *Psychological Review, 89*(3), 231–249. doi: 10.1037/0033-295x.89.3.231

Pollick, F. E., Paterson, H. M., Bruderlin, A., & Sanford, A. J. (2001). Perceiving affect from arm movement. *Cognition, 82*(2), B51–B61. doi: 10.1016/S0010-0277(01)00147-0

Purves, D., Brannon, E. M., Cabeza, R., Huettel, S. A., LaBar, K. S., Platt, M. L., & Woldorff, M. G. (2008). *Principles of cognitive neuroscience*. Sunderland, MA: Sinauer Associates.

Reisenzein, R. (1994). Pleasure-arousal theory and the intensity of emotions. *Journal of Personality and Social Psychology, 67*(3), 525–539. doi: 10.1037/0022-3514.67.3.525

Remland, M. S. (1982). The implicit ad hominem fallacy: Nonverbal displays of status in argumentative discourse. *Journal of the American Forensics Association, 19*, 79–86.

Remland, M. S. (2009). *Nonverbal communication in everyday life*. Boston, MA: Pearson Allyn and Bacon.

Richmond, V. P., McCroskey, J. C., & Hickson, M. (2007). *Nonverbal behavior in interpersonal relations*. Bostin, MA: Pearson/Allyn and Bacon.

Riggio, R. E., & Feldman, R. S. (2005). *Applications of nonverbal communication*. Mahwah, NJ: Lawrence Erlbaum Associates.

Riggio, R. E., & Friedman, H. S. (1986). Impression formation: The role of expressive behavior. *Journal of Personality and Social Psychology, 50*(2), 421–427. doi: 10.1037/0022-3514.50.2.421

Rosenfeld, H. M. (1966). Approval-seeking and approval-inducing functions of verbal and nonverbal responses in the dyad. *Journal of Personality and Social Psychology, 4*(6), 597–605. doi: 10.1037/h0023996

Russell, J. A. (1980). A circumplex model of affect. *Journal of Personality and Social Psychology, 39*(6), 1161–1178. doi: 10.1037/h0077714

Russell, J. A. (2009). Emotion, core affect, and psychological construction. *Cognition and Emotion, 23*(7), 1259–1283. doi: 10.1080/02699930902809375

Russell, J. A., & Bullock, M. (1985). Multidimensional scaling of emotional facial expressions: Similarity from preschoolers to adults. *Journal of Personality and Social Psychology, 48*(5), 1290–1298. doi: 10.1037/0022-3514.48.5.1290

Russell, J. A., & Fernández-Dols, J. M. (1997). *The psychology of facial expression*. New York, NY: Cambridge University Press.

Russell, J. A., & Mehrabian, A. (1977). Evidence for a three-factor theory of emotions. *Journal of Research in Personality, 11*(3), 273–294. doi: 10.1016/0092-6566(77)90037-x

Schaal, S. (2007). The new robotics — towards human-centered machines. *HFSP journal, 1*(2), 115–126. doi: 10.2976/1.2748612

Scheflen, A. E. (1964). The significance of posture in communication systems. *Psychiatry: Journal for the Study of Interpersonal Processes, 27*(4), 316–331.

Scheflen, A. E. (1972). *Body language and the social order: Communication as behavioral control*. Englewood Cliffs, NJ: Prentice–Hall.

Scherer, K. R. (2005). What are emotions? And how can they be measured? *Social Science*

Information, 44(4), 695–729. doi: 10.1177/0539018405058216

Schlosberg, H. (1941). A scale for the judgment of facial expressions. *Journal of Experimental Psychology, 29*(6), 497–510. doi: 10.1037/h0061489

Schlosberg, H. (1952). The description of facial expressions in terms of two dimensions. *Journal of Experimental Psychology, 44*(4), 229–237. doi: 10.1037/h0055778

Schlosberg, H. (1954). Three dimensions of emotion. *Psychological Review, 61*(2), 81–88. doi: 10.1037/h0054570

Scholl, W. (2013). The socio-emotional basis of human interaction and communication: How we construct our social world. *Social Science Information, 52*(1), 3–33. doi: 10.1177/0539018412466607

Schouwstra, S. J., & Hoogstraten, J. (1995). Head position and spinal position as determinants of perceived emotional state. *Perceptual and motor skills, 81*(2), 673–674.

Shannon, C. E., & Weaver, W. (1949). *The mathematical theory of communication*. Champaign, IL: University of Illinois Press.

Shepard, R. N. (1962a). The analysis of proximities: Multidimensional scaling with an unknown distance function. Part I. *Psychometrika, 27*(2), 125–140. doi: 10.1007/bf02289630

Shepard, R. N. (1962b). The analysis of proximities: Multidimensional scaling with an unknown distance function. Part II. *Psychometrika, 27*(3), 219–246. doi: 10.1007/bf02289621

Sokolov, E. N., & Boucsein, W. (2000). A psychophysiological model of emotion space. *Integrative Physiological & Behavioral Science, 35*(2), 81–119. doi: 10.1007/bf02688770

Stevenage, S. V., Nixon, M. S., & Vince, K. (1999). Visual analysis of gait as a cue to identity. *Applied Cognitive Psychology, 13*(6), 513–526. doi: 10.1002/(sici)1099-0720(199912)13:6<513::aid-acp616>3.0.co;2-8

Street, R. L., & Giles, H. (1982). Speech accommodation theory: A social cognitive approach to language and speech behavior. In M. E. Roloff & C. R. Berger (Eds.), *Social cognition and communication* (pp. 193–226). Beverly Hills, CA: Sage.

Takehara, T. (2007). Dimensional structure of emotional facial expression recognition and complex systems. In F. R. Lewis (Ed.), *Focus on nonverbal communication research* (pp. 65-88). Hauppauge, NY: Nova Science Publishers.

Tao, L., Liu, Y., Fu, X., & Cai, L. (2008). *A computational study on PAD based emotional state model.* Paper presented at the Proceedings of the 26th ACM CHI Conferences on Human Factors in Computing systems, Florence, Italy, 5-10 April, 2008.

Teitelbaum, O., Benton, T., Shah, P. K., Prince, A., Kelly, J. L., & Teitelbaum, P. (2004). Eshkol–Wachman movement notation in diagnosis: The early detection of Asperger's syndrome. *Proceedings of the National Academy of Sciences of the United States of America, 101*(32), 11909–11914.

Teitelbaum, P., Teitelbaum, O., Nye, J., Fryman, J., & Maurer, R. G. (1998). Movement analysis in infancy may be useful for early diagnosis of autism. *Proceedings of the National Academy of Sciences of the United States of America, 95*(23), 13982–13987.

Thoresen, J. C., Vuong, Q. C., & Atkinson, A. P. (2012). First impressions: Gait cues drive reliable trait judgements. *Cognition, 124*(3), 261–271. doi: 10.1016/j.cognition.2012.05.018

Tickle-Degnen, L., & Rosenthal, R. (1987). Group rapport and nonverbal behavior. In C. Hendrick (Ed.), *Group processes and intergroup relations* (pp. 113–136). Thousand Oaks, CA: Sage Publications.

Tiedens, L. Z., & Fragale, A. R. (2003). Power moves: Complementarity in dominant and submissive nonverbal behavior. *Journal of Personality and Social Psychology, 84*(3), 558–568.

Tiemens, R. (2005). A content analysis of political speeches on television. In K. L. Smith, S.

Moriarty, G. Barbatsis & K. Kenney (Eds.), *Handbook of visual communication: theory, methods, and media* (pp. 385). Mahwah, NJ: Lawrence Erlbaum Associates.

Tomkins, S. S. (1962–1963). *Affect/imagery/consciousness* (Vol. 1–2). New York, NY: Springer.

Tomkins, S. S., & McCarter, R. (1964). What and where are the primary affects? Some evidence for a theory. *Perceptual and motor skills, 18*(1), 119–158. doi: 10.2466/pms.1964.18.1.119

Trautner, H. M. (1991). *Children's and adults awareness of sex-stereotyped postures*. Paper presented at the Eleventh Biennal Meeting of the ISSBD, Minneapolis.

Triandis, H. C., & Lambert, W. W. (1958). A restatement and test of Schlosberg's theory of emotion with two kinds of subjects from Greece. *The Journal of Abnormal and Social Psychology, 56*(3), 321–328. doi: 10.1037/h0045487

Troje, N. F. (2002). The little difference: Fourier based synthesis of gender-specific biological motion. In W. P. Würtz & M. Lappe (Eds.), *Dynamic Perception* (pp. 115–120). Berlin, Germany: AKA.

Troje, N. F. (2008). Retrieving information from human movement patterns. In T. F. Shipley & J. M. Zacks (Eds.), *Understanding events: From perception to action* (Vol. 4, pp. 308–334). New York, NY: Oxford University Press.

Troje, N. F., Westhoff, C., & Lavrov, M. (2005). Person identification from biological motion: Effects of structural and kinematic cues. *Perception & Psychophysics, 67*(4), 667–675. doi: 10.3758/bf03193523

Valdez, P., & Mehrabian, A. (1994). Effects of color on emotions. *Journal of Experimental Psychology: General, 123*(4), 394–409. doi: 10.1037/0096-3445.123.4.394

Vince, J. (2007). *Vector analysis for computer graphics*. London, UK: Springer.

Vince, J. (2010). *Mathematics for computer graphics* (3rd ed.). London, UK: Springer.

Vince, J. (2011). *Rotation transforms for computer graphics*. London, UK: Springer.

Vogeley, K., & Bente, G. (2010). “Artificial humans”: Psychology and neuroscience perspectives on embodiment and nonverbal communication. *Neural Networks, 23*(8–9), 1077–1090. doi: 10.1016/j.neunet.2010.06.003

Vogeley, K., & Bente, G. (2011). Neuronale Mechanismen sozialer Kognition. In M. Reimann & B. Weber (Eds.), *Neuroökonomie: Grundlagen - Methoden - Anwendungen* (pp. 111–137). Wiesbaden, Germany: Gabler.

Vogeley, K., & Roepstorff, A. (2009). Contextualising culture and social cognition. *Trends in Cognitive Sciences, 13*(12), 511–516. doi: 10.1016/j.tics.2009.09.006

Wallbott, H. G. (1995). Congruence, contagion, and motor mimicry: Mutualities in nonverbal exchange. In I. Marková, C. F. Graumann & K. Foppa (Eds.), *Mutualities in dialogue.* (pp. 82–98). New York, NY: Cambridge University Press.

Watzlawick, P., Beavin, J., & Jackson, D. (2008). Some tentative axioms of communication. In C. D. Mortensen (Ed.), *Communication theory* (2nd ed., pp. 74–80). Piscataway, NJ: Transaction Publishers. (Original work published 1967 in Pragmatics of Human Communication by New York, NY: Norton & Company, Inc.)

Westhoff, C., & Troje, N. F. (2007). Kinematic cues for person identification from biological motion. *Perception & Psychophysics, 69*(2), 241–253. doi: 10.3758/bf03193746

Weyl, H. (1989). *Symmetry*. Princeton, NY: Princeton University Press.

Williams, G. P., & Kleinke, C. L. (1993). Effects of mutual gaze and touch on attraction, mood, and cardiovascular reactivity. *Journal of Research in Personality, 27*(2), 170–183.

Woodworth, R. S. (1938). *Experimental psychology*. New York, NY: Holt and Company.

Woodworth, R. S., & Schlosberg, H. (1954). *Experimental psychology*. New York, NY: Henry Holt and Company.

Wundt, W. M. (1896). *Grundriss der Psychologie*. Leipzig, Germany: Verlag von Wilhelm Engelmann.

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